



Robert William Whitby

Digital photograph taken on 15 December 2001.

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Octahedron

the Universe defined

*A description of the atomic shapes
and how they join
which follows from the discovery
that the periodicity of the atomic elements
matches the periodicity of recurring form
in which identical regular octahedra combine
to form ever larger regular octahedra*

*by
the discoverer*

Robert William Whitby

<http://web.me.com/whitby/Octahedron/Welcome.html>

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And what is this smile of the world, to win which we are bidden to sacrifice our moral manhood; this frown of the world, whose terrors are more awful than the withering up of truth and the slow going out of light within the souls of us? Consider the triviality of life and conversation and purpose, in the bulk of those whose approval is held out for our prize and the mark of our high calling. Measure, if you can, the empire over them of prejudice unadulterated by a single element of rationality, and weigh, if you can, the huge burden of custom, unrelieved by a single leavening particle of fresh thought. Ponder the share which selfishness and love of ease have in the vitality and the maintenance of the opinions that we are forbidden to dispute. Then how pitiful a thing seems the approval or disapproval of these creatures of the conventions of the hour, as one figures the merciless vastness of the universe of matter sweeping us headlong through viewless space; as one hears the wail of misery that is forever ascending to the deaf gods; as one counts the little tale of the years that separate us from eternal silence. In the light of these things, a man should surely dare to live his small span of life with little heed of the common speech upon him or his life, only caring that his days may be full of reality, and his conversation of truth-speaking and wholeness.

John Morley 1838-1923

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INTRODUCTION

Form

Atomic shapes

The author discovered in 1977 that the periodicity of the atomic elements matches the periodicity of recurring form wherein identical simple regular octahedra join edge-to-edge to form compound regular octahedra thus providing the shape of each of the atomic elements.

Atomic joins

Building models of the atoms and fitting them together to make the chains, helices, and rings described in the literature shows that the atoms join together so that the octahedra of one atom are in identical orientation with those of each adjoining atom.

Crystal

It follows that identical regular octahedra can join together in crystalline order to produce each of the crystalline forms. It shows that each crystalline face is defined by a topological feature of the octahedron.

Crystal forming unit (cfu)

The existence of different types of cubic crystal lattices shows that crystals are formed by the additive joining of identical units consisting of atoms or groups of atoms which are called CFUs or crystal-forming units.

Diamond and graphite

The crystalline arrangement of the CFUs in diamond shows that it is composed of four C-atoms while that of graphite is composed of three C-atoms. The molecular weights of the respective CFU fulfill the Dulong and Petit relationship.

Quasicrystal

Electron micrographs of pentagonal dodecahedral crystals leads to the discovery that the regular octahedra which form the elements assemble structurally to produce the quasicrys-

talline forms.

Viral capsid

The electron microscopic images of icosahedral viral capsids shows arrangements of spikes and peaks which are modelable using regular octahedral units in structural assemblies.

DNA

The "X" pattern of DNA is produced by reflections from a crystal having the general form of the rhombic dodecahedron. It is not the quasicrystalline form which a twenty-fold helix would produce.

Amino acid

The crystalline atoms produce a main chain portion of the amino acids which joins to produce the protein substructures.

Cell

Soap films join with the same angle as the faces of the rhombic dodecahedron. The straight lipid chain has an axis which is normal to a face of the rhombic dodecahedron. Since the soap film is a lipid solution, it follows that the closed form of the lipid bilayer membrane of the biological cell has the general structure of the rhombic dodecahedron.

Motion

Light

Pinhole diffraction

The crystalline atom, in which there is no motion between its parts, suggests that photons are atoms or groups of atoms. This prompted a look at what has been considered evidence of the wave nature of light. It was discovered that the pattern of light and dark rings described as pinhole diffraction are due to multiple reflections of the light by the cylindrical wall. This phenomenon is shown to be purely geometrical and consistent with particle trajectories.

Life

The crystalline atom leads to the conclusion that photons are atoms or groups of atoms. It follows that stars are planets whose surfaces are atomically afire, its atoms disintegrating into their components hydrogen and helium.

Life is the active agent in concentrating unstable atoms to produce heat. This results in the production of ever larger numbers of unstable atoms. This leads to uncontrolled fission which leads to high surface temperature and the planet thus becomes a sun.

Each star was once an earth populated with humans who attained the technology possessed by our contemporaries.

Polar communication

Each of the edges of the octahedron which joins with identical octahedra to form the atoms is a magnetic pole. The edge of one octahedron has a polar effect on each edge of each octahedron towards which it is directed. This effect is modified by any change in the orientation of the octahedron. The effect is immediate; there is no delay, no matter how remote the edges may be. This effect offers the possibility of the inhabitants of one planet communicating with the inhabitants of other planets throughout the universe. The inhabitants must have reached the same technological level at the same time.

SHOWING

DISCOVER

As a child, I was awestruck by the idea that someone had made a discovery which permitted us to know that new atomic elements would be found. At the same time, I was disappointed that this most wondrously predictive discovery was no longer mine to make. What else was left for me to discover?

When I was in the Marine Corps in 1954, I was stationed at Quantico, Virginia near the airfield. A wooden geodesic dome was being tested there as a helicopter-towable aircraft hangar. It was my first observation of this type of dome.

The second time that I took notice of a geodesic dome was on a cover of *Time* magazine. The illustrator, Boris Artzybasheff, depicted R. Buckminster Fuller with a geodesic dome for his cranium.

I helped to erect several prefabricated domes. I explored the use of geodesic structural ideas in sailboat designs and other structures. I built tensegrity models using wooden struts and nylon fish line, and I built polyhedra using panels made of cardboard or wood. Through these activities, I came to a tactile understanding of structure.

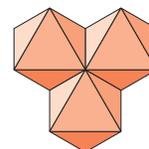
By chance, while reading *Synergetics*¹ by Fuller which explores the structural properties of crystallinely associated regular polyhedra, I also read Linus Pauling's *Architecture of groups*² and James Watson's *Double Helix*³. Both of the latter show the polyhedral nature of molecular formations and support the efficacy of modeling as a tool for discovery. It occurred to me that polyhedral structure is essential to the building of the atomic elements.

I looked first at building compound polyhedral atomic units using an integral number of

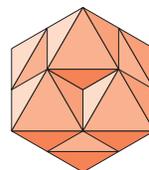
polyhedra, each with a specific mass. But mass is a polar attraction which varies with distance and this does not produce exactly integral numbers.

Then I tried building symmetrical units using assemblies of regular octahedra with the atomic number being the guide. At first I tried to make the most symmetrical assembly which the number of octahedra would allow, while maintaining the octahedra in crystalline order—identically oriented and joined edge to edge in structurally stable assemblies.

Three octahedra formed a triplet;



Six octahedra formed a compound regular octahedron.



Eighteen octahedra formed a triplet of compound regular octahedra.

Twenty-four octahedra were best accommodated by adding a fourth compound octahedron to the compound triplet formed by eighteen octahedra.

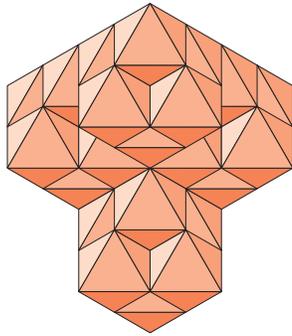
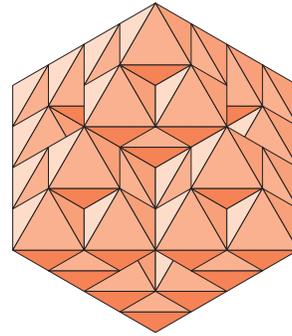
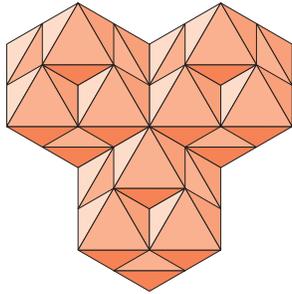
Thirty octahedra made a pyramidal assem-

1. R. Buckminster Fuller, *Synergetics*, Macmillan, 1975

2. Linus Pauling and Roger Hayward, *The Architecture of groups*, W. H. Freeman & Co., 1964

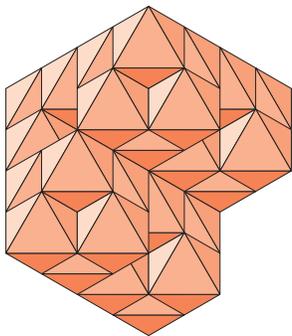
3. James D. Watson, *The Double Helix*, Signet, 1968

simple octahedra each.



Light dawns. Rather than the atom having to reorganize itself with each addition, each addition joins structurally to the existing atom to produce a new structure. Building in this way requires a basic structural unit composed of three regular octahedra, a triplet. The addition of a triplet to the first triplet produces the first compound octahedron. Subsequent triplet additions pair as compound octahedra to produce the triplet of compound octahedra, the structural grouping of four compound octahedra, the pyramid of five compound octahedra, and the octahedron of six compound octahedra. What I have before me is a Hydrogen atom, a Helium atom, a Carbon atom, an Oxygen atom, a Neon atom, a Magnesium atom. With these models before me, the pattern is apparent.

bly composed of five compound octahedra.



Thirty-six octahedra formed an octahedron consisting of six compound octahedra of six

ORTHODOX

The principal obstacle to the correction of erroneous conceptions is their edification as orthodoxy. The student is not presented with facts alone, but with the interpretative dogma of the time. This dogma inhibits consideration of the facts, since the facts come bundled with their dogmatic interpretation. The dogma must be subdued before a new path can be considered.

Discovery debases orthodoxy

Orthodoxy is familiar and comfortable; it defines the expert. Discovery is strange and foreign; it debases orthodoxy. The discoverer is faced with a publishing apparatus in which each sect tests the discovery for conformity with its particular dogma. The discovery of universal applicability faces rejection because the discoverer is an outsider to virtually any group which controls the publication of a journal, since any such group is limited to considering an abstraction of a limited portion of reality using means which are limited to those permitted by the orthodoxy of the group. What can be considered, how it may be considered, and by whom it may be considered, each is arbitrarily restricted by each group in a manner which is peculiar to the group. Even within this constrictive institutional framework, the discoverer is assessed on the basis of his institutional association—to what university, to which corporation, to whose laboratory. And still more, the discoverer must find a person of prestige within the group to co-author his paper and, by such validation, to have it considered. The basis of acceptance being the stature of the co-author, the prestige of the institution, the reputation of the laboratory, the nationality of the author, and other prejudicial constraints which have nothing to do with the contents of the paper.

The expression of the concept must fit the jargon of the sect. The expression in words or diagrams must fit the limited linguistic attainment of the editor referee, who may be illiterate in the standard usage of literal language and unable to understand the graphical lan-

guage required to represent multiplanar forms upon a single plane.

No home for the discoverer

A discoverer who has no credentials belongs to no box, has nowhere to publish the discovery. If the discovery affects all the boxes, the discoverer has entry to none. The discoverer is foreign to all. Thus, the discovery is foreign to all. If the discovery is fundamentally at variance with orthodoxy, then orthodoxy cannot be amended, it must be reformed.

The octahedral particle: A foundation, a terminus

The discovery that atoms are formed by the crystalline association of identical regular octahedral particles establishes a new foundation for understanding the universe. It establishes a new basis for the understanding of all phenomena. It is boundless in its application. It is chemistry and physics and astronomy; it is mineralogy, biology, metallurgy; it is crystallography. It is optics, heat, electricity, magnetism. It excludes nothing.

The octahedral particle provides a foundation, a beginning, a first principle, an absolute. It defines each atom, each group, each crystal, each material, each body, each phenomenon. It is thereby testable. Its form must cause the forms of the atomic elements. And these forms taken together must establish the periodicity which is manifest in the Periodic Table of the Atomic Elements. The forms of the atoms must cause the forms of the groups. The forms of the groups must cause the forms of the crystals. These forms provide a basis for defining the phenomena related to light, electricity, heat, magnetism, the states of matter. Together, these discoveries require a reconsideration of the interpretations which have been applied to the principal experiments that underlie the current orthodoxy.

Manifestations of the octahedral particle

The octahedral periodicity of the atomic elements

The octahedral particle as first principle is discovered by its manifestations. It is not an answer to a set of conditions. Its discovery is not made by analyzing all that is known and, then, seeking a commonality. It is found by simply comparing the numerical sequence corresponding to the number of octahedra in compound octahedra with the numerical sequence corresponding to the number of units in the atoms within a column of the Periodic Table of the Atomic Elements.

The quantum numbers correspond to the coordinates of the positions of the structural units which compose the octahedral atom, and this is a manifestation of the octahedral particle.

The octahedron in crystalline forms

Each of the limited symmetries observed in crystals corresponds to a principal orientation of the regular octahedron, and the limited symmetries are, then, a manifestation of the octahedral particle.

A number of symmetries have been found which do not fit within the normal crystalline symmetries, and these are termed quasicrystalline. Each of the quasicrystalline symmetries is modelable using an assembly which is composed of regular octahedra in a coherent structure. These forms are manifestations of the regular octahedral particle.

The octahedron in protein substructures

The amino acids which form the principal protein substructures, the alpha helix and the pleated sheets, define a backbone unit which is composed of a few atoms. A backbone unit constructed of octahedral atoms in crystalline order produces the principal substructures as structurally coherent assemblies. The backbone unit can be constructed as one of two mirror images. The two, either alone or together, can form numerous rings, or cyclic peptides, some of which have been produced as antibiotics. These structures are also manifestations of the octahedral particle.

The octahedron in plastics, lipids, and minerals

Common plastic monomers and lipid chains

are precisely modelable with octahedral atoms.

Silica and alumina modeled with octahedral atoms are capable of forming the chains and rings and helices and cages which occur in the mineral crystals.

The equivalence of the Fluorine atom and the water group in mineral crystals is a manifestation of the octahedral atom.

The facial joining of regular octahedral structures is seen in the electrolytic recrystallization of silver which produces five

adjoining wedges and a gap of $\arctan \sqrt{\frac{1}{60}}$. The

wedge angle is identical to the angle between the opposed faces of a regular octahedron at a vertex, and the gap is equivalent to 360° less five times the angle between two faces across a vertex.

The axes of the rays of the stellar crystalline twins of the orthorhombic mineral Staurolite are parallel to the edgial diameters of the regular octahedron. This is a manifestation of the regular octahedron.

The monoclinic mineral Phillipsite has crystalline twins in which each of the faces is defined by edges of the regular octahedra of which it can be modeled. Here, as well as in Staurolite, the asymmetry of the crystal class masks the symmetry of the octahedra of which it is composed. But that symmetry is revealed by twinning.

PERIODIC

Periodicity of the Atomic Elements

The periodicity of the atomic elements emerged from the independent discovery of the atomic elements over many years. While the naturally occurring elements have been known for some time, the cause of their periodicity has been elusive.

Rutherford beguiled by astronomy.

Science went astray with the solar system model devised by Rutherford and Bohr. It has wallowed in the figures of revolution, and especially so the sphere. This is due to the dominance of astronomy in the development of science and the discovery derived therefrom that the Sun and Earth and other planets are spheroidal.

Scientists ignorant of polyhedra.

With the exception of the cube, scientists have generally been unfamiliar with polyhedra. The tetrahedron, octahedron, rhombic dodecahedron and other forms are the province of crystallographers and mineralogists. The icosahedron, pentagonal dodecahedron, tricontahedron are known to quasicrystal specialists.

Fuller reveals polyhedral structure.

Science has been ignorant of structure. It was not until Buckminster Fuller's geodesic domes became ubiquitous that the concept of structure advanced beyond the plane triangle. Fuller gave structure its third dimension.

He developed the concepts of tensegrity which give us a tactile sense of structure.

He showed how a given *simple* polyhedron could be joined to identical polyhedra to form crystalline assemblies having the same form, *compound* polyhedra.

Polyhedral periodicities.

The number of simple polyhedra in compound polyhedra of edge lengths 1, 2, 3, 4, and so on form a series which is unique to the polyhedron. For the familiar cube this series is 1, 8, 27, 64,... n^3 , and the simple cubes are joined face to face. For the octahedron the series is 1,

6, 19, 44,..., and the simple octahedra are joined edge to edge.

Atomic periodicity is octahedral.

The octahedral series matches the series of the atomic numbers of the atomic elements in odd numbered rows of the second column of the Periodic Table: 2, 12, 38, 88. The numbers of the atomic number series are twice those of the octahedral series. The elements of the series are He, Mg, Sr, and Ra.

Octahedral structure.

Regular octahedra joined edge to edge form regular tetrahedral voids or hollows. Each octahedron supplies a face to the tetrahedron and each octahedron is joined to each of the other octahedra by an edge. The minimum polyhedron is a tetrahedron. Three octahedra joined edge to edge with a common vertex form a stable structure. The void is regular tetrahedral with one face open. This triplet formation is the minimum crystalline association of regular octahedra. This is the structure of the two-isotope of H, or deuterium.

When compound octahedra are formed of simple octahedra by the addition of units, the preceding units remain in their entry locations.

The simple octahedra of the compound octahedra are arranged in layers. There are always an odd number of layers. The odd numbered layers have an odd number of octahedra and the even numbered layers have an even number of octahedra. The number of octahedra in the

1						
1	4	1				
1	4	9	4	1		
1	4	9	16	9	4	1

early layers remain constant as the compound octahedra become larger because those layers are filled. When they are filled, the number of octahedra they contain is the square of the number of the layer.

Periodicities:

- number of octahedra in compound octahedron of edge length 1 2 3 4...n
1 6 19 44...
- number of octahedra in layer of edge length 1 2 3 4...
1 4 9 16....
- number of octahedra in sublayer of edge length 1 2 3 4...
1 3 5 7...
- number of layers in compound octahedron of edge length 1 2 3 4...
1 3 5 7...
- number of triplets in element of atomic number
- number of octahedra in near octahedron of even layers of column 2
2 10 28....
- periodicity of form in each column of the table

Octahedral periodicity unforeseen.

The periodicity which has emerged has done so with the complete ignorance of the scientific community. The discovery that this periodicity is octahedral is purely and totally independent of the discovery of the atomic elements. It has not been rigged, or contrived, or planned, or foreseen by the discoverers of the elements. It has gone unremarked until its discovery in the year 1977.

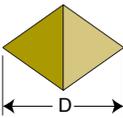
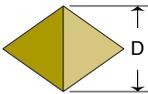
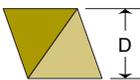
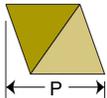
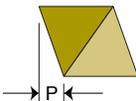
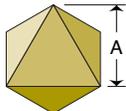
OCTAHEDRON

twelve edges, and six vertexes. The edges are the same length, the faces are triangular. In the following table the dimensions are expressed using the length of the edge, s .

Octahedron: Faces, edges, and vertexes

The regular octahedron has eight faces,

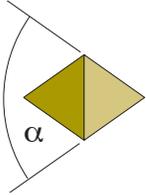
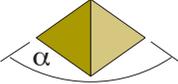
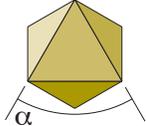
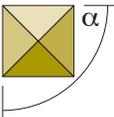
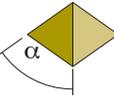
Table 1: Octahedron: dimensions

	Description	Expression
	Vertexial diameter	$D = s \times \sqrt{2}$
	Edgial diameter	$D = s$
	Facial diameter	$D = s \times \sqrt{\frac{2}{3}}$
	Projection of vertexial diameter on facial plane	$P = s \times \frac{2}{\sqrt{3}}$
	Projection of altitude of face upon plane of adjacent face	$P = \frac{s}{2\sqrt{3}}$
	Altitude of face	$A = s \times \frac{\sqrt{3}}{2}$

The angular relationships between the topological features of the octahedron are shown in

the next table.

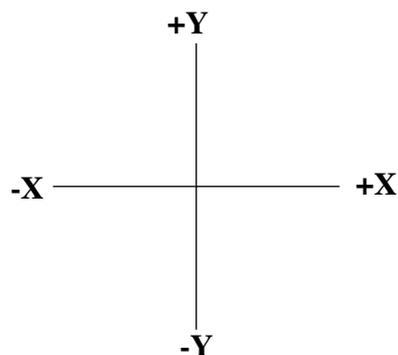
Table 2: Octahedron: angles

	Description	Expression	Degrees
	Between faces across vertex	$\alpha = \text{atan} \sqrt{8}$	70°31'43"
	Between faces at edge	$\alpha = 2 \times \text{atan} \sqrt{2}$	109°28'16"
	Between edges on face	$\alpha = \text{atan} \sqrt{3}$	60° exact
	Between edges across vertex	$\alpha = 2 \times \text{atan} 1$	90° exact
	Between face and edgial equator	$\alpha = \text{atan} \sqrt{2}$	54°44'08"
	Between face and vertexial diameter	$\alpha = \text{atan} \sqrt{\frac{1}{2}}$	35°15'51"

Octahedron: Graphical representations

To show the symmetry of an assembly of atoms or to give a true geometrical representation the orthographic projection is used. The table presented here shows the principal projections of the octahedron. The graphic coordinates listed in the table have their origin at the centroid of the octahedron which lies at the intersection of lines joining opposite vertexes. **+X** is towards the right and **-X** is toward the left; **+Y** is towards the top of the page and **-Y** is towards the bottom of the page; **+Z** is towards the reader and **-Z** is away from the

reader.



+Z towards; **-Z** away

Table 3: Octahedron: orthographic views

	vertex	xdelt	ydelt	zdelt
	1	0	1	0
	2	0.707107	0	0.707107
	3	-0.70711	0	0.707107
	4	-0.70711	0	-0.70711
	5	0.707107	0	-0.70711
	6	0	1	0
	1	0.816497	-0.57735	0
	2	0.408248	0.57735	0.707107
	3	-0.40825	-0.57735	0.707107
	4	-0.40825	-0.57735	-0.70711
	5	0.408248	0.57735	-0.70711
	6	-0.8165	0.57735	0
	1	1	0	0
	2	0	0.707107	0.707107
	3	0	-0.70711	0.707107
	4	0	-0.70711	-0.70711
	5	0	0.707107	-0.70711
	6	-1	0	0

Table 3: Octahedron: orthographic views

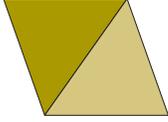
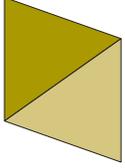
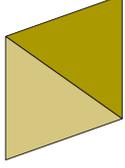
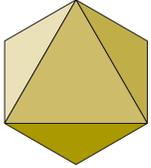
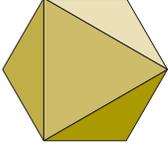
	vertex	xdelt	ydelt	zdelt
	1	0.816497	0.57735	0
	2	-0.40825	0.57735	0.707107
	3	0.408248	-0.57735	0.707107
	4	0.408248	-0.57735	-0.70711
	5	-0.40825	0.57735	-0.70711
	6	-0.8165	-0.57735	0
	1	0.57735	0.816497	0
	2	-0.57735	0.408248	0.707107
	3	0.57735	-0.40825	0.707107
	4	0.57735	-0.40825	-0.70711
	5	-0.57735	0.408248	-0.70711
	6	-0.57735	-0.8165	0
	1	-0.57735	0.816497	0
	2	-0.57735	-0.40825	0.707107
	3	0.57735	0.408248	0.707107
	4	0.57735	0.408248	-0.70711
	5	-0.57735	-0.40825	-0.70711
	6	0.57735	-0.8165	0
	1	0	-0.8165	0.57735
	2	0.707107	0.408248	0.57735
	3	-0.70711	0.408248	0.57735
	4	-0.70711	-0.40825	-0.57735
	5	0.707107	-0.40825	-0.57735
	6	0	0.816497	-0.57735
	1	0.816497	0	0.57735
	2	-0.40825	0.707107	0.57735
	3	-0.40825	-0.70711	0.57735
	4	0.408248	-0.70711	-0.57735
	5	0.408248	0.707107	-0.57735
	6	-0.8165	0	-0.57735

Table 3: Octahedron: orthographic views

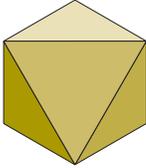
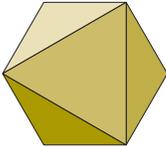
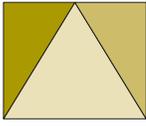
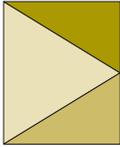
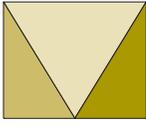
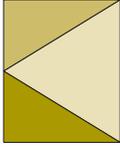
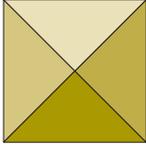
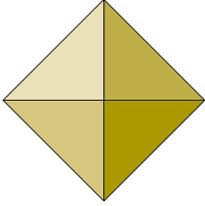
	vertex	xdelt	ydelt	zdelt
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	5	-0.70711	0.408248	-0.57735
	6	0	-0.8165	-0.57735
	1	-0.8165	0	0.57735
	2	0.408248	-0.70711	0.57735
	3	0.408248	0.707107	0.57735
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	6	0.816497	0	-0.57735
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	2	0.57735	-0.70711	0.408248
	3	0.57735	0.707107	0.408248
	4	-0.57735	0.707107	-0.40825
	5	-0.57735	-0.70711	-0.40825
	6	-0.57735	0	-0.8165
	1	0	0.57735	0.816497
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	3	-0.70711	0.57735	0.408248
	4	-0.70711	-0.57735	-0.40825
	5	0.707107	-0.57735	-0.40825
	6	0	-0.57735	-0.8165

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	5	0.57735	0.707107	-0.40825
	6	0.57735		-0.8165
	1	0	0	1
	2	0.707107	0.707107	0
	3	0.707107	-0.70711	0
	4	-0.70711	-0.70711	0
	5	-0.70711	0.707107	0
	6	0	0	-1
	1	0	0	1
	2	0	1	0
	3	1	0	0
	4	0	-1	0
	5	-1	0	0
	6	0	0	-1

BUILDING

ATOM

A crystal is composed of identical groups of atoms. Each group has an orientation which is identical to that of each of the other groups which comprise the crystal. Each group is joined with each neighboring group in a precise way. The joins define a volume for the group which is a polyhedron. The group polyhedron of a crystal has dimensions of 10^{-9} meters or less. The crystal itself has a polyhedral shape, and these have been found with diameters in excess of a meter. Yet the group determines the shape of the crystal despite the enormous size difference.

The atoms which comprise the group are few. Within each group, each atom has a position relative to that of any other atom of the group. Thus, the atoms have positions that determine the shape of the group; and the atoms in these positions within the group determine the position of an identical group in identical orientation with which it joins; and by this means the atoms within the group determine the shape of the crystal.

It would be consistent if each atom had a shape, and that its shape determines how the atom fits with another atom, and in this way the relative positions of the atoms and their relative orientations within any group are determined.

It would also be consistent, if the atom is composed of parts, that each part has a shape, and that this shape determines the position and orientation of the part within the grouping of parts which is the atom. Thus, the part determines the relative positions and orientations of other parts which determines the shape of the atom and how that atom can join with another atom.

The consistent application of shape, position, and orientation leads from a crystal a meter in diameter to the parts of the atoms which compose it. It suggests that the crystal's form is determined by the parts of the atoms which compose it. Parts which have shape, position, and orientation and which determine the form of a crystal immensely larger have the crystalline quality of precise form.

Compound polyhedra: the periodicity of recurring form

The tetrahedron, cube, and octahedron, the three regular polyhedra which are natural crystalline forms, can each be modeled by the joining of identical polyhedra of the same shape in the same orientation to form larger compound polyhedra. The tetrahedra join vertex to vertex, the cubes face to face, and the octahedra edge to edge. The edge lengths of the compound polyhedra are integral multiples of the modeling unit's edge length. The number of units in each of the compound polyhedra arranged by increasing edge length produces a series of numbers which is unique to each of these forms. For the octahedron, the number of simple octas n composing a compound octahedron

with edge ratio r is $n = \frac{r}{3}(r+1)(2r+1) - r^2$

Table 4: Polyhedra in compound polyhedron

polyhedron	congruency	edge length			
		1	2	3	4
tetrahedron	vertexial	1	4	10	20
cube	facial	1	8	27	64
octahedron	edgial	1	6	19	44

This recurrence of the same form is periodic in the same way as the properties of the elements of the Periodic Table. If each of the elements in a column of the Periodic Table has the same form as the others, or some portion of its form is identical with that of the others, then their chemical similarities may derive from this cause. A comparison of the periodicities of polyhedral growth with the periodicity of the atomic elements shows that each of the octahedral numbers is equal to one half of the atomic number of one of the elements of

Group 2a of the Periodic Table.

Table 5: Periodicity of Group 2a-elements and octahedron

Symbol	He	Be	Mg	Ca	Sr	Ba	Ra
Number	2	4	12	20	38	56	88
Number/2	1	2	6	10	19	28	44
Units	1		6		19		44
Row	1	2	3	4	5	6	7
Layer	1		3		5		7

The octahedral periodicity of the Atomic Elements

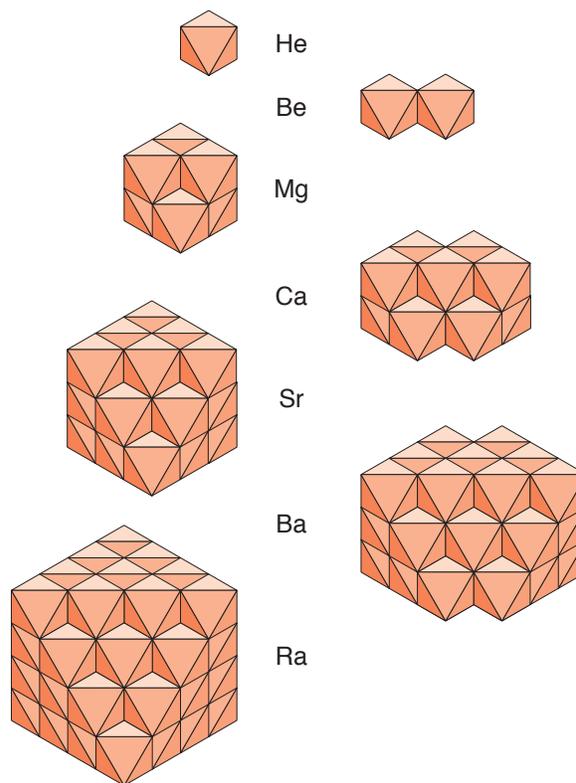
Each of the elements Mg, Sr, and Ra has an atomic number which is exactly twice the number of octahedra in one of the compound octahedra.

Beginning with He and ending with Mg, there are exactly six elements whose atomic numbers are multiples of two and there are exactly six octahedra in a compound octahedron of edge length two.

There are exactly nineteen even numbered elements beginning with He and ending with Sr, and there are exactly nineteen octahedra in a compound octahedron of edge length three.

And, there are exactly forty-four even numbered elements beginning with He and ending with Ra, and there are exactly forty-four octahedra in a compound octahedron of edge length four.

So, if the even numbered elements are to be built of identical octahedra, and each of the compound octahedral elements contains only as many octahedra as there are even numbered elements up to and including the number of the element, then Sr will contain each of the octahedra of Mg, and Ra will contain each of the octahedra of Sr. That suggests that the element of Mg is transformed to the element Sr by the addition of thirteen octahedra and that Sr is transformed to Ra by the addition of twenty-five octahedra.



The elements of column 2 of the Periodic Table

The elements in the left column are compound regular octahedra. Each is in an odd row of the Periodic Table. Each has an odd number of layers. The elements on the right have an even number of layers. Each lies in an even-numbered row.

The layer

The octahedra that form the compound octahedra are arranged in layers perpendicular to a vertexial diameter. Each of these layers is a square array of octahedra. The odd-numbered layers have an odd number of octahedra, and the even-numbered layers have an even number of octahedra. Each of the odd layers has an octahedron at its center while the even layers do not. Each of these regular compound octahedra has an odd number of layers. The middle layer has as many octahedra as the square of

the layer number. Each of the compound octahedra has just one unit in layer 1, as does He which has just one octahedron. Each of the compound octahedra beginning with Mg has four units in layer 2. Each of the compound octahedra beginning with Sr has nine units in layer 3. This suggests that the larger compound octahedron retains the units of the smaller octahedron in the same positions relative to the first position, that of He. That is, there is no reordering of the previously entered units.

Table 6: Octahedra in each layer of regular octahedral atoms

Atomic Symbol	Layer number						
	1	2	3	4	5	6	7
He	1						
Mg	1	4	1				
Sr	1	4	9	4	1		
Ra	1	4	9	16	9	4	1

Table row is layer of last entry

The number of layers in the He octahedron is one, and He appears in the first row of the Periodic Table, or Period 1. The number of layers in the Mg octahedron is three, and Mg appears in the third row, or Period 3. There are five layers in the Sr octahedron, and Sr is in the fifth row. The Ra octahedron has seven, and Ra is in the seventh row. There is an exact correlation between the number of layers which each of these octahedra contain and the row of the Periodic Table in which the element is located. Each of these elements is the first even atomic numbered element in the row. This suggests that the last numbered unit, the element-forming unit, is in the last layer of that unit. The second row has just four elements with even atomic numbers, and there are just four units in the second layer of the Mg octahedron. This, too, suggests that the number of the row is identical with the number of the layer in which the element-forming unit is located. For each of the regular octahedral elements, listing the

atomic symbols of each of the even-numbered elements, up to and including that of the element itself, in the same row that it has in the Periodic Table, provides just the number of symbols required to label each of the units of each of the layers.

Octahedral coordinates

The regular octahedron has three vertexial diameters. The diameters are mutually perpendicular. Together they establish a set of coordinate axes for the units of the compound octahedron. If the intersection of these axes is placed at the centroid of the He unit of each even-numbered element, then the centroid of each additional unit within the atom can be specified relative to the centroid of the He unit. The growth direction (He unit to Mg unit) is labeled the +Z direction. The direction of the Be unit normal to the z-axis is labeled +Y. The direction of the C unit to the z-axis is labeled +X. The placement of the C unit establishes a counterclockwise layer-growth direction, and the choice is arbitrary. Consistently applied, it provides a single shape for each of the elements. If elements evolve through clockwise layer-growth, some will be as the mirror images of those which are produced by the counterclockwise layer-growth.

The position of the Be unit differs from that of the He unit by a translation in the zx-direction which is equal to the edge length of the unit. This positions the unit at $\text{edge}/\sqrt{2}$ in the z direction, and the same amount in the x direction.

$$1 \text{ Axial Unit} = \frac{\text{Edge}}{\sqrt{2}}$$

The O-unit is placed in the -x direction and the Ne-unit is placed in the -y direction. The second layer units provide a location for the Mg-unit in which each has an edge congruent with an edge of the Mg unit.

The Si-unit is in the same layer as the Mg-unit and is added in the xy-direction. It shares an edge with the Be, Ne, and Mg units. Maintaining the counterclockwise direction of layer growth, the S unit is added to the Si unit in the

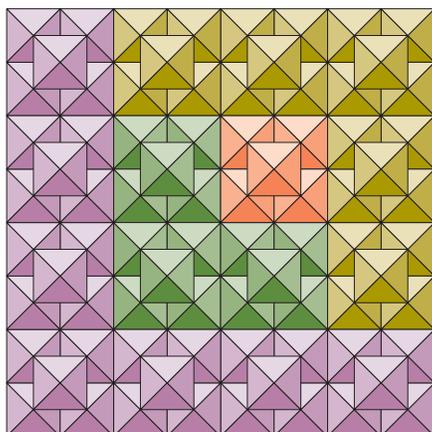
xy-direction. It shares an edge with the Si and Be units. The Ar unit completes the square sharing edges with the Mg, S, and C units. The Ca unit like the Mg unit is placed so that it shares an edge with each of the units of the layer below it.

Consistently following the growth direction chosen, the Ti is added to the Ar unit in the -xy-direction and shares an edge with the C unit. The Cr unit adds to the Ti unit in the -x,-y direction and shares an edge with the Mg, C, and O units in addition to the Ti unit. The Fe, Ni, and Zn units complete the square.

The Ge unit adds to the Ca unit in the -xy-direction. And then Se and Kr complete the square. Sr begins a new layer.

Layer formation: the Gnomon

Layers build by the addition of epn-triplets one by one. The odd triplet is paired by the next entering triplet to form a He-octa. In the building of the atom, the triplets enter the layer until the He-octas form a square array. The next



The gnomons of an atomic layer.

A layer of He-octas viewed normally. The He-octas belonging to a given gnomon have the same hue.

triplet joins another layer. The layer is built-up from a single He-octa to four He-atoms in a square array, from four He-octas to nine He-octas in a square array, from nine He-octas to sixteen He-octas in a square array, until its maximum size is attained. This interrupted

growth of the layer from square array to larger square array requires an odd number of units which, taken together, are in the shape of a carpenter's square, or *gnomon*.

Table 7: y-coordinates of layer units relative to first unit

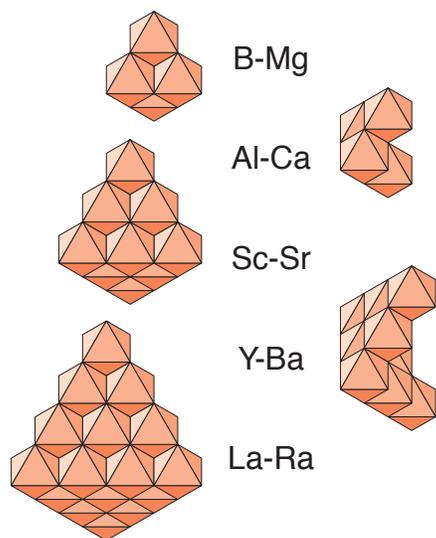
Gnomon	Layer				
	1	2	3	4	5
0	0	0	0	0	0
1		1	-1	1	-1
		0	0	0	0
		-1	1	-1	1
2			2	-2	2
			1	-1	1
			0	0	0
			-1	1	-1
			-2	2	-2
3				3	-3
				2	-2
				1	-1
				0	0
				-1	1
				-2	2
				-3	3

The maximum value of the y-coordinate in each gnomon is the same as the gnomon number.

The elements are arranged in rows according to the layer in which the element-forming triplet is located, and they fall into columns in the order in which the triplet enters the layer.

Following the atomic numbers sequentially portrays the evolution of the element. Following along a row from left to right portrays the evolution of the layer. The elements in each column have the same entry-layer development.

The He-octas which transform one column 2 element to another column 2 element define a gnomon array which has its own form. The form and its orientation reveal the pattern of the development of the compound octahedra.



Gnomon arrays

The odd atomic numbered elements

The triplet

The octahedral units of the even numbered elements must be equally divisible to account for the odd numbered elements. A six unit compound octahedron can be divided into a pair of identical triplets by splitting it parallel to a pair of faces. The orientation of each octahedron of the triplet is identical to that of either of the others. Each octa of the triplet shares an edge with each of its neighbors. Each of the octas contributes a face to form a central regular tetrahedral cup. The three edges of the cup are the paired edges of the octahedra. If each edge of each octa is polar—has the quality of a magnetic pole—and if the paired edges of the triplet are attractive opposites, then this triplet is structurally stable and rigid.

The shared edge join is a hinge. A pair of octahedra joined by a common edge would not

be rigid. But each of the hinges in the triplet is fixed by the octahedron opposite it.

The edge length of the triplet-forming octahedron is exactly half the edge length of the He-octa. The triplet-forming octa will fit into the tetrahedral voids created by the crystalline association of the He-octas. A hinged pair of He-octas such as in the Be-atom is stabilized by the presence of the triplet-forming octahedron.

The epn

Now each of the elements can be built using an association of identical regular octahedral particles with polarly attractive edges which cause the octahedra to adhere edge-to-edge in fixed positions with a common orientation. The first step in building the elements is to form the triplets. This triplet brings to mind the electron, proton, neutron triplet that has been used in a previous attempt to explain the elements. It shall be called the “epn triplet”. The octahedral particle will be called the “epn”. This name combines the first letters of the names of the **e**lectron, **p**roton, and **n**eutron.

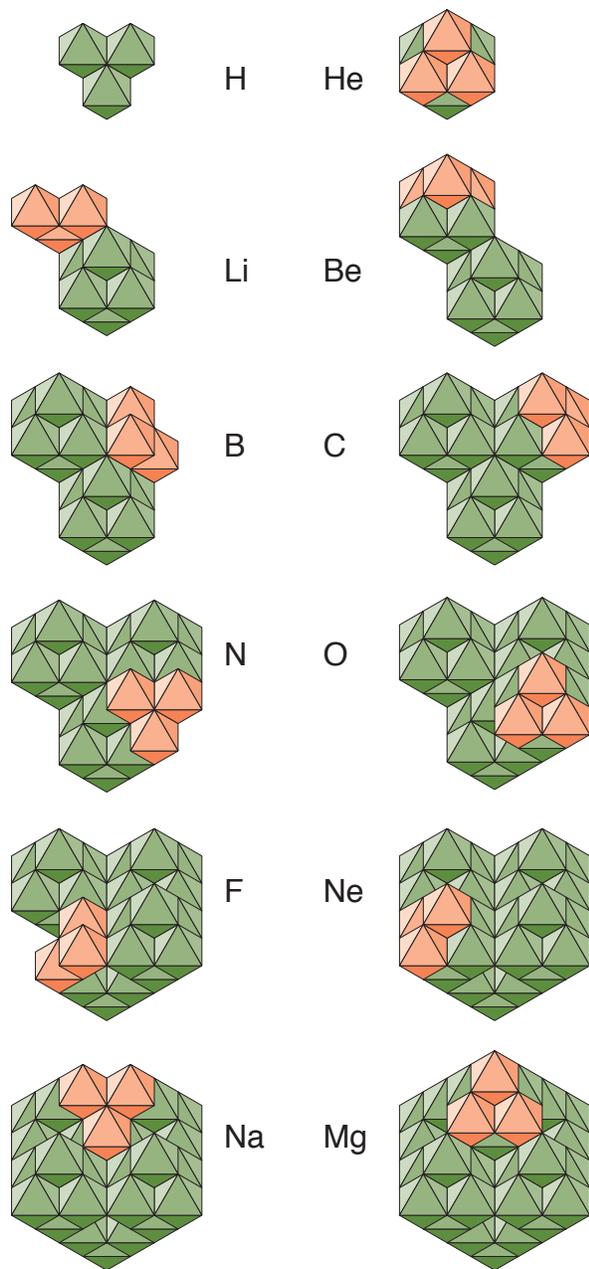
The even numbered elements have been described using He-octas which are paired triplets. The odd numbered elements each have but one unpaired triplet. The atomic number is the number of the triplets from which the element has been built.

Coordinates of epns

The centroid of the He-atom is at 0,0,0. The centroids of the six epns which constitute the atom lie in the axial directions which are vertexial. The distance is one-half of the vertexial diameter of the epn which is exactly half the vertexial diameter of the He-atom. Since the coordinates of the He-octas have been given as integral multiples of one-half of the vertexial diameter of the He, then the epn centroids have locations that differ by a half unit from the centroid in the six axial directions. The axial directions will be assigned numbers in the sequence and in the direction which has been chosen for the even numbered elements He through Mg.

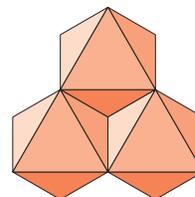
Table 8: Epn coordinates for He-octahedron location X,Y,Z

Axial Direction	Axial Number	epn coordinates		
		x-coordinate	y-coordinate	z-coordinate
-z	1	X	Y	Z-1/2
-x	5	X-1/2	Y	Z
-y	4	X	Y-1/2	Z
+x	3	X+1/2	Y	Z
+y	2	X	Y+1/2	Z
+z	6	X	Y	Z+1/2



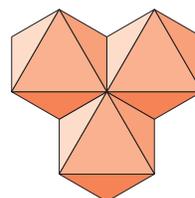
H to Mg: Growth of elements by triplet addition

The epn triplet has an axis of threefold symmetry. When viewed along this axis in one direction the tetrahedral cup can be seen.



epn-triplet showing tetrahedral

When viewed from the opposite direction the cup is not visible. The latter side is the joining

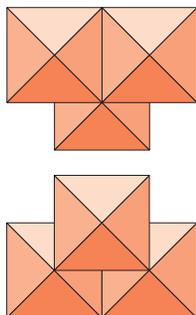


epn-triplet, showing joining side

side and the three near faces lie on the joining plane. For the triplets to join one must be rotated relative to the other 180° about an axis

perpendicular to the threefold symmetry axis. The first triplet of any He-octa includes the $-z$

epn-triplet viewed in anti-growth direction, first half of He-octa.

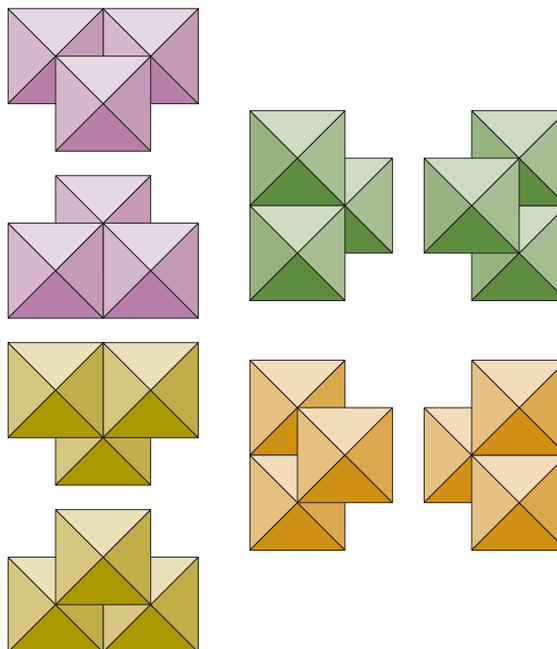


epn-triplet viewed in anti-growth direction, second half of He-octa

or **1** epn. The second or completing triplet includes the $+z$ or **6** epn. The first will have the z -coordinate Z of the He octahedron location less $1/2$; the second will have Z plus $1/2$. These two values are identical with the two allowed values of the *electron spin* quantum number.

The spiral growth pattern of the octahedral layer results in four orientations for both the entry epn-triplet and the completing epn-triplet.

Because the periodicity of the elements describes an octahedral growth pattern, the atomic number alone determines the position and orientation of each epn of each epn-triplet of which it is composed. And using the atomic number the layer, gnomon, and position within the gnomon is calculable. If the number is odd, then the position and orientation of the lone unpaired triplet is also determined. If any deviation from the pattern is permitted, then there must be more elements than what are now included in the Periodic Table.



Quantum numbers and spatial coordinates

The crystalline atom vs. the Bohr atom

The crystalline atom defined by the periodicity of the elements is the antithesis of the Bohr model of the atom. The Bohr atom has no shape, it is unstructured. Its parts have motions which are easily disturbed; they are easily lost. The parts are spheres which, being featureless, have no orientation and no surface feature for joining to other spheres. Its most repulsive parts reside in utmost intimacy within a nucleus; and, as well, at the boundary where the all-repulsive satellites intermingle and somehow cause the atoms to adhere. The unit of charge is not determinable, since it uniformly coats the satellites, and it is these coated particles which have polar values.

The meaning of the quantum numbers

The orbits of the supposed satellites were thought to explain the optical spectra of the elements and the effects of magnets thereupon. Numbers were used to define the characteristics of the supposed orbits which were called *quantum numbers*. These numbers have meaning for the crystalline atom. They describe the

positions of the epn triplets which combine to build each of the elements.

There is a correlation between the *gnomon number* and the *orbital quantum number*. There is a correlation between the *y-coordinate* and the *magnetic quantum number*. There is a correlation between the *layer number*, which is the z-coordinate + 1, and the *principal quantum number*. There is a correlation between the orientation of the epn triplet and the *spin*

Table 9: Quantum numbers and spatial coordinates

Bohr	Octahedral	Quantum mechanical	
		number	values
shell	layer or z-coordinate	principal	$n=1,2,3,4,\dots$
subshell	sublayer or gnomon	orbital	$l=0,1,2,3\dots(n-1)$
	x or y coordinate	magnetic	$m=-l(-l+1)\dots(l-1),l$
	triplet off-sets: x, y, & z	spin	$s=-\frac{1}{2},+\frac{1}{2}$

For each unit, the sum of the absolute values of the x and y coordinates is

$$|x| + |y| + (1 - \text{Layer mod } 2) = \text{Gnomon}$$

Because the pattern of growth defines the position and orientation of each of the triplets of an element, the number of triplets defines the element. The atomic number, however, large, is sufficient data to enable a computer program to build the element in epn detail, but not to place the extra epns which have been described as *neutrons*.

The pattern of growth described is fully octahedral

The numerical series 1 6 19 44 is a strong indicator that the atomic elements are octahedral. But this is made emphatically clear by the number of units in the completed layers and the manner in which the layers are filled.

The number of units in the completed layer is twice the number of the layer squared. This

is a strong indication of the octahedron. The number of He-octas in the first layer of the octahedron is one, in the second is four, in the third is nine, in the fourth is sixteen; and the number elements in the first row of the periodic table is twice one, in the second row twice four, in the third row twice nine, in the fourth row is twice sixteen.

The method of filling the layer is by adding units which build ever larger squares.

Table 10: Vector addresses of He-octas

OctaNumber	OctaName	vector1	vector2	vector3	vector4	vector5	vector6
1	he	0	0	0	0	0	0
2	be	0	1	0	0	0	1
3	c	0	0	1	0	0	1
4	o	0	0	0	1	0	1
5	ne	0	0	0	0	1	1
6	mg	0	0	0	0	0	2
7	si	0	1	0	0	1	2
8	s	0	2	0	0	0	2
9	ar	0	1	1	0	0	2
10	ca	0	1	0	0	0	3
11	ti	0	0	2	0	0	2
12	cr	0	0	1	1	0	2
13	fe	0	0	0	2	0	2
14	ni	0	0	0	1	1	2
15	zn	0	0	0	0	2	2
16	ge	0	0	1	0	0	3
17	se	0	0	0	1	0	3
18	kr	0	0	0	0	1	3
19	sr	0	0	0	0	0	4
20	zr	0	1	0	0	2	3
21	mo	0	2	0	0	1	3

Table 10: Vector addresses of He-octas

OctaNumber	OctaName	vector1	vector2	vector3	vector4	vector5	vector6
22	ru	0	3	0	0	0	3
23	pd	0	2	1	0	0	3
24	cd	0	1	2	0	0	3
25	sn	0	1	0	0	1	4
26	te	0	2	0	0	0	4
27	xe	0	1	1	0	0	4
28	ba	0	1	0	0	0	5
29	ce	0	0	3	0	0	3
30	nd	0	0	2	1	0	3
31	sm	0	0	1	2	0	3
32	gd	0	0	0	3	0	3
33	dy	0	0	0	2	1	3
34	er	0	0	0	1	2	3
35	yb	0	0	0	0	3	3
36	hf	0	0	2	0	0	4
37	w	0	0	1	1	0	4

Table 10: Vector addresses of He-octas

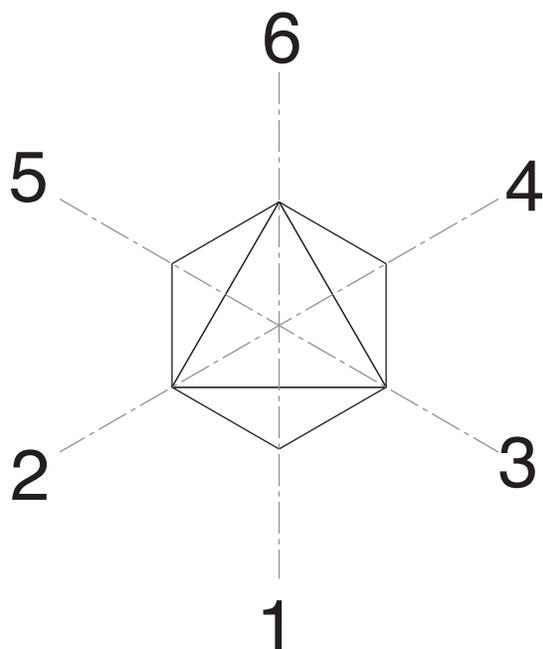
OctaNumber	OctaName	vector1	vector2	vector3	vector4	vector5	vector6
38	os	0	0	0	2	0	4
39	pt	0	0	0	1	1	4
40	hg	0	0	0	0	2	4
41	pb	0	0	1	0	0	5
42	po	0	0	0	1	0	5
43	rn	0	0	0	0	1	5
44	ra	0	0	0	0	0	6
45	th	0	1	0	0	3	4
46	u	0	2	0	0	2	4
47	pu	0	3	0	0	1	4
48	cm	0	4	0	0	0	4
49	cf	0	3	1	0	0	4
50	fm	0	2	2	0	0	4
51	no	0	1	3	0	0	4
52	rf	0	1	0	0	2	5

CRYSTAL

The periodicity of the elements defines an atomic growth pattern which requires that the atoms be formed of identical regular octahedra in identical orientation. If atoms join so that each octahedron of one atom has an orientation which is identical to that of each octahedron of the other atom, it follows that any crystalline form which results from such joining must be modelable using identical regular octahedra in identical orientation.

Crystalline geometry

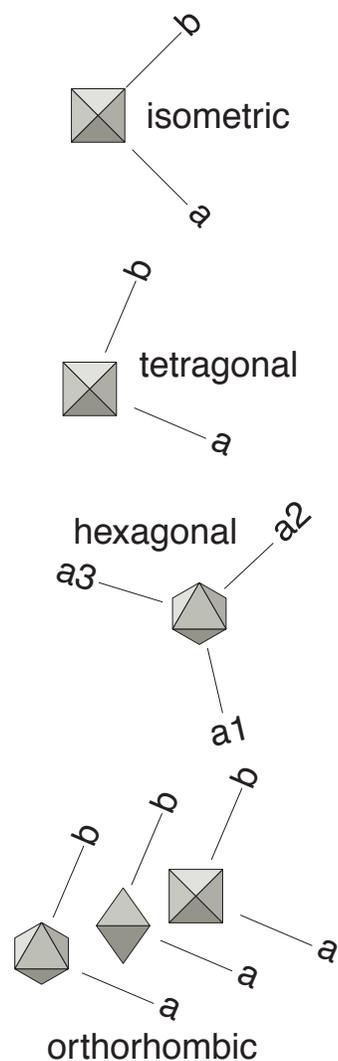
The geometry of the regular octahedron defines the geometry of the crystal. The regular octahedron has three vertexial diameters which intersect at its centroid. These diameters are in the same relationship as the Cartesian coordinates. If there is no motion between adjoining



octahedra in crystalline order, then the position of one relative to another is expressible using integral multiples of the vertexial diameter of the octahedron divided by two. The location of one octahedron relative to another is expressible with three integers which represent the axial directions.

Crystal axes

The symmetry of the crystal class shows the orientation of the octahedra of which its atoms are composed.



Orientation of octahedra in crystals.

The symmetries of the crystals within the crystal classes indicates the possible orientations of the octahedra of which its constituent atoms are formed. The views here are parallel to the c-axes.

The **isometric** class is the most well defined in this regard. The crystal axes must be equal in length and at right angles to each other. This

condition can only be met if the crystal axes are parallel to the three vertexial diameters of the octahedron. Each of the axial increments is an integral multiple of the vertexial hemi-diameter of the He-octa.

The **tetragonal** class requires the three axes to be mutually perpendicular. Two of the axes must be equal in length. This requires that the c-axis be parallel to a vertexial diameter of the octahedron. The c-axial increment is an integral multiple of the vertexial hemi-diameter of the He-octa.

The **hexagonal** class requires that three axes be equal in length, at 120° , and at right angles to the c-axis. The c-axis must be parallel to a facial diameter of the octahedron to meet these criteria. The c-axial increment is an integral multiple of the facial diameter of the He-octa.

The **orthorhombic** class requires that its three axes be mutually perpendicular. This condition can be met if the c-axis is parallel to an edgial, a facial, or a vertexial diameter of the octahedron.

Moving between octahedral locations

In defining the locations of the parts of the octahedral assembly, the relation of one location to another can be described in terms of *moves*. A reference octahedron is specified and its centroidal address is taken as 0,0,0. Its vertexes are numbered from 1 to 6 and all moves within the assembly are specified in terms of the directions of these vertexes from the centroid. A convention has been adopted wherein the vertexial directions are assigned xyz-directions.

Table 11: Correlation of octahedral directions with Cartesian coordinates

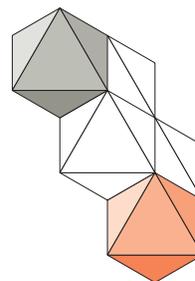
XYZ	Octa vertexial
+x	3
-x	5
+y	2
-y	4

Table 11: Correlation of octahedral directions with Cartesian coordinates

XYZ	Octa vertexial
+z	6
-z	1

Edgial move

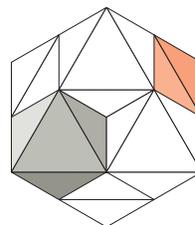
Edgial moves are in the direction from the centroid to the middle of an edge. It is normal to the edge. The direction designation is the pair of numbers of the vertexes which terminate the edge. Each edgial move increments



the values of each of the two coordinates matched by the vertexial numbers by ± 1 . The move 13,2 adds 2 to the x-coordinate and subtracts 2 from the z-coordinate.

Vertexial move

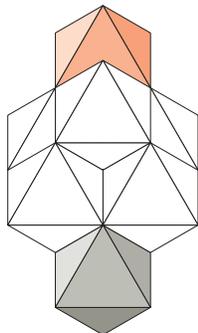
Vertexial moves are in the direction from centroid to vertex. The coordinate is the vertexial number. The vertexial move increments



a single coordinate by ± 2 . The move 4,1 subtracts 2 from the y-coordinate.

Facial move

The facial move is in the direction from the centroid of the octahedron to the centroid of the octahedral face. It is normal to the face. There is no octahedron whose centroid can lie in the facial direction in the first two layers. It is in the third layer that there can be an octahedron in the requisite crystalline order. The facial move increments the three coordinates



by ± 2 . The move 546,1 subtracts 2 from the x- and y-coordinates and adds 2 to the z-coordinate.

Planar moves between octahedra

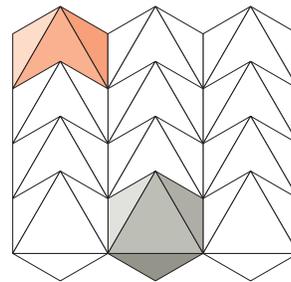
The location of one octahedron is reachable from the location of another octahedron by a series of moves which are in the plane. These are referred to as planar moves. The planes of an octahedral assembly are defined by the topological features of the octahedron. The *vertexial plane* is defined by its vertexes, the *facial plane* by its faces, and the *edgial plane* by its edges. There being no other topological features, any plane is one of these three types.

Vertexial planar moves

The vertexial plane can be normal to a vertexial diameter of the octahedron or at another angle to it. The latter cannot be generalized. The normal and special planes are described.

The normal vertexial plane

The location of any octahedron defining the *normal vertexial plane* is reachable by edgial



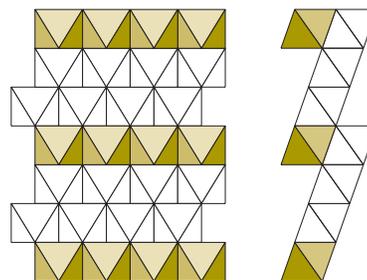
The normal vertexial plane.

The normal vertexial plane is at right angles to the vertexial diameters of each of the octahedra whose vertexes define the plane. The locations of the two octahedra which are colored differ by edgial moves which are parallel to the plane.

moves parallel to the plane. There are four edgial directions in a normal vertexial plane. Some locations are reachable by a vertexial move. The (100) faces of crystals of the isotropic system are defined by octahedral vertexes and are normal vertexial planes.

The special vertexial plane

The *special vertexial plane* is a type of vertexial plane which arises from the facial move. There are two edgial moves and two facial



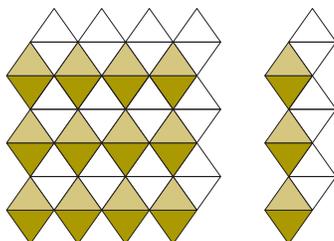
The special vertexial plane.

The view on the left is normal to the plane and parallel to a pair of faces of the octahedra which constitute it. The plane is defined by a vertex of each of the octahedra which is colored yellow. The view on the right is parallel to the plane.

moves in the special vertexial plane. These planes are normal to a pair of faces of the regular octahedron and can occur as hexagonal prisms.

Edgial planar moves

The move from one octahedral location to another in the edgial plane is accomplished



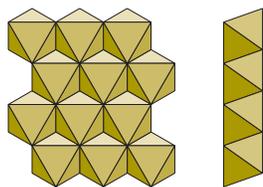
The edgial plane.

The view on the left is normal to the edgial plane. That on the right is parallel to the edgial plane. An edge of each of the octahedra colored yellow defines the edgial plane.

with the two edgial directions, four facial directions, and two vertexial directions. These planes are exemplified by the (110) planes of the isometric system.

Facial planar moves

There are six edgial moves in the facial plane. These planes are exemplified by the (111) planes of the isometric system and the (0001) planes of the hexagonal system.



The facial plane.

The view on the left is normal to the facial plane. That on the right is parallel to the facial plane. A face of each of the octahedra defines the facial plane.

The isometric system

Closed forms

A closed form is defined by crystal planes which are so oriented that they enclose a volume. Each plane of a closed form has axial intercepts which are numerically identical with those of every other plane of the form. Modeling the closed forms is a rigorous test which the shape that defines the forms of the atomic elements must pass. Each of the closed forms of the isometric system is definable through the edge to edge association of regular octahedra. Each of the crystalline planes is defined solely by one of the three topological features of the regular octahedron—edge, vertex, or face.

Crystal planes specified by vertexial axes of the octahedron

For modeling the crystal planes of the isometric system using regular octahedra, the planes may be specified by axes defined by the vertexial diameters of the octahedron. These axes are the same as those used for describing the positions of the He-octas in the atomic elements. Specifying the plane in this way establishes an absolute description of the plane. The axial intercepts of the octahedral plane are expressed as integral lengths of the vertexial hemi-diameters of the He-octa. The vertexial hemi-diameter is equal to the edge of the He-octa divided by $\sqrt{2}$.

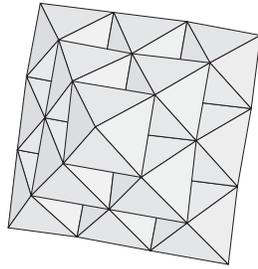
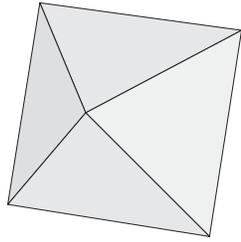
Planes defined by octahedral faces

The (111) planes of the crystals of the isometric system are defined by faces of the octahedra which make up the atoms of which the crystal is formed. There are two closed forms which have only (111) faces—the regular octahedron and the regular tetrahedron.

Octahedron (111)

Faces of the simple octahedra which compose the compound octahedron define the

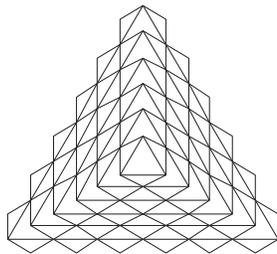
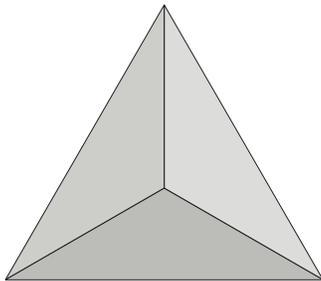
(111) planes of the regular octahedron.



Octahedron (111)

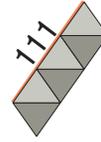
Tetrahedron (111)

Here the faces of the octahedra define the faces of a regular tetrahedron. The octahedron has eight faces which can be seen as two sets



Tetrahedron (111)

of four faces each. Each set includes the faces of a regular tetrahedron.



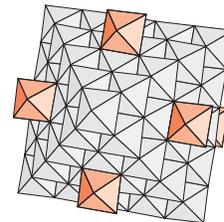
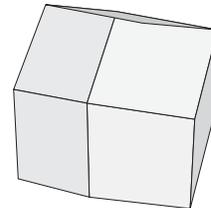
Tetrahedral planes (111)

Planes defined by octahedral edges

Three closed forms of the isometric system are the *rhombic dodecahedron*, the *trisoctahedron*, and the tetragonal *tristetrahedron*.

Rhombic dodecahedron (hh0)

Each of the rhombic dodecahedral planes is normal to an edgial diameter of the regular octahedron and is defined by the edges of the octahedra. The rhombic dodecahedral assembly depicted here is the minimal such assembly. It is composed of a 5-octa which has 1-octas mounted on its face centers. An edge of 5-octa combines with an edge of each of two of the 1-octas to define each of the rhombic



Rhombic dodecahedron.

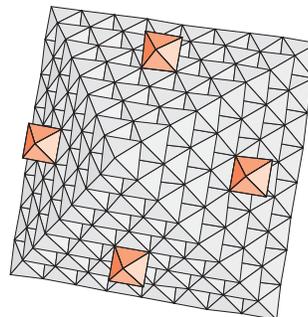
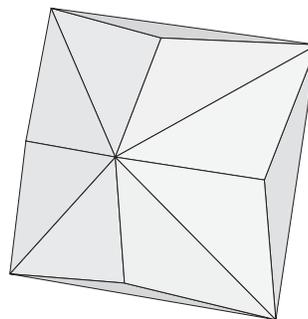
dodecahedral planes.



Rhombic dodecahedral plane (110)

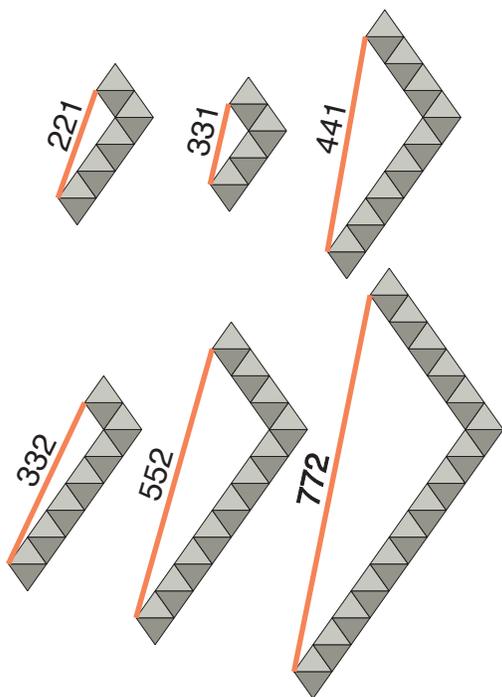
Trisoctahedron (h_hk)

The trisoctahedron features a tetrahedron upon each of the eight faces of a regular octahedron. The threefold-axis of the tetrahedron is colinear with the facial centroid to octahedral



Trisoctahedron (331)

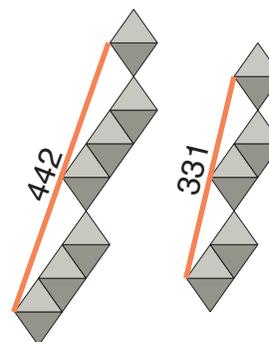
This compound octahedron has faces which each have a facial centroidal position where a simple octahedron can join. The next smaller compound octahedron which has facial centroidal attachment positions is the 5-octa. The faces produced thereon are rhombic dodecahedral as is shown above.



Trisoctahedral planes, *h_hk*

Tetragonal tristetrahedron (h_hk)

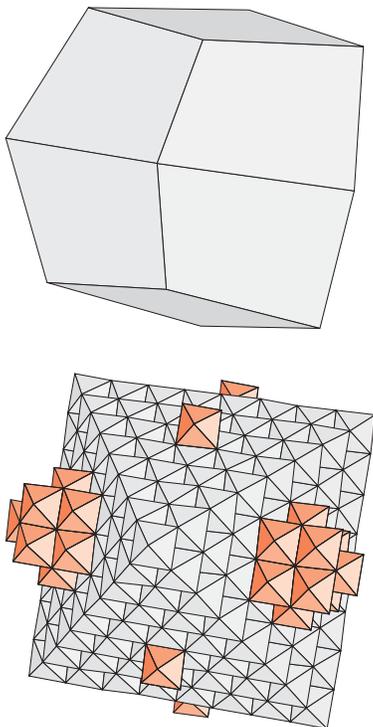
The tetragonal tristetrahedron has twelve faces of four edges each. Each face is parallel to a pair of octahedral edges. The plane is



defined by one of these edges. The faces meet

centroid vector of the face upon which it is situated. The figure shows the minimal trisoctahedron which can be built of identical octahedra. The base octahedron is an 8-octa.

at two different types of vertexes—three plane and four plane. The two types alternate. The three-plane vertexes lie on facial-centroidal axes. The four-plane vertexes lie on vertexial diameter axes.

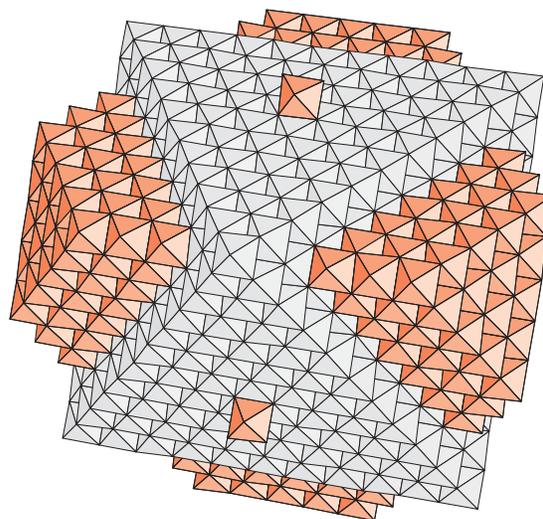
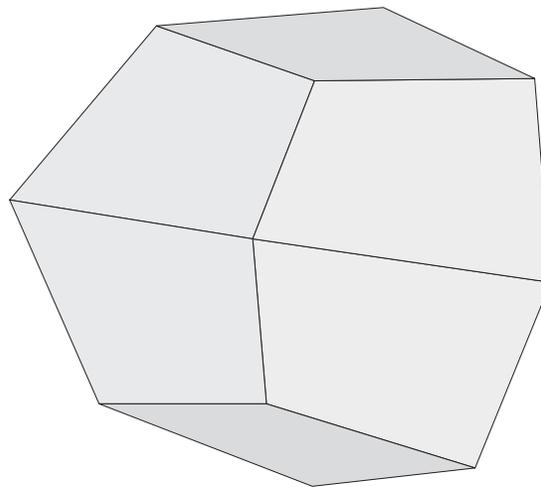


Tetragonal tristetrahedron (331)

The structure of the tetragonal tristetrahedron can be seen in the two examples. The first of these, the (331) is minimally modeled using a single octahedron on four faces which together define a regular tetrahedron. The other four faces have a two layer pyramidal group which is symmetrical about the facial centroid axis. The faces they occupy define a regular tetrahedron as well. The 331-planes are defined by an edge of one octahedron of this group, an edge of the lone octahedron on an adjacent face and an edge of the eight octahedra which define the intervening edge of the 8-octa which is the foundation of the crystal model.

The (442) tetragonal tristetrahedron has an 11-octa for its foundation. A tetrahedral group of the 8-octa faces have a single octahedron at

their centroids. The remaining four tetrahedral faces have a pyramidal assembly which is three layers high. Each of the tetragonal tristetrahedral faces is defined by a edge of four octahedra of the three layer pyramidal group, an edge of the lone octahedron on an adjacent face, and an edge of each of the eleven octahedra which define the intervening edge of the 11-octa.



Tetragonal tristetrahedron (442)

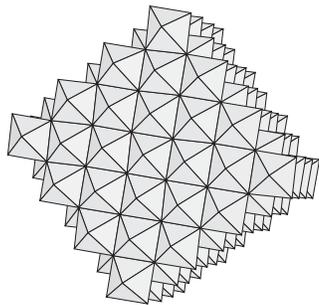
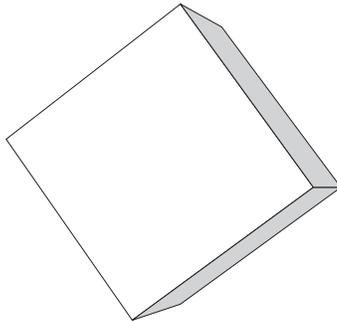
Planes defined by octahedral vertexes

Vertexes of the octahedra define these closed

forms of the isometric system—the *cube*, the *tetrahexahedron*, the *trapezohedron*, the *tristetrahedron*, the *pyritohedron*, the *gyroid*, the *diploid*, and the *hexoctahedron*

cent 5-octa faces.

Cube (h00)

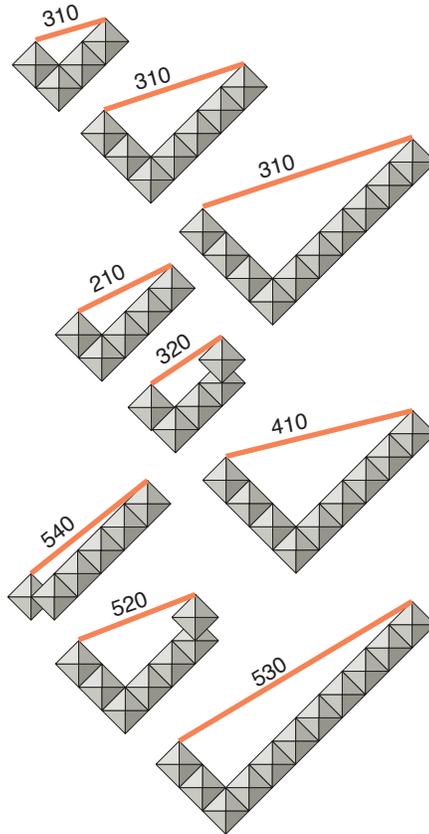
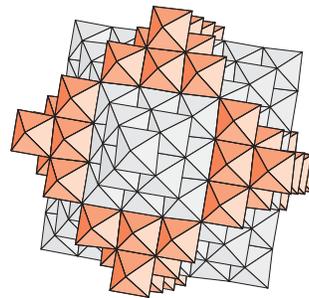
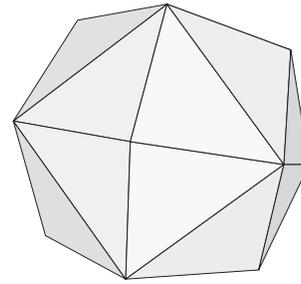


Cube (h00)

A cube has six (100) faces. The cube faces are defined by octahedral vertexes. Each cube face is perpendicular to a vertexial diameter of each of the octahedra which define it. The octahedral model shown here defines a cube with a facial diameter of four octahedral vertexial diameters.

Tetrahexahedron (hk0)

The tetrahexahedron is modeled using a 5-octa foundation. Upon each face of the 5-octa is placed a two layer pyramidal group which is symmetric about a facial centroidal diameter. Each face of the tetrahexahedron is defined by a vertex of the 5-octa and a vertex of each of two octahedra of a pyramidal group on adja-



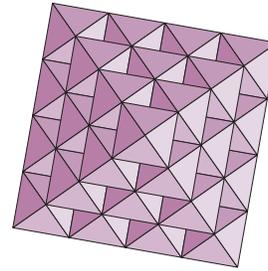
The plane of the tetrahexahedron is parallel

to a vertexial diameter of the regular octahedron. This is seen when the plane is viewed edge-on.

Trapezohedron (hkk)

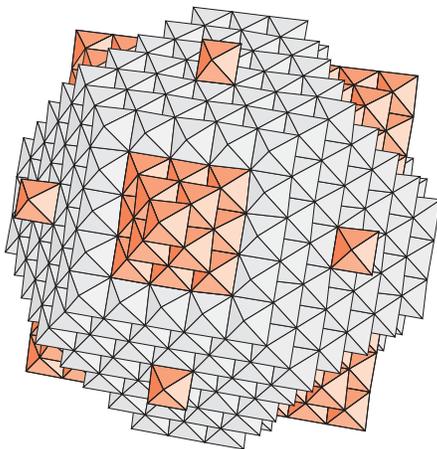
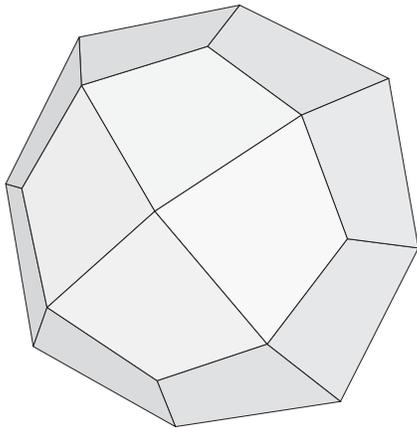
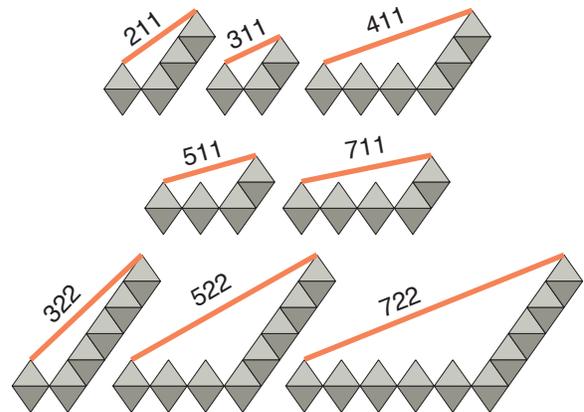
The trapezohedron has twenty-four faces. The model of the trapezohedron (211) has an 11-octa for a foundation. A single octahedron has been placed upon the centroid of each face of the 11-octa. A one octahedron thick square pyramidal cap has been removed from each 11-octa vertex which exposes a portion of a 9-octa. Each face of the trapezohedron is defined by a vertex of the 9-octa and a vertex of a lone facial octahedron and a vertex of each of five 11-octa octahedra which form the edge where the cap was removed.

The planes of the trapezohedron are parallel to a pair of edges of the octahedron whose ver-



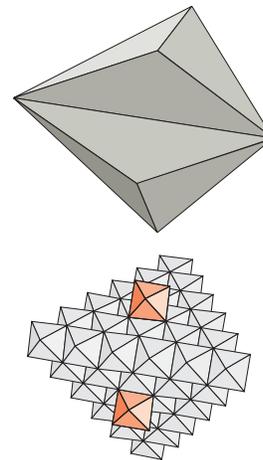
Vertexial cap removed from 11-octa in modeling trapezohedron.

texes define it.



Tristetrahedron (hkk)

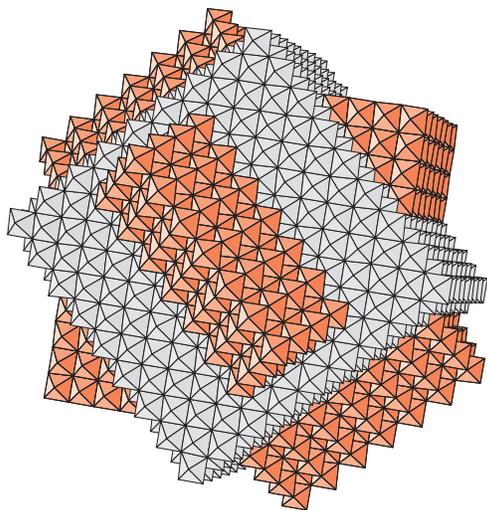
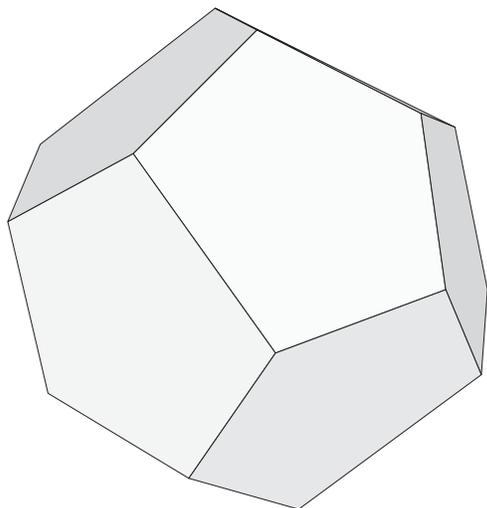
A regular tetrahedron constructed with identical octahedra and having six octahedra along each edge is the foundation for the tristetrahedron model. A single octahedron is mounted



centroidally on each of the four faces. A vertex of the facially mounted octahedron and a vertex of each of the six edgial octahedra of the tetrahedron define the tristetrahedral plane. The formation is such that a triangular pyramid is mounted on each of the tetrahedral faces.

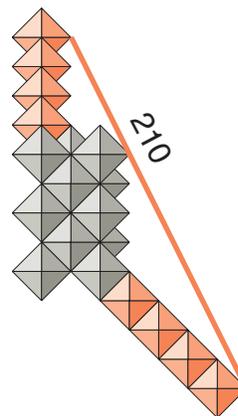
Pyritohedron (hk0)

The foundation for the pyritohedron (210) model is a cube composed of identical octahedra. The cube edge is defined by nine octahedra. A triangular prism which is seven octahedron vertexial diameters long and four vertexial layers high is mounted on each face of the cube. The prisms on opposite faces are mirrored. The three pairs of prisms are mutually perpendicular. The pyritohedral face is



defined by an octahedral vertex at the end of the top layer of one prism, a vertex of each of the octahedra in the top layer of a prism on an adjoining face, and a vertex of each of the octahedra along the edge between the faces.

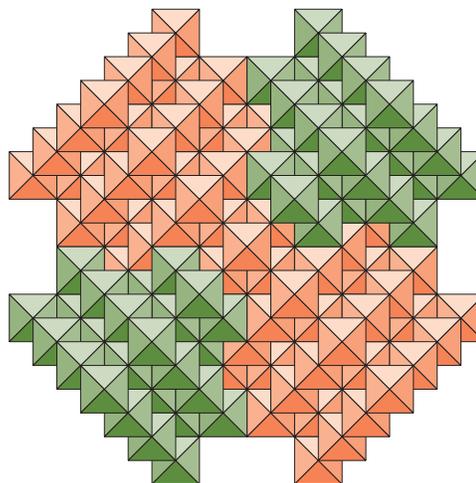
The pyritohedral planes are parallel to a ver-



tical diameter of the regular octahedra which define it. Each of the defined planes is an irregular pentagon.

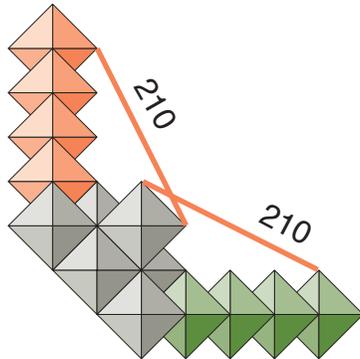
Iron cross twin

The iron cross twin of the pyritohedron has the same base. But the triangular prism on each of the cube faces is replaced by an interpenetrant triangular prismatic cross. The cross



has the same triangular prism which is shown in red with the green additions which make the cross. The planes of the iron cross twin are the same as the pyritohedron. But the planes are now defined by a vertex of an octahedron at the

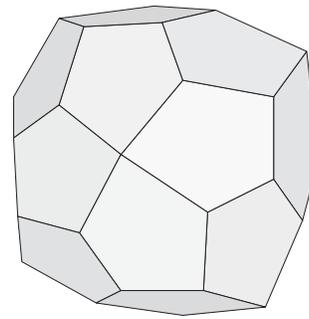
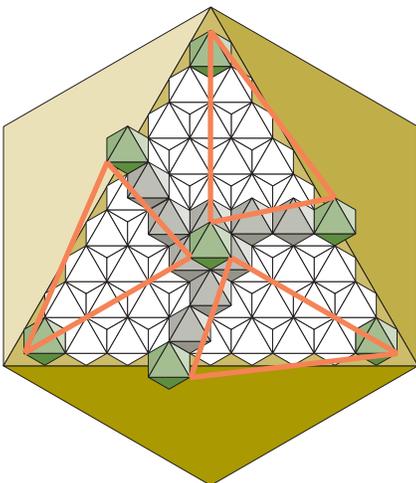
end of the top layer of one leg of the cross and a vertex of each of the nine octahedra which define the cube edge. The planes on either side of a cube edge are shown in the next figure.



Pyritohedral planes of iron cross twin.
The gray colored octahedra belong to the base cube. The red colored octahedra belong to one cross and the green to another cross.

Gyroid (hkl)

Left handed gyroid
The left handed gyroid can be modeled by mounting an assembly which is shown in the figure upon each face of a 10-octa so that it is symmetrical about the facial centroidal axis.



Right handed gyroid
The right handed gyroid can be modeled by mounting an assembly which is shown in the

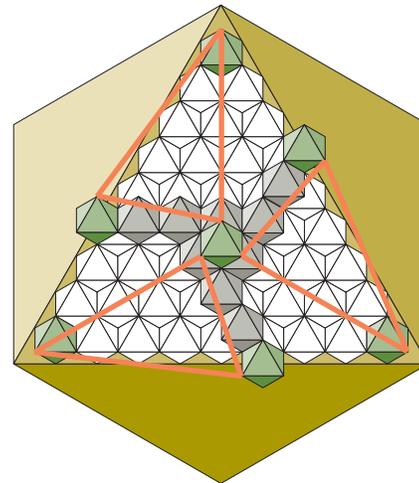
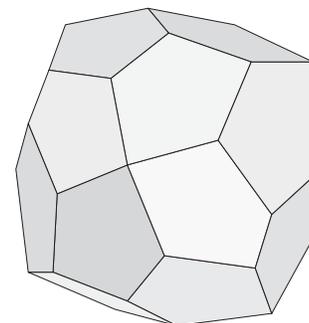
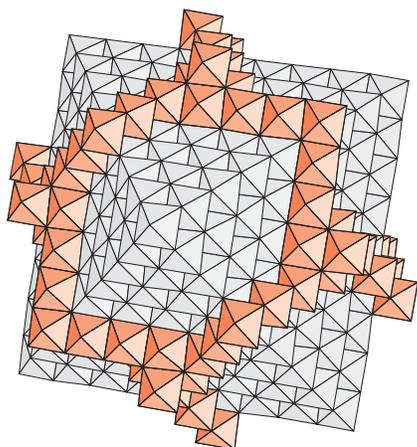


figure upon each face of a 10-octa so that it is symmetrical about the facial centroidal axis.



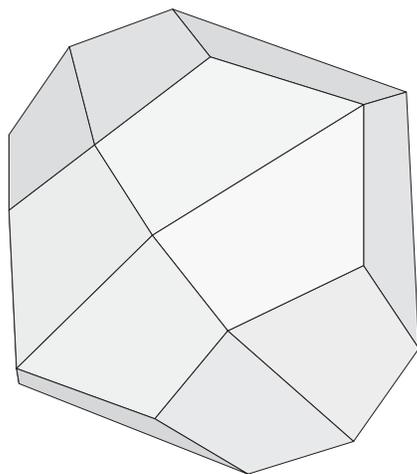
Diploid (hkl)
The diploid model has a 9-octa for its four-

dition. A two layer octahedral pyramid is



mounted on the centroid of each 9-octa face. Along a pair of opposite edges at a 9-octa vertex there is an octahedron joined to the *fourth* octahedron of each of the two edges. Along each edge of the remaining pair of edges which join to form the vertex there is an octahedron joined to the *fifth* octahedron of each edge.

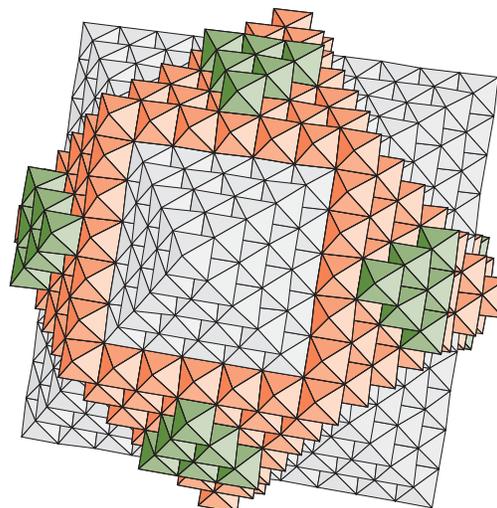
The diploid plane is defined by a vertex of



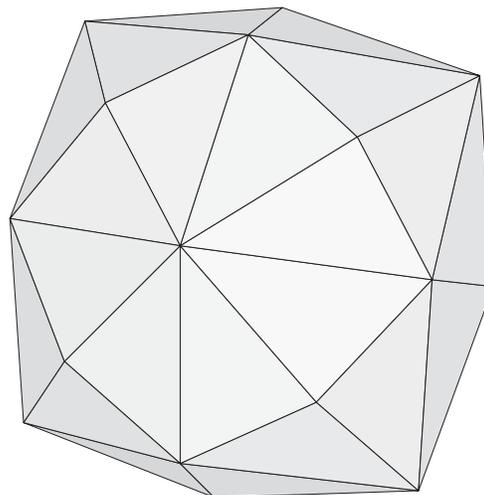
the top layer of the facial pyramid, the vertex which is at the vertex of the 9-octa, and a vertex of each of the two octahedra which are joined to the 9-octa edges.

Hexoctahedron

An 11-octa is the foundation for the model of the hexoctahedron (321). A two layer pyramid

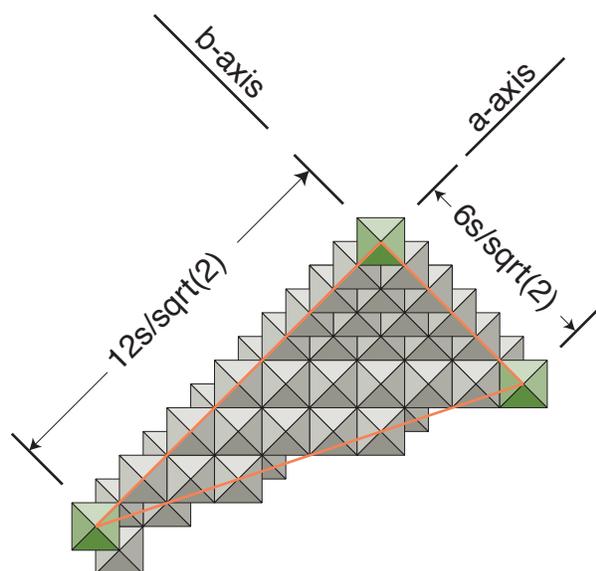


is mounted on the centroid of each face. An octahedron is mounted at the middle of each edge. The hexoctahedral plane is defined by a vertex of the 11-octa, a vertex of the octahedron at a mid-edge and a vertex of an octahedron in the top layer of the facial pyramid.



Hexoctahedron (321)

The isometric (123) plane.



The isometric (123) plane can be modeled so that each of the three octahedra which provide a vertex which defines the plane is lying on a planar axis. The value of each of the axial intercepts is found by counting the vertexial hemi-diameters between the defining vertexes in the three axial directions. From the figure, the distances along the axes are 12 for **a**, 6 for **b** and 4 for **c**. The Miller indices are found by dividing the distances by the highest value 12 and taking the reciprocal. $12/12$, $6/12$, $4/12$ becomes $1, 1/2, 1/3$ with the reciprocals being **1,2,3**.

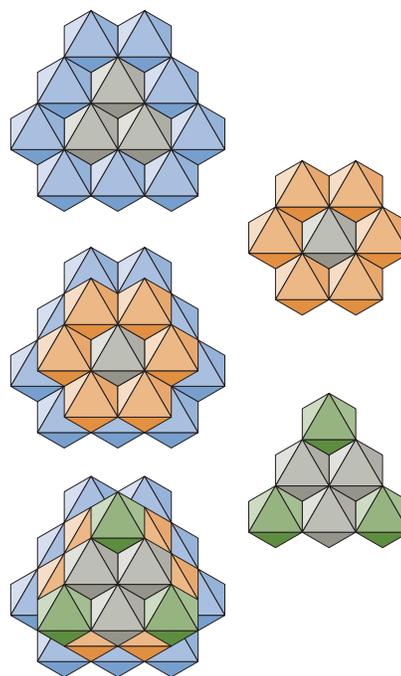
Hexagonal forms

It can be seen that the orthographically projected perimeter of the facial view of the regular octahedron is a regular hexagon. The facial diameter through the centroid appears, then, as an axis of sixfold symmetry. This diameter is parallel to the axis of symmetry of the hexagonal crystals which is designated the *c*-axis. The *c*-plane (0001) is perpendicular to this axis which means that it is defined by octahedral faces. The octahedra which make up the crystal are in layers normal to the *c*-axis. It follows from this that the *c*-axis is an integral multiple of the facial diameter of the octahedron which

makes it up. This has the value $\sqrt{\frac{2}{3}} \times \text{edge}$.

Hexagonal layers

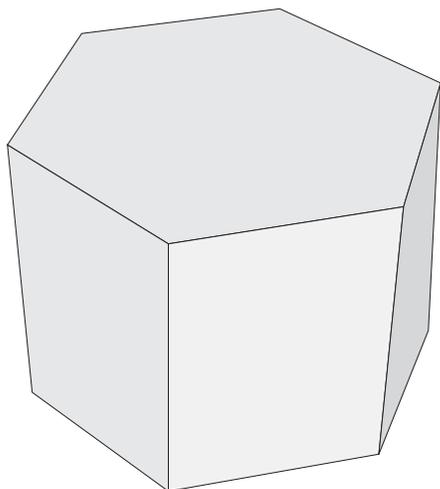
The layers of octahedra which form an hexagonal crystal are normal to the *c*-axis. The relationship of an octahedron in one layer to that in another is shown in the figure. The mid-



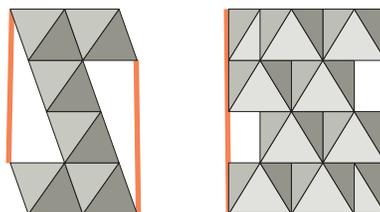
Octahedral layers in hexagonal crystals.

dle layer with the orange colored octahedra has an octahedron at the layer centroid. Each of the other two layers has a vertexial junction of three octahedra at the centroid of the layer.

The three layer assembly can join crystally with identical assemblies in the *c*-axial direction. An octahedron in one blue layer will differ from an octahedron in an identical planar position by a translation parallel to the *c*-axis.



In the next figure, the two views are normal to



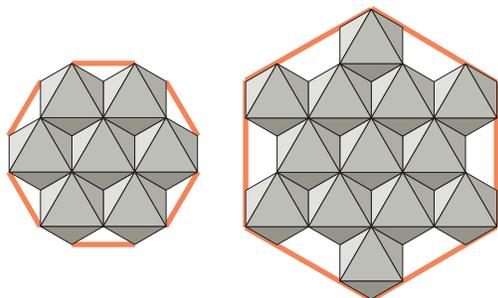
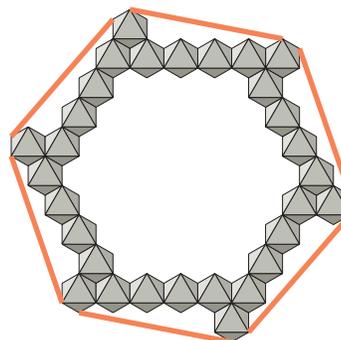
the c-axis The prism planes of the assembly on the left are defined by the vertexes of the octahedra. The assembly on the right has prism planes which are defined by octahedral edges.

Prisms defined by vertexes can be parallel to an edge of the octahedra which define it as shown above, or at an angle to the edge as the next figure shows.

Hexagonal prisms

The planes which are parallel to the c-axis are called the m-planes. These are defined either by octahedral edges or by octahedral vertexes.

Prisms defined by octahedral edges have axes which are integral multiples of one half of the edgial diameter of the regular octahedron.



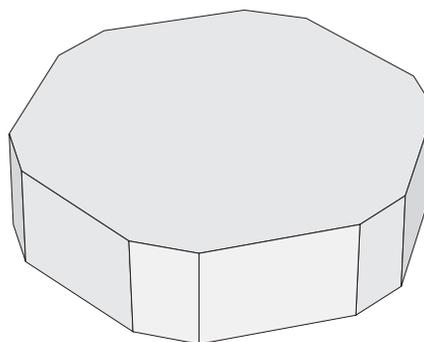
Hexagonal prisms are edgial or vertexial planes.

On the left, the prisms are defined by octahedral vertexes.

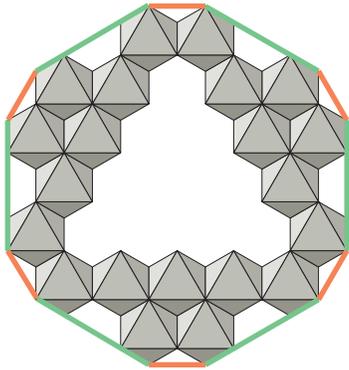
On the right, the prisms are defined by octahedral edges.

Hexagonal diprisms

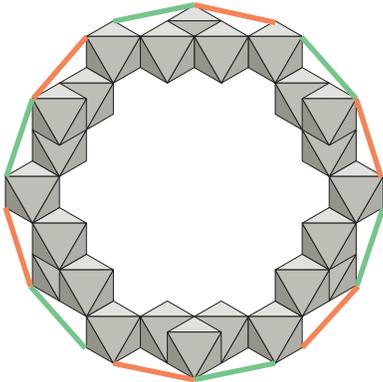
Hexagonal diprisms have two sets of prisms each of which is hexagonal. The octahedral



assembly shown here has two sets of prisms.



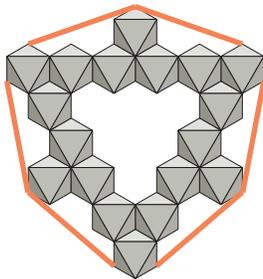
One set is defined by octahedral edges and the other is defined by octahedral vertexes. The two sets of prisms in the next figure are defined



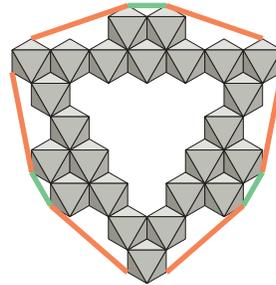
by octahedral vertexes.

Scaleno-hedral base

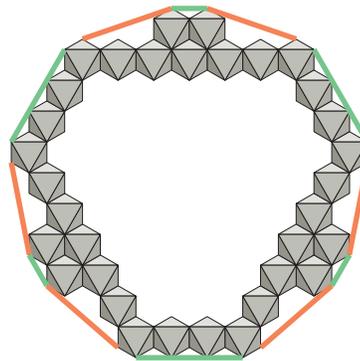
The scaleno-hedral base has double threefold symmetry. In the octahedral assembly of the figure, alternate faces are 120° to one another.



Adjacent faces are symmetrical. The next figure has the same faces as the previous figure

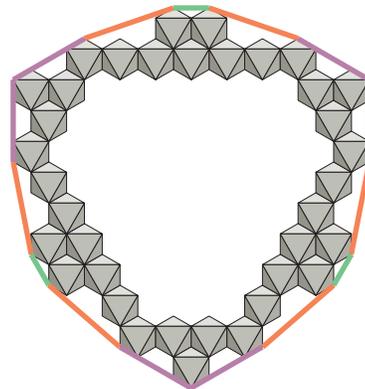


with the addition of three faces which also have threefold symmetry. Three additional faces have been added in the next figure. These



are colored green and combine with the previous green faces to provide a group of sixfold faces to go with the double threefold group. Each of the faces of the octahedral assembly are defined by octahedral vertexes.

The next figure has five sets of threefold

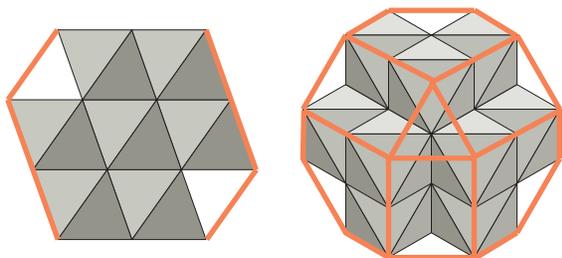


faces. The first three sets are defined by octahedral vertexes. The two additional sets are

defined by octahedral edges.

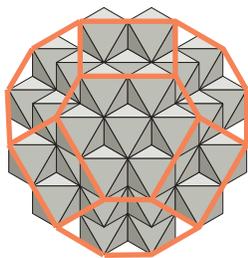
Hexagonal dipyramid

Pyramidal faces are inclined to the c -axis. If the pyramids share the same base, the result is the dipyramid. The figure shows two views of



the same dipyramid. On the left is a view normal to the c -axis. On the right the view is along the c -axis. The alternate planes of this dipyramid are defined by octahedral faces. The other planes are defined by octahedral vertexes.

The octahedral assembly in the next figure produces a hexagonal dipyramid which has planes defined by octahedral vertexes alternating with planes defined by octahedral edges. Planes which are defined by edges in the near



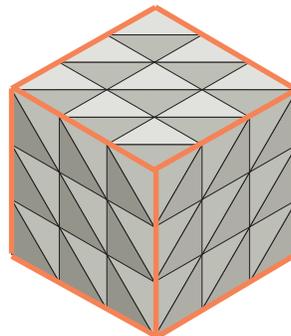
pyramid are defined by vertexes in the pyramid below. The same is true for the other planes.

Rhombohedron

A rhombohedron is a closed form which has threefold symmetry about one axis. Its name derives from the shape of its six identical faces each of which has four edges of equal length.

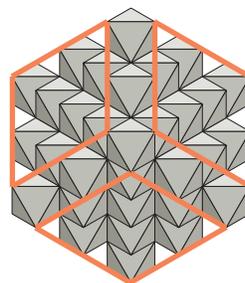
The planes of the rhombohedron depicted

below are defined by the faces of regular octa-



hedra.

The rhombohedron depicted here has its planes defined by octahedral vertexes. The set of planes is identical to the planes of the isometric cube.



CFU

Introduction

Crystal data is given on the basis that matter is a fluid capable of filling any volume without voids. From the symmetry of the crystal and spectral data a unit cell shape is determined. A chemical analysis is done. A density is determined. The atoms are placed in locations within the cell based on chemical data. Then the number of groups per cell is determined. Then the axial lengths which determine the size of the unit cell are determined. The weight of the number of groups is divided by the density of the crystal which gives the volume of the unit cell, and the axial lengths are calculated based on this volume.

But the shape of the epn determines the shape of the atom, and the shapes of the atoms determines the shape of the group, and the shapes of the groups determine the shape of the *crystal forming unit*, or CFU, whose shape determines the direction of the join and the length of the join, and it is this which determines the shape of the unit volume and its size. The crystal is formed by its particles; the particles are not formed by the crystal¹.

Molecular volume considerations

For a cfu which consists of many groups, there is adequate room in the unit cell to fit the groups, as in the glu-glu cells. For cfus consisting of just one or two atoms, there is almost no room. For one water group there is no space. For ten water groups there seems as much room as for benzyl glutamate.

Defining the Crystal Forming Unit (CFU)

It is essential to the concept of the crystal that the groups of atoms which join to produce it are identical and in identical orientation. It follows that these identical groups exist before

they join. If they are to be identical, then they are made of identical groups. It follows that these identical groups exist before they join to form the group. If the groups are to be identical, then they are made of identical atoms. It follows that these atoms exist before they join to form the groups. The pattern is established that identical assemblies require identical parts. The crystal is built from just one kind of assembly whatever its complexity. These assemblies are *crystal forming units* or CFUs.

The volume of the CFU

A CFU in a given position and orientation has places where an identical CFU in identical orientation can attach itself. An attached CFU differs from the reference CFU by a translation, a move of a given length in a given direction with no rotation. If the place of attachment of the reference CFU is called A and the place where A attaches is called A', then, since the CFUs are identical, it must be that the reference CFU has an A' place of attachment. That is, if A to A' then A' to A. Each of these moves has the same length but opposite direction. This is true for each of the places of attachment. Each move belongs as well to each of the two positions.

The half move in every attachment direction defines the volume of the CFU in the following manner. At the junction of the half moves of adjacent units, a plane is defined which is perpendicular to the move direction. As stated before, the half move in a given direction has an equal and opposite half move. This, too, defines a plane which is parallel to the first. Thus, each move direction provides a pair of parallel join planes. Where a plane meets one other plane, an edge is defined. Where a plane meets more than one plane, a vertex is defined. The edges define the faces. With the faces, edges, and vertexes defined, the CFU is defined.

Locations of CFUs

For identical groupings of epns as crystal forming units, the location of one CFU relative to another in a join direction is expressible with three integers representing the axial direc-

1. C. W. Bunn *Chemical Crystallography* refers to the cfu as the "unit of pattern" (p.224) or "pattern-unit" (p.118).

tions. This distance is the same from any vertex of any epn of one CFU to the equivalent vertex of the equivalent epn of the adjoining CFU. These locations are points on a line. A third epn added to the first in a different join direction is expressible with another set of integers. This location establishes a second line with the first location. The three locations define a plane, and the plane is defined by the vertexes or edges or faces of the epns which constitute the cfus. The points of the plane lie at intervals which are described by the distance between pairs of adjoining cfus. The only plane distances are those which are expressible with integral multiples of the epn vertexial semi-diameters. There are no other points between them. The points have the qualities of the cfu. In a crystal, the cfu has an integral number of join directions. An extension of the crystal in any two join directions produces a pair of planes defined by the diameter of the cfu perpendicular to the planes, no part of which may extend beyond the two planes. The planes are the material limits of the cfu.

There are no decimals on such a plane. No circles. No pi. No infinities. No curves. No fractions of a join distance.

Crystalline lines and planes

A crystalline line is formed by the repeated addition of cfus in a single join direction. A crystalline plane is formed by the addition of a parallel line which establishes a second join direction. A second plane is established by the addition of units to the units of the first line in a third join direction. The first line is common to both planes.

Specifying a crystal plane

The plane of a crystal intersects one or more of the crystal axes. These intersections are termed axial intercepts of the plane. In the Miller system, the planes are expressed as integers which are the reciprocals of fractions which represent the relation between the axial intercepts. In an actual crystal, the planes are defined by cfus. The positions of the cfus which define a plane are related by moves between adjoining cfus. These moves are in

the directions of the joins, and each is counted and referred to a set of axes.

Regular polygonal crystal prisms

For the crystal forming unit to produce a regular polygonal prism, the join directions between adjacent units must be symmetrical about the axis of the prism. The projections of the join directions upon a plane normal to the axis of symmetry will have the same symmetry as the polygon they produce. If the polygon has an odd number of sides, then there must be as many moves as there are sides. Polygons with an even number of sides require one half the number of moves as there are sides. The sides of the hexagon and the equilateral triangle have the same directions.

Besides the symmetrical directions, the moves must have the same length, and the joins must be identical. Thus the group itself must be symmetrical. And this symmetry results from symmetrical groups produced by symmetrical atoms produced by symmetrical particles.

Facial diameter changes resulting from cfu moves

If two units are on the same facial plane, the sum of the two lowest absolute values of the differences between their xyz-coordinates will equal the absolute value of the third difference. That is, $|x_1-x_2|, |y_1-y_2|, |z_1-z_2|$ without regard to order is equivalent to $m, n, m+n$.

Unit Cells defined by CFUs

The idea of building crystals with unit cells leads to crystal surfaces defined by diced portions of the CFUs. It also promotes the idea that the volume determines the content, and leads to the idea of "populating the cell" with atoms. The crystal concept requires that the CFUs be whole and that the CFU joins define its volume. The cubic system unit cells provide an example of the effect that this realization has upon the understanding of the crystalline structure.

Crystal forming units of the cubic system

The cubic system has three main cells in which the CFU are located in different places within the cube which is the unit cell. The types are the *simple*, the *face-centered*, and the *body-centered*. Each will be examined.

Relationships between cube and octahedron

The cube and the octahedron are related—

- the cube has eight vertexes and the octahedron has eight faces
- the cube has twelve edges and the octahedron has twelve edges
- the cube has six faces and the octahedron has six vertexes
- the cubal facial diameter is parallel to the octahedral vertexial diameter
- the cubal edgial diameter is parallel to the octahedral edgial diameter
- the cubal vertexial diameter is parallel to the octahedral facial diameter.

The Cubic Lattices

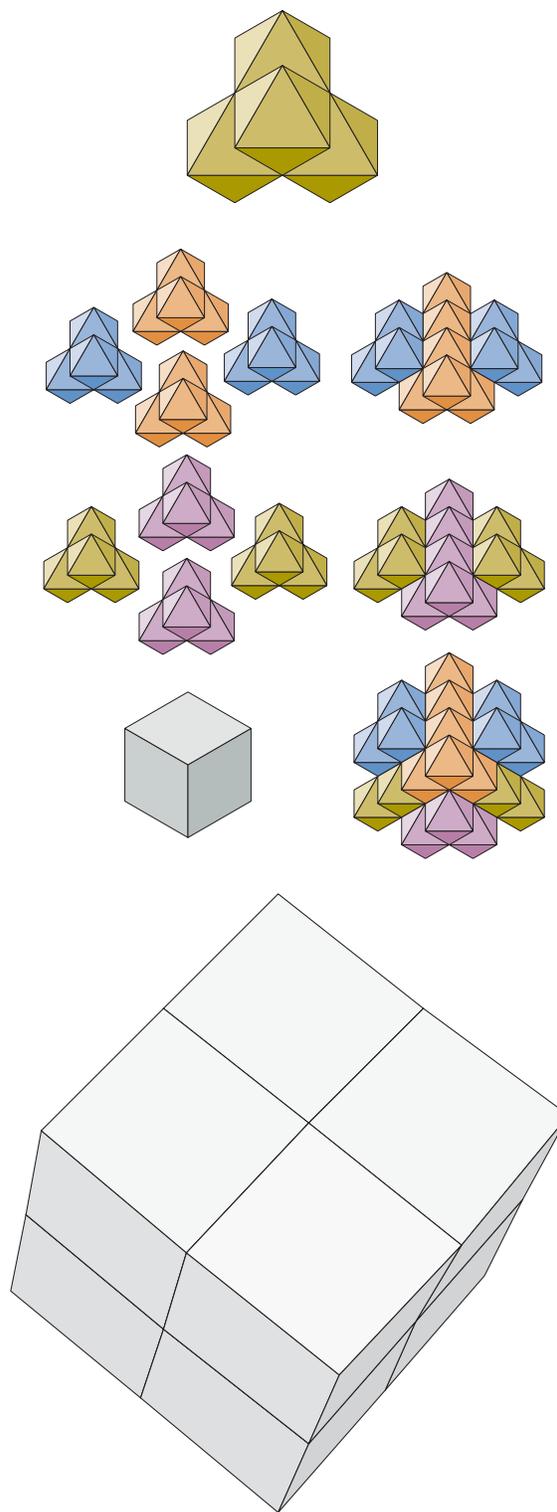
Simple Cubic

In the simple cubic crystal, CFUs join in directions which are parallel to the cubal facial diameters and the octahedral vertexial diameters. The volume defined by these join directions is a cube. The volume is not fully occupied; but, because of the crystalline order, the volume defined by the join directions belongs wholly and solely to the individual CFU. The length of the join in the octahedral vertexial direction is $n \times HeEdge / \sqrt{2}$. There are three join directions.

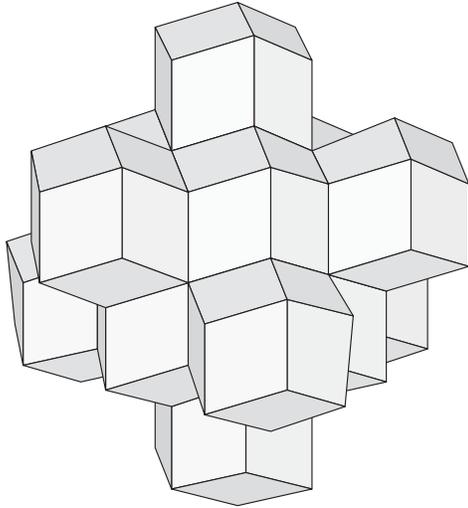
At the top of the figure on the right, there is a tetrahedral group consisting of four octahedra. This could be a simple cubic CFU. Below it is shown how eight identical units join cleftly to produce a simple cubic crystal. Each of the CFU centroids is at a vertex of a cube.

The volume defined by the CFU attachment moves is not the unit cell. The simple cubic unit cell is constructed so that a CFU is at each vertex of cube, and the unit cell contains a

eightth of each of eight different CFUs. In the figure to the right, a compound cube is shown which is composed of eight smaller cubes.



Each of the smaller cubes is a CFU-volume.
The centroid of each of the cubes is located at
a vertex of a cube which is the unit cell.

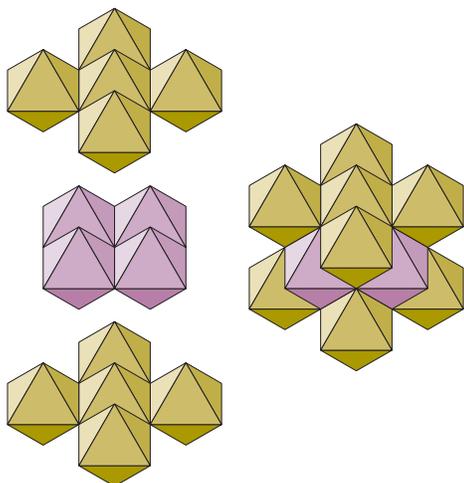


The FCC CFU.

The figure at the top shows a cube composed of fourteen rhombic dodecahedra.

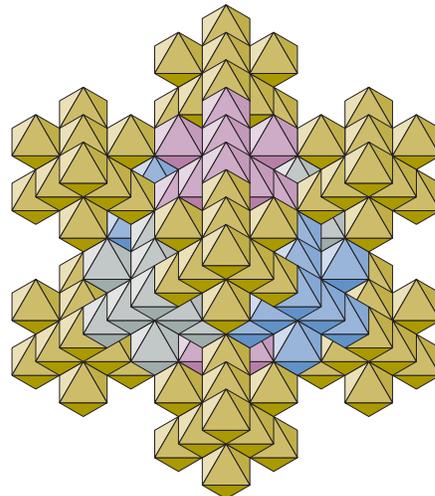
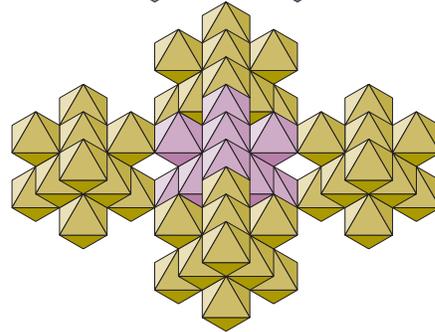
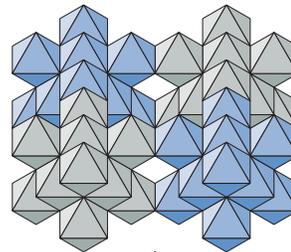
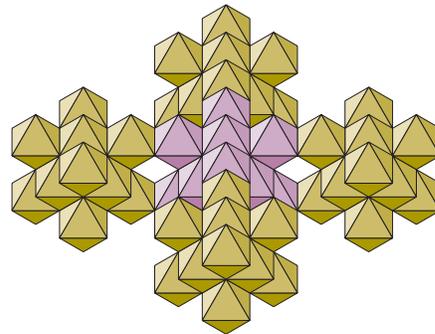
The figure at the bottom shows the assembly of a CFU composed of fourteen octahedra which will be used to construct an FCC crystal. The join between two CFUs will involve an edge of each of two octahedra of each CFU.

An assembly of fourteen CFUs to form a cube is shown on the right.



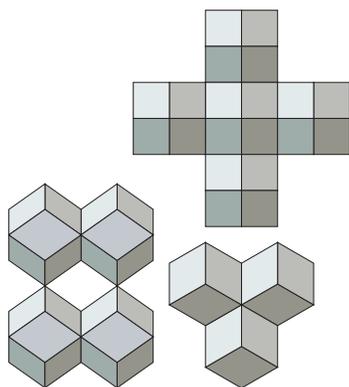
Face-centered Cubic

The face centered cubic cell requires attachment moves parallel to the facial diagonals and this produces a rhombic dodecahedral CFU



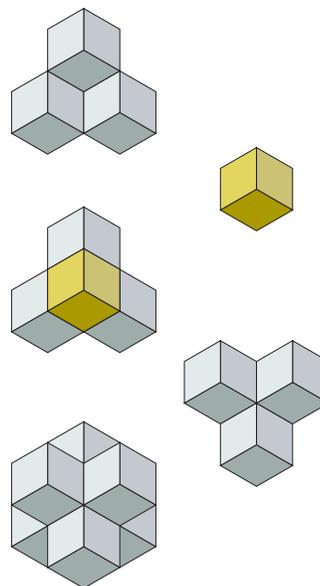
volume which wholly contains a single CFU. The unit cell contains one eighth of each of the

eight vertexial CFU volumes and one half of each of the six facial CFU volumes.



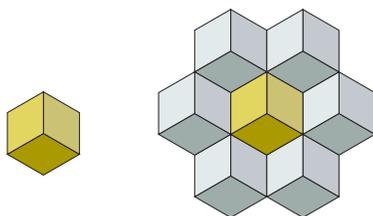
Facial, edgial, and vertexial layers of FCC

Three types of planes of the FCC crystal which are defined by features of the CFU-volume are shown here. The 4-vertexes of the top group of five rhombic dodecahedra define a 100-plane. Below it is a rhombic dodecahedral triplet whose 3-vertexes define a 111-plane. To the left of it is a group of four rhombic dodecahedra whose faces define a 110-plane.



Interlayer (111) joins of FCC cfu.

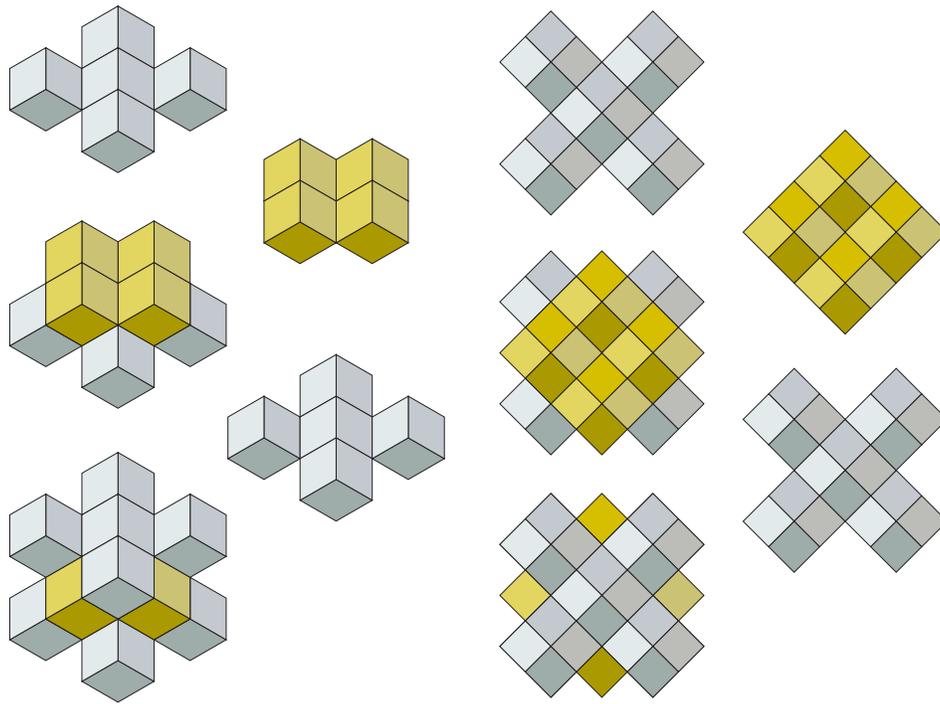
The figure shows the relationship between the CFUs of adjoining 111-planes of the FCC-crystal. The assembly depicted is composed of two triplets joined by a single dodecahedron. The assembly progresses from in the left-hand column from top to bottom. The adding units are shown in the righthand column. There are three layers in the final assembly.



Intralayer (111) joins of FCC cfu

The dodecahedron colored yellow on the left can be joined facially to six identical dodecahedra within a 111-plane of an FCC-crystal.

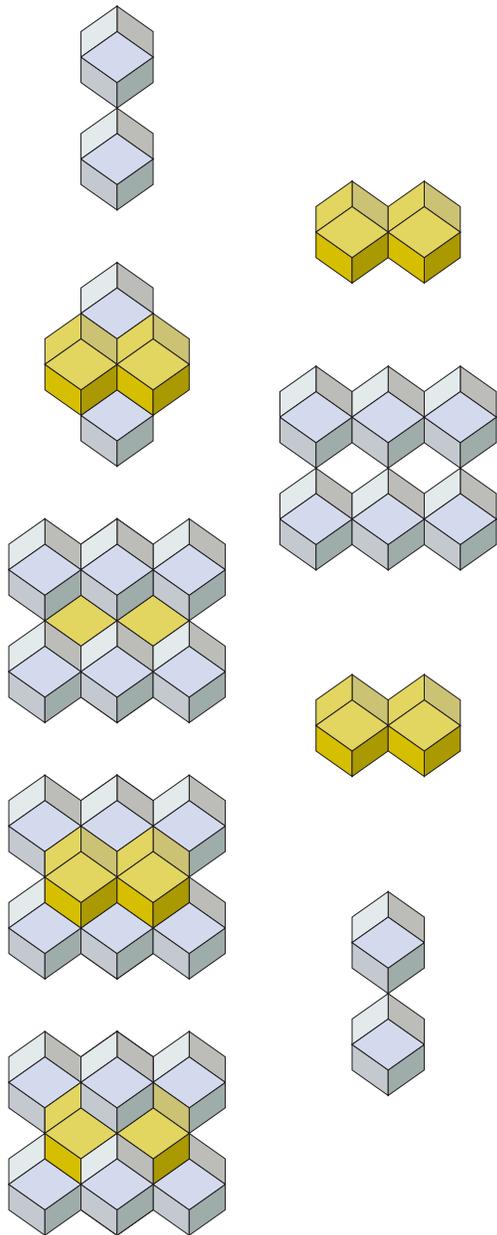
Facial layers (111) of FCC cube



Cubal facial layers of the FCC-crystal.

Two views of the assembly of rhombic dodecahedra in three layers are shown above. The assembly on the right is perpendicular to an FCC 100-face. The assembly on the left is perpendicular to an FCC 111-face. The fourteen dodecahedra in each assembly form an FCC cube.

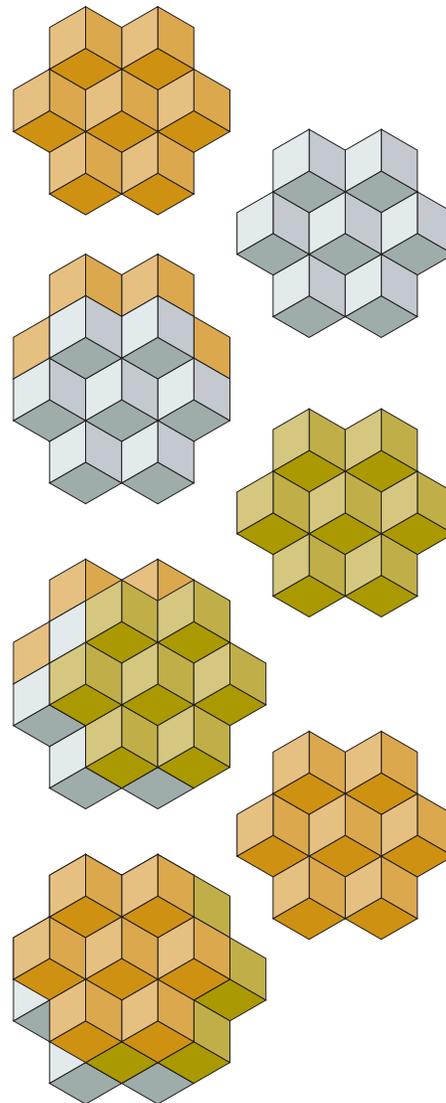
Edgial layers (110) of FCC cube



Edgial layers of the FCC-cube.

The fourteen dodecahedra that form an FCC-cube are shown as an assembly of 110-layers. The assembly progresses from top to bottom in the lefthand column through the addition of the layers shown in the righthand column.

Relationship of (111) planes

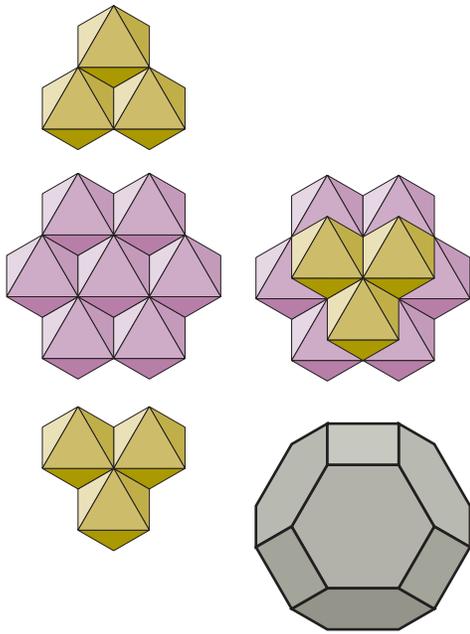
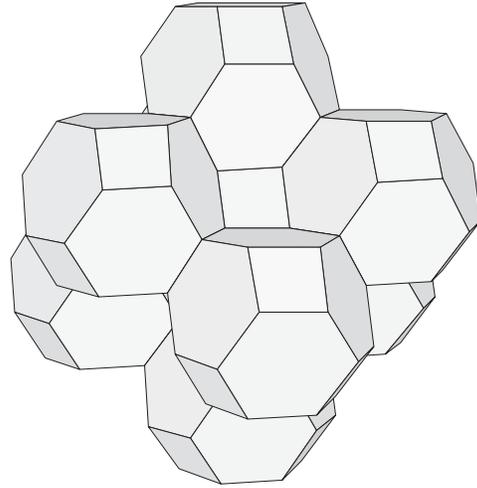


Vertexial layers of the FCC crystal.

The figure shows the addition of 111-layers to form a stack. The assembling stack is on the left, the adding layers are on the right. The stack at the bottom has four layers. The projections of the first and fourth layers are congruent.

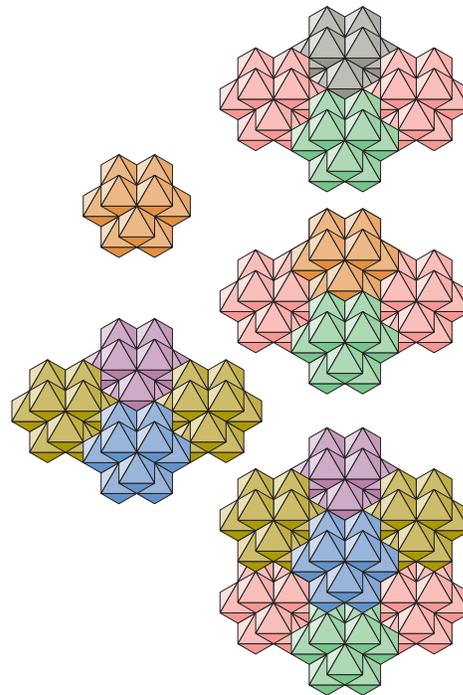
Body-centered Cubic

The body centered cubic cell requires attachment moves from the cube center to the cube vertexes which produces a cuboctahedral CFU volume. The next figure shows a cube composed of nine cuboctahedra. The centroid of one of the cuboctahedra coincides with the centroid of the cube. The centroids of the others are at the vertexes of the cube.



Assembly of a CFU for a BCC.

The three layers of an octahedral assembly which can serve as the CFU for a BCC are shown in the left hand column. The triplet at the top of the column is the bottom layer of the assembly shown in the right hand column..



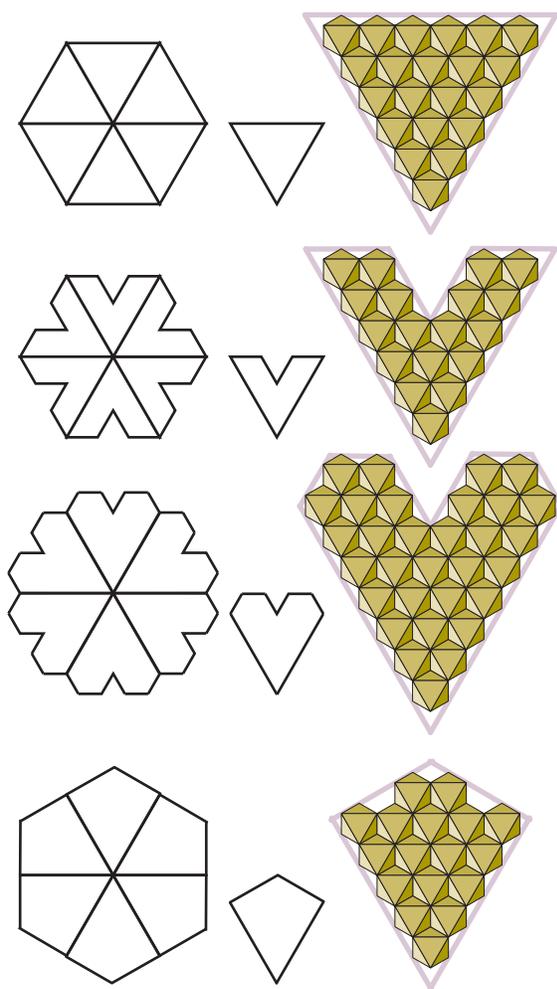
Cube assembled from BCC CFUs.

The assembly is composed of three layers. The assembly progresses from the top of the right hand column to the bottom. There is a triplet join between adjoining CFUs.

MINERAL

Minerals whose crystals belong to neither the isometric class nor the hexagonal class produce twinned crystals which have symmetries characteristic of those classes. The twin is termed a *pseudomorph*. The symmetry often indicates the orientation of the epn.

Crystals of the orthorhombic class occur in what are referred to as *hexagonal pseudomorphs*. The figure shows four forms of naturally



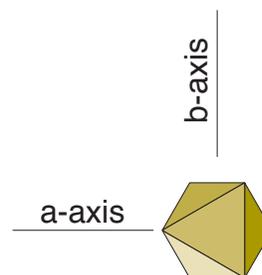
occurring sixlings. The left column shows an outline of the form of the sixling. The middle column shows an outline of the panel which makes up the perceived sixling. The right column shows each of the panels defined by an octahedral assembly. The hexagonal nature of

the sixlings requires that the octahedron of which the atoms are formed be in an orientation in which the axis of sixfold symmetry is parallel to one of its facial diameters.

Chrysoberyl

Chrysoberyl crystals are orthorhombic, having three mutually perpendicular axes of unequal lengths. Twinning results in hexagonal sixlings.¹ Because the twin is hexagonal, its axis of symmetry must lie parallel to a facial diameter of the He-octa. The incremental lengths along the threefold-axis must be an integral multiple of three times the facial diam-

eter of the He-octa which is $s \times \sqrt{\frac{2}{3}}$, where s is the edge length of the He-octa. Of the two remaining axes, one is parallel to an edge of



Chrysoberyl axes.

View parallel to c-axis of chrysoberyl axes.

the He-octa and one is parallel to a facial altitude which is perpendicular to that edge. The relationship of the latter two axes is shown in the figure.

The axial ratios for chrysoberyl² are $a/b=0.4701$ and $c/b=0.5800$. In this case, the a-axis is listed as the three-fold axis. Dividing

1. John Sinkankas *Mineralogy*, Van Nostrand Reinhold 1964, p.348

2. E. S. Dana & W. E. Ford *A Textbook of Mineralogy*, 4th ed., John Wiley 1932, p. 494

the ratio of a/b by $\sqrt{\frac{2}{3}}$ equals $1/(\sqrt{3})$ times 0.9972. The ratio of c/b equals $1/(\sqrt{3})$ times 1.0045. This latter ratio must hold for the two orthorhombic axes which are perpendicular to the threefold axis for the case of hexagonal twins. Both the axial ratios have $\sqrt{3}$ as part of their denominators so the b -axis is parallel to a facial altitude of the He-octa. The c -axis is parallel to the edge which is perpendicular to the facial altitude.

Working from the axial ratios and the requirements of the octahedral assembly, the following axial values are found

$$a = 3 \times \sqrt{\frac{2}{3}} \times s$$

$$b = 6 \times \frac{\sqrt{3}}{2} \times s$$

$$c = 6 \times \frac{s}{2}$$

Axial values for chrysoberyl are 4.42, 9.39, and 5.47. These values can be used to obtain a value for s which is an integral multiple of the edge length of the He-octa.

$$s = \frac{4.42}{3 \times \sqrt{\frac{2}{3}}} = 1.8045$$

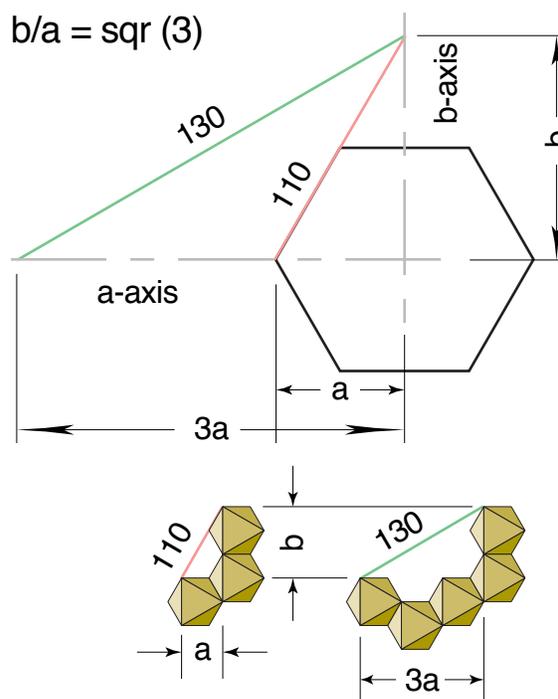
$$s = \frac{9.39}{6 \times \frac{\sqrt{3}}{2}} = 1.8071$$

$$s = \frac{5.47}{3} = 1.8233$$

Axial relationships

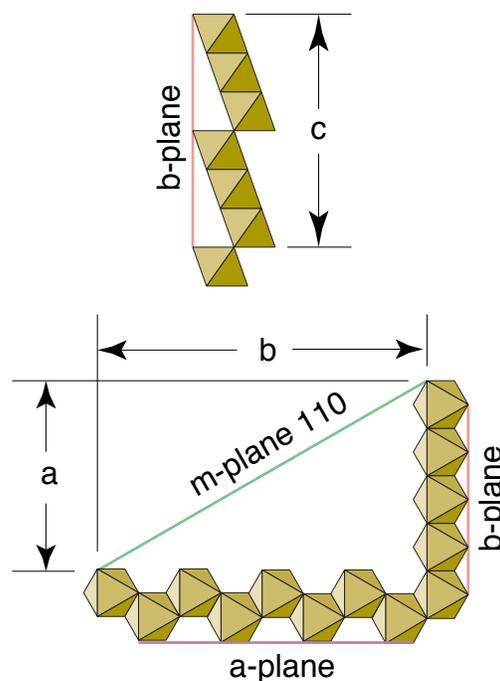
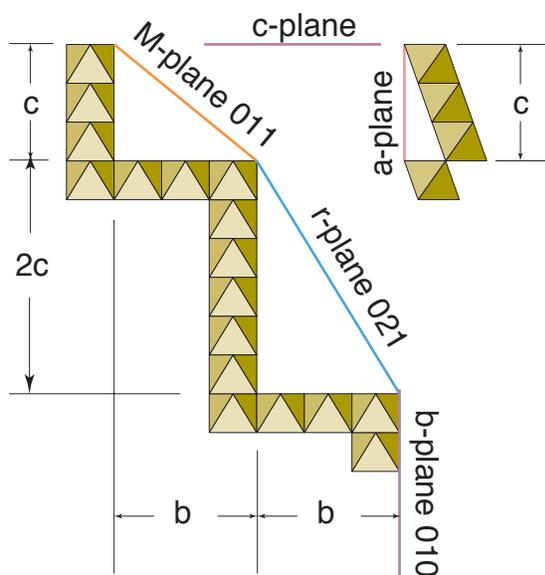
For orthorhombic crystals like chrysoberyl whose twins have hexagonal symmetry, the ratio of the two axes perpendicular to the axis of symmetry is $\sqrt{3}$. These two axes are labeled a and b in the figure. The relationship of the planes which are parallel to the axis of symme-

try, the 110-plane and the 130-plane, is shown in the upper part of the figure. They are shown with the two axes and all are related to the regular hexagon. The lower part of the figure shows how the planes are defined by regular octahedra. The 110-plane is shown to be defined by octahedral edges. The 130-plane is defined by octahedral vertexes and is parallel to an edge of the octahedral face which is perpendicular to the axis of symmetry. The 130-plane is the twinning plane in chrysoberyl sixlings.



Relationship of orthorhombic sixling planes to the octahedron.

The relationship of the planes of chrysoberyl which are parallel to the a-axis (parallel to a facial altitude of the octahedron) is shown in the next figure. In the upper right, the octahedra which define the a-plane are shown. The 011-plane and the 021-plane are defined by octahedral vertexes.



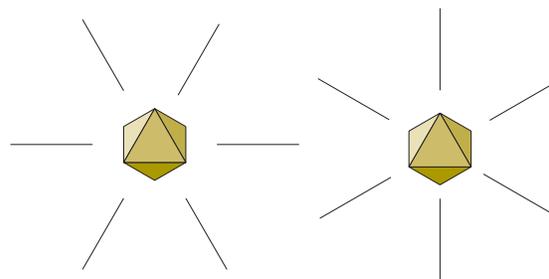
Aragonite

Table 12: Aragonite series axes

Mineral	Axial factors		
	s, Å	a-axis	b-axis
Aragonite	1.1696	1.0580	0.9822
Cerrusite	1.2471	1.0323	0.9802
Strontianite	1.2431	1.0316	0.9776
Witherite	1.3370	0.9835	0.9554

Sixling axes.

Hexagonally symmetrical sixling axes must project onto a plane which is parallel to a face of the regular octahedron. Two of the simplest arrangements of sixling axes are shown in the figure. The axes around the octahedron in the

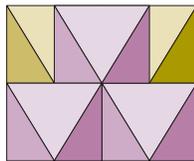
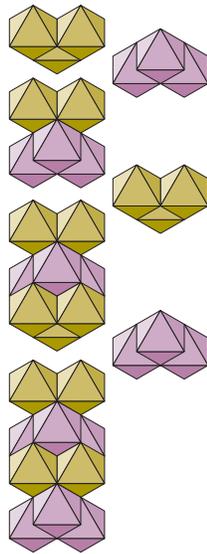


upper part of the figure are parallel to the edges of the upper face of the octahedron. Each is parallel to the upper face of the octahedron. They are called *edgial-axes*. The axes of the lower octahedron differ from those about the upper octahedron in being perpendicular to the edges of the upper face of the octahedron. They are called *special-axes*.

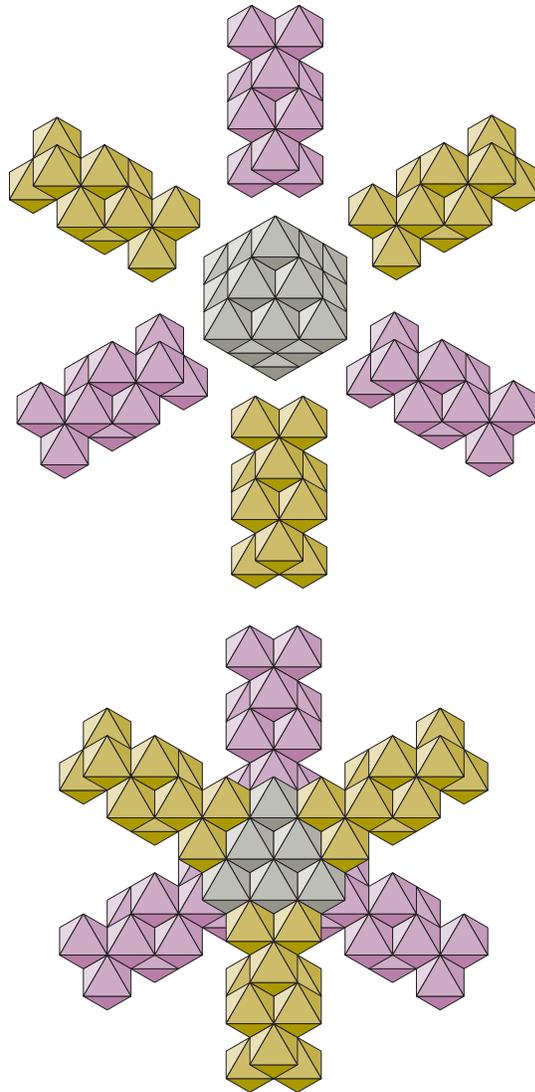
Special-axised sixlings.¹

Sixlings can be viewed as spokes attached to a hub. A special-axised spoke can be assembled using octahedral triplets. The figure below shows the assembly of a spoke consisting of four triplets.

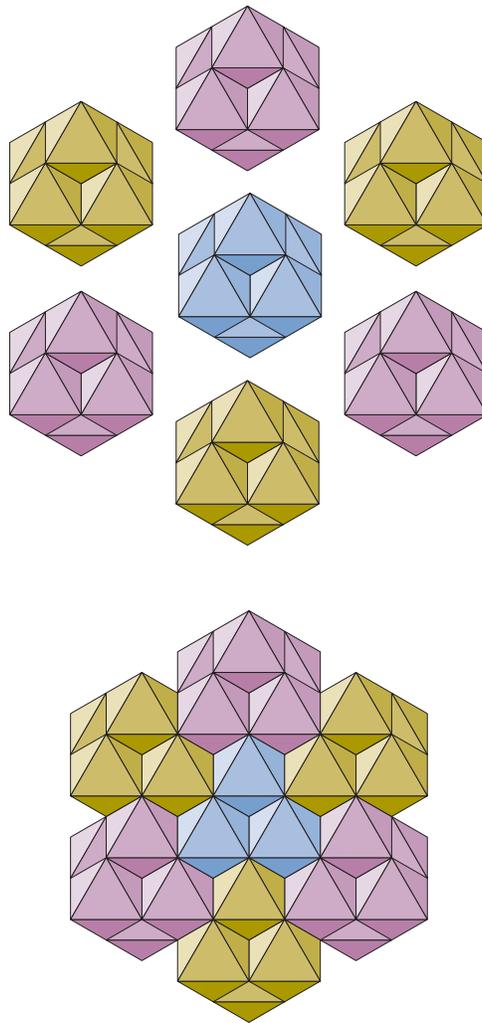
1. Dana & Ford, *ibidem* Fig. 479, p. 193



Axial view of spoke.

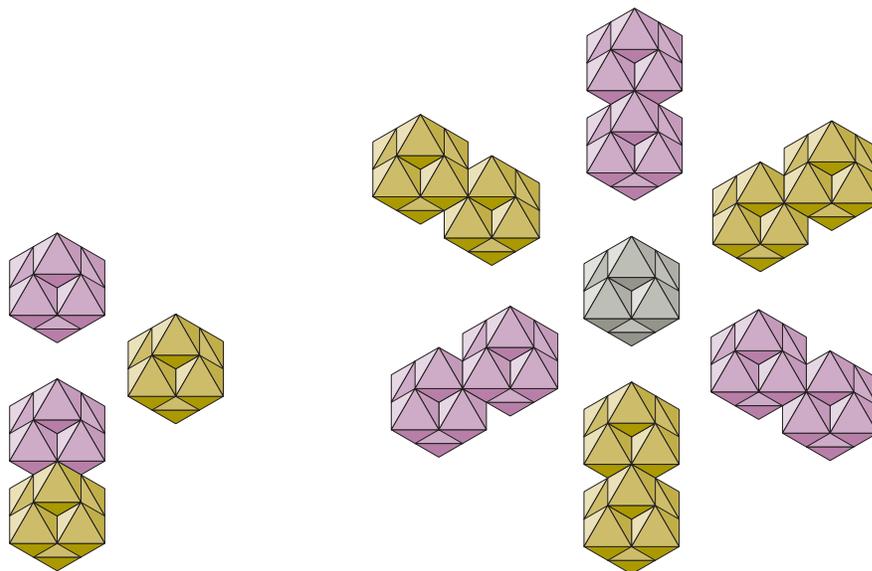


In the top figure, six spokes are arrayed around a 3-octa which is to serve as their hub. The six spokes are in two sets of three spokes each. Each spoke is rotated 120° to each of the other spokes in its set. Adjacent spokes differ by a half rotation about the spoke axis. The spokes are joined to the hub in the bottom figure.

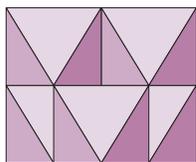


Tabular crystal with reentrant planes parallel to octahedral edges.

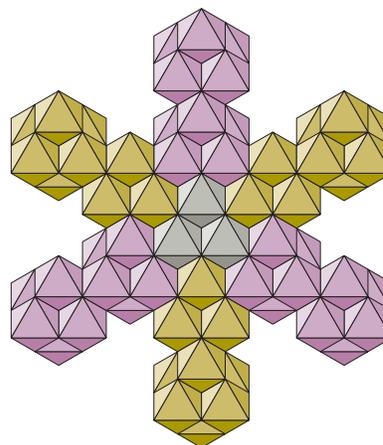
The axis of hexagonal symmetry is parallel to a facial diameter of the octahedron. This form is found in chrysoberyl of the orthorhombic class. A tabular crystal can be composed solely of 2-octas in the arrangement which is shown in the next figure. A 2-octa hub is shown in blue with six 2-octas arranged about it to act as the six spokes



Each of the 2-octa spokes can be lengthened by adding another 2-octa in the manner shown in the figure. The radial view of the spoke is shown here.



Axial view of special axised spoke



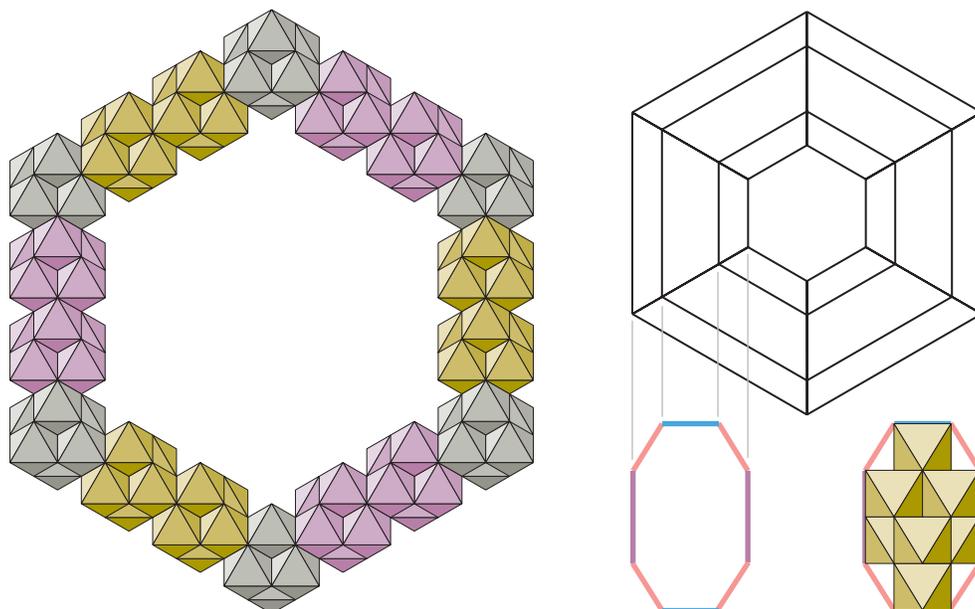
Special axis sixling twin ¹
The hub and spokes are joined here.

1. Dana & Ford, *ibidem*, Fig. 479, p. 193

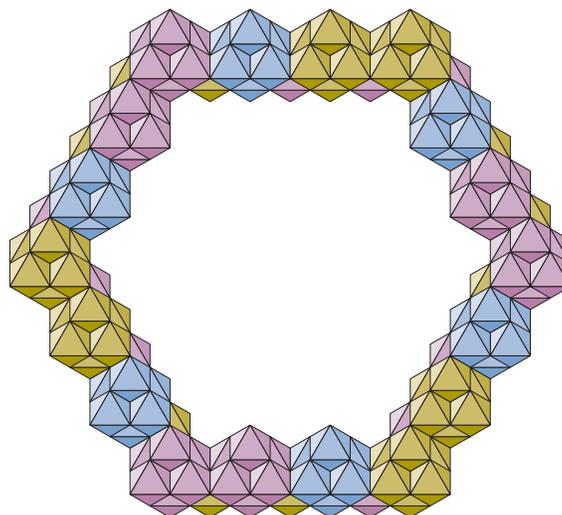
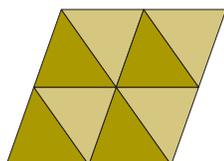
Rutile sixling.¹

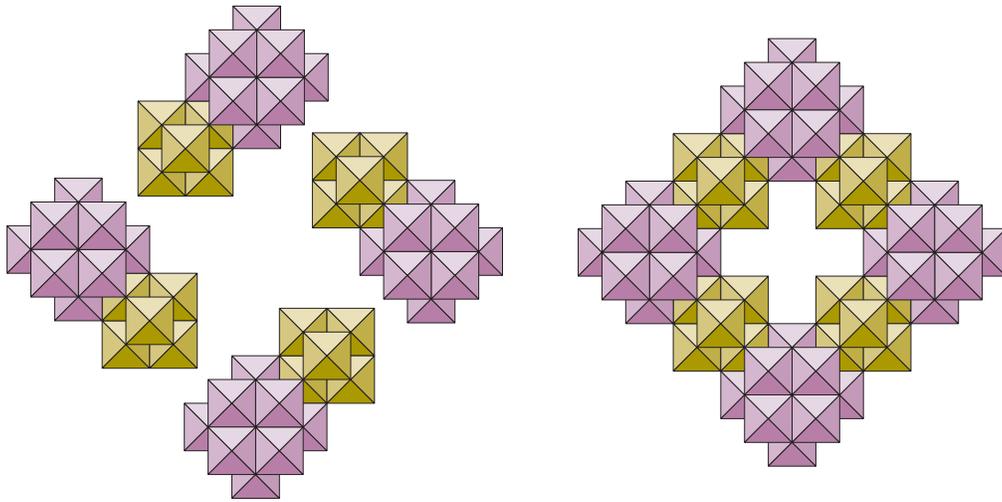
Rutile is a tetragonal crystal which occurs in hexagonal rings. These rings can be formed in two ways. One uses specially-axised units like those shown in the figure. The ring is composed of 2-octas only. With a 1-octa mounted on each of the two faces of the 2-octas which are normal to the axis of symmetry, an octagonal array of planes about the axis of each unit is produced. The planes are suggestive of the arrangement of the planes in the rutile sixling.

1. Sinkankas, *ibidem*, Fig. 40, p. 99



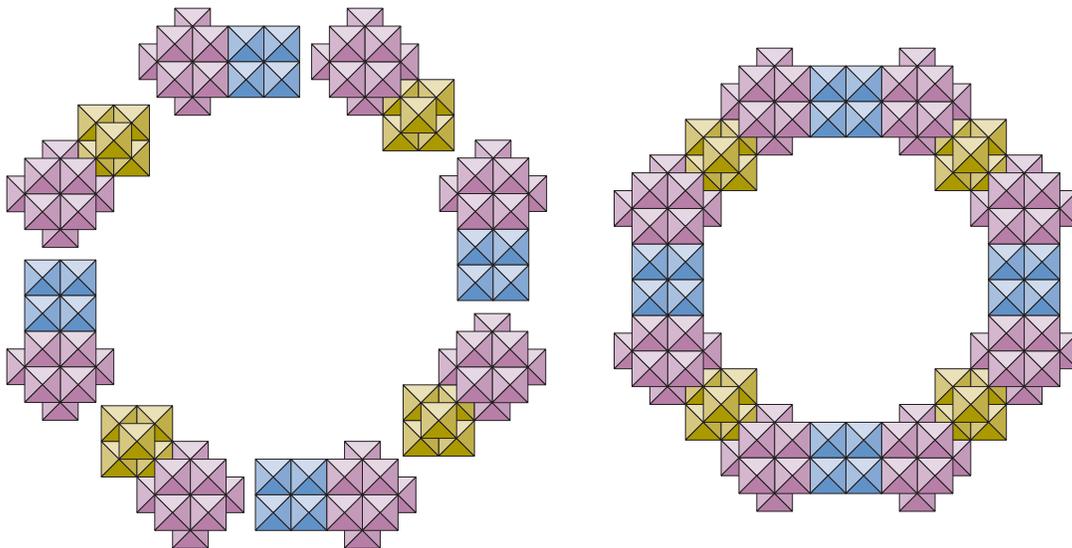
The next ring is composed of edgially-axised units. The units are composed of 2-octas with 1-octa stabilizers





Tetragonal ring

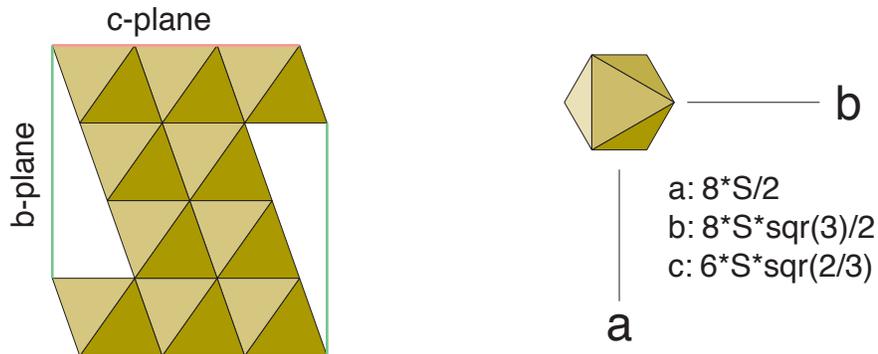
A fourling with vertexial octahedral axes is depicted here. Each leg is composed of two units—a 3-octa absent its vertexial octas and a 2-octa. An octa of the 2-octa replaces an absent octa of the 3-octa in forming the unit. The four units which are to form the ring assembly are shown in the left figure. The units join so that an octa of the 2-octa of each unit substitutes for an absent octa of the 3-octa of another unit to form the assembly on the right.



Octagonal ring

An eightling which is truly a double fourling is built from the eight units shown in the left figure. The four units of the previous ring are combined with four new units. Each new unit is composed of a 3-octa from which the vertexial octas have been removed and a second 3-octa from which the vertexial octas and four edgial octas have been removed. The latter is shown in blue. An edgial octa of the violet 3-octa occupies the position of the absent edgial octa of the blue 3-octa. Each violet-yellow-violet leg is vertexially axised; each violet-blue-violet leg is edgially axised. The completed ring is shown on the right. The yellow 2-octas fill vertexial voids in the violet 3-octas and the violet 3-octas fill edgial voids in the blue 3-octas.

Cerrusite

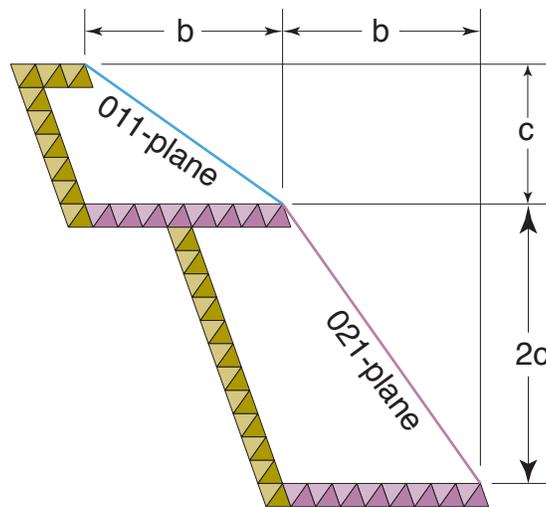


Cerrusite planes

The figure shows the arrangement of the b-plane and the c-plane of the cerrusite crystal relative to the octahedron. The view is parallel to the a-axis.

Cerrusite axes.

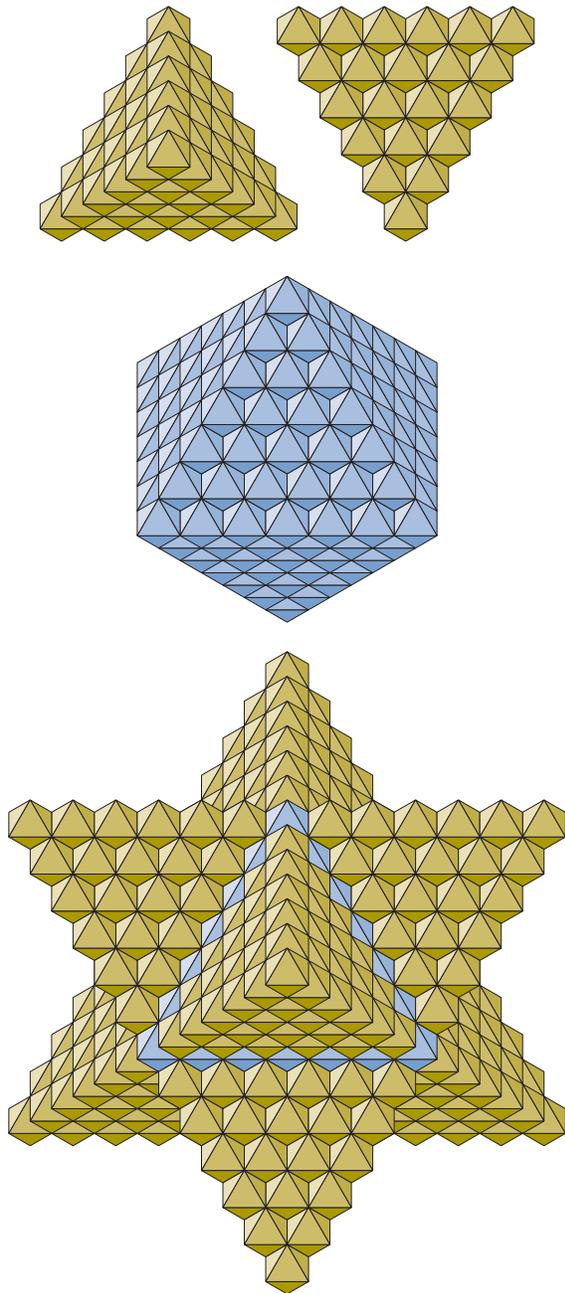
The axes of the twins should not be confused with the hexagonal axes. Each of the spokes is considered a separate crystal of the orthorhombic class.



Cerrusite planes defined by octahedral edges.

The 011-plane and 021-plane of cerrusite are defined by octahedral edges. The two planes are shown edge-on in the figure. The view is parallel to the a-axis.

Tetrahedrite

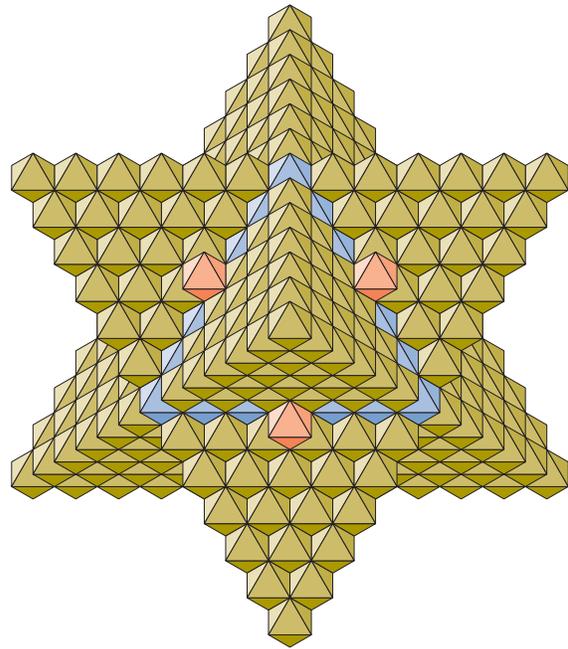


Tetrahedrite penetration twin¹

This twin is producible by mounting a 6-tetra on each face of a 7-octa to produce the assembly at the bottom. The 7-octa is shown in blue and the 6-tetras are shown in yellow. The 6-tetras are identical and are in one of the two orientations shown at the top.

1. Dana & Ford, *ibidem*, Fig.418, p. 184

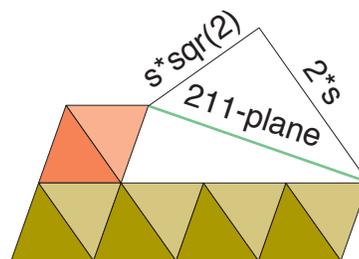
Eulytite



Eulytite penetration twin¹

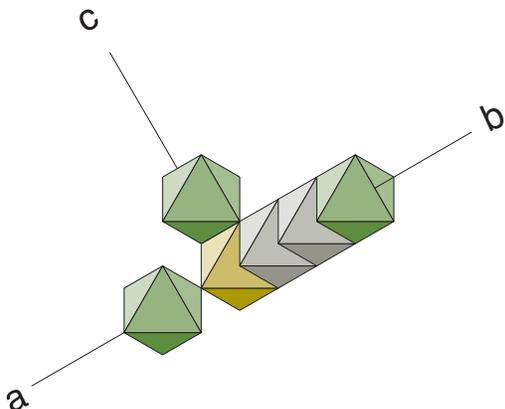
The assembly shown above is the same as that of the tetrahedrite twin. It differs by the addition a red colored octa at the middle of each of the 7-octa's edges to produce the 211-planes in the manner shown below.

1. Dana & Ford, *ibidem*, Fig. 435, p. 187



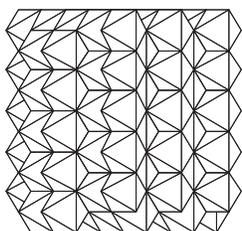
Staurolite

The axes of Staurolite are as $\sqrt{2}:3:1$. The $\sqrt{2}$ in the value for the first axis suggests means that the axis is parallel to a vertexial diameter. The other two values are integers and so these axes are each parallel to an edge which is perpendicular to the vertexial axis.



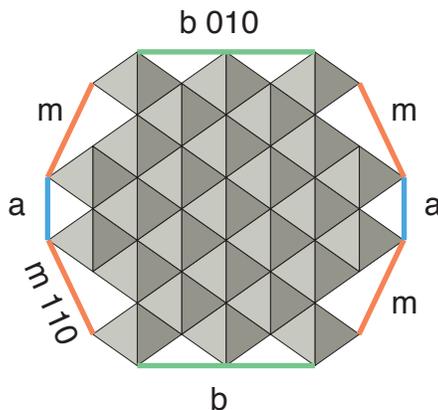
The figure shows three green colored octahedra whose centroids are on three mutually perpendicular axes. The centroid of the yellow octahedron is at the junction of the three axes. The positions of the green octahedra are as the crystalline axial ratios of staurolite.

A view of an octahedral assembly which is perpendicular to the c-axis is shown in the figure. Two c-planes are defined by the octahedral



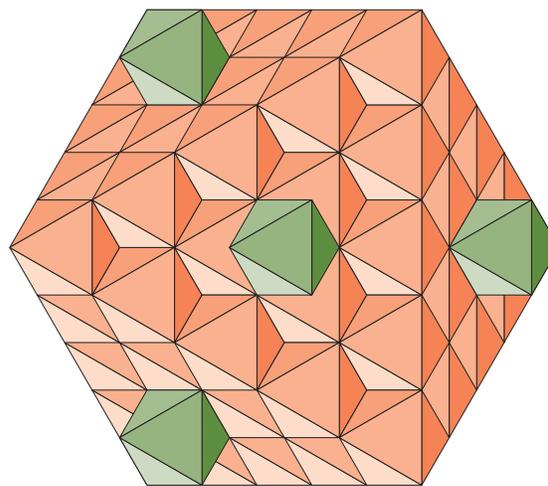
edges at the top and bottom of the assembly. Three rows of octahedra which are nearest on the right side of the assembly define a b-plane with their outermost edges.

The relationship of the planes parallel to the c-axis are seen in the next view of the same



octahedral assembly which is normal to the c-planes.

This assembly can be joined to a compound octahedron so that its centroid and the com-



ound octahedral centroid lie on the same edge-dial diameter. By adding additional assemblies which are identical to the first as spokes to the octahedron as hub the staurolite twins can be modeled.

Interpenetrant twins

Staurolite forms interpenetrant twins that appear as crosses. These twins are either at 90° or at 60° .

The staurolite crystal faces can be precisely modeled using the regular octahedron as the modeling unit. The c -axis is edgial. The c -planes and the b -planes are edgial; the m -planes and the r -planes are vertexial. An axial view of the crystal as formed by a minimal number of octahedra shows the r -plane defined by a vertex of each of a trio of octas at elevation #5 and a vertex of a single octa at elevation #1. This provides a c -axial separation between the elevational contacts of twice the edge length of the octahedral unit, or $2 \times s$. The radial separation is $\sqrt{2} \times s$. The angle of the r -plane with the c -axis is $\text{atan}(\sqrt{2} \times \frac{s}{2} \times s)$ which is $\text{atan} \frac{1}{\sqrt{2}}$, or 35.264389699° . The angle between r and c is then $90^\circ + \text{atan} \frac{1}{\sqrt{2}}$ or 125° , the value given in Sinkankas.

The m -plane is seen in the same axial view as an edge contacting the vertex of an octa at

elevation #1 and an octa at elevation #2. Each contact octa is just the topmost of a column of identical octas paralleling the c axis of the crystal. The offset parallel to the a axis is one half of the vertexial diameter of the octa or $\frac{s}{\sqrt{2}}$; and that parallel to the b -axis is one and a half edge lengths or $3 \times \frac{s}{2}$. The m -plane makes an angle with the b -axis whose tangent is $\frac{s}{\sqrt{2}} \div \frac{3 \times s}{2}$ or the $\text{atan} \frac{\sqrt{2}}{3}$ which is 25.23940182° .

This gives an angle between planes b and m of 115.2394018° , and between two m planes an angle of 129.5211964° . The values from Sinkankas are 115° and 129.5° .

The 90° cross is viewable in the vertexial direction that is perpendicular to the c -axis of each of the twins. The 60° cross is viewable in the facial direction that is perpendicular to the c -axis of the each of the twins.

It becomes apparent in the modeling that the octas of the common intersection of the legs of the "individuals" belong as much to one as to the other. They are jointly held. The individuals are then mere branches of a single crystal.

Table 13: Crystal plane angle^a comparison

Planes	Miller	Octa	Dana ^b	Octa/Dana
mm'	110 [^] 110	50°28'44"	50°40'	0.996294
cr	001 [^] 101	54°44'08"	55°16'	0.990390
rr'	101 [^] 101	109°28'16"	110°32'	0.990390
mr	110 [^] 101		42°02'	

a. These are the angles between the normals to the planes and are the supplements of the interfacial angles.

b. Dana & Ford, *ibidem*, p. 637

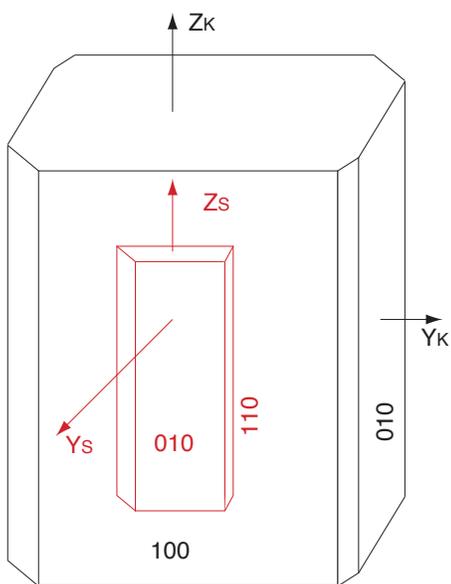
The regular octahedron has twelve edges. These edges can be viewed as six pairs of parallel edges. These edge pairs can be viewed as paired so that together they constitute the perimeter of one of the orthographically projected vertexial views of the regular octahedron of which they are topological features. There are three such pairings.

A staurolite twin has its c -axis parallel to one of the edge pairs. If that edge pair makes a square with the edge pair that is parallel to the c axis of its twin, then the axes of the twins make an angle of 90° . If it does not, then the axes of the twins make an angle of 60° . Thus, of the six pairs, one pair is taken up by each twin. For a given crystal, there is but one 90°

crossing. There are four 60° crossings. For each crossing there are two legs.

When the axis of a crystal is parallel to the edges of its octahedral components, then it is

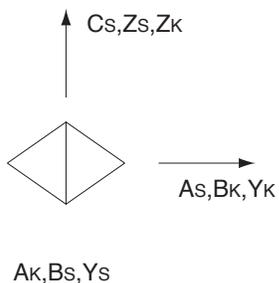
an edgial axis. An edgial axis viewed axially is an edgial view. The *c*-axis of a staurolite crystal is thus an edgial axis. So is the *b*-axis. But the *a*-axis is vertexial.



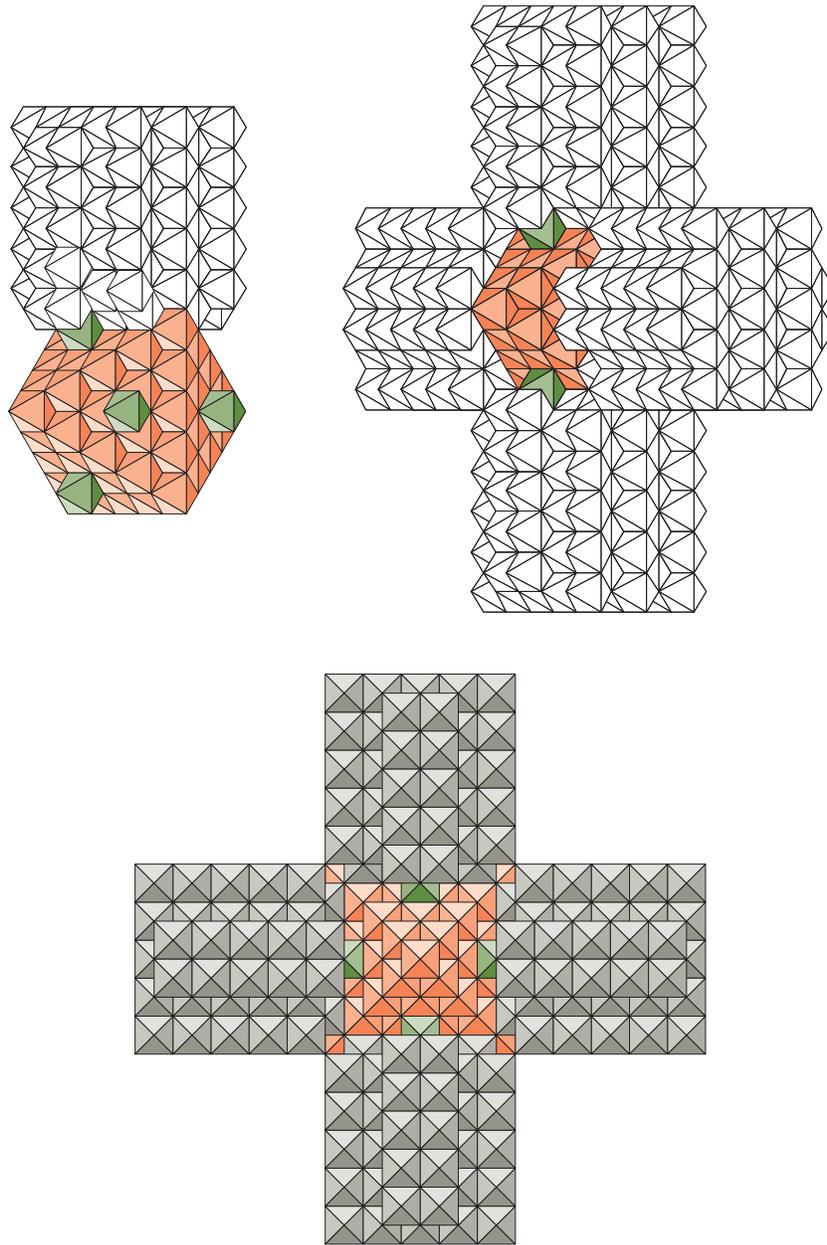
Staurolite crystal inside Kyanite crystal.¹

The *b*-axis of kyanite is oriented the same as the *a* axis of staurolite. Assuming that the octahedra of the two crystals are in the same orientation, and referring to the orientation of the staurolite octahedra derived from the axial ratios, *b* staurolite and *a* kyanite are edgial axes.

The orientation of the epn is shown below the crystal diagram.



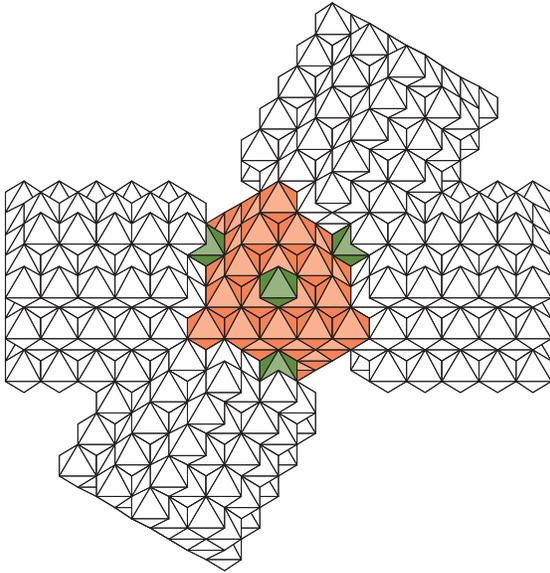
1. W. A. Deer *ibidem* Fig. 35, p. 157



Staurolite twin, right angled cross¹

The figure on the upper left shows one spoke joined with the hub. The upper right shows the hub with four identical spokes. The same four spoke assembly is shown at the bottom wherein the axis of each spoke is parallel to the plane of the paper. The fourfold symmetry shows the right angle relationship of the spoke with each of its two neighbors.

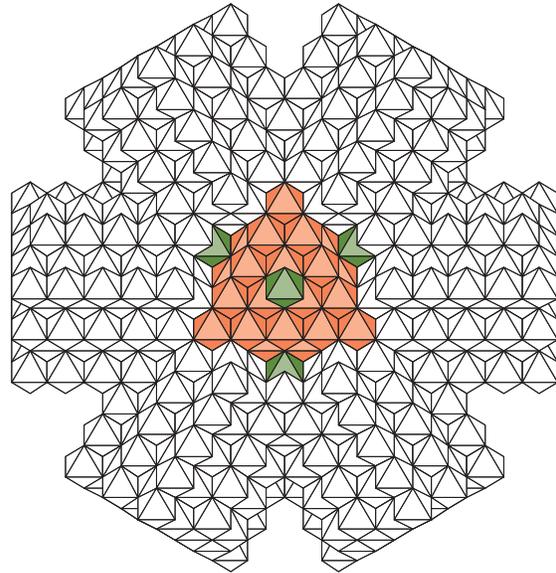
1. Dana & Ford, *ibidem*, Fig. 464, p. 191



Staurolite "sawhorse twin"¹

The figure shows the same hub and the same four spokes of the right angle cross joined to form a 60-degree cross which is called a "sawhorse twin".

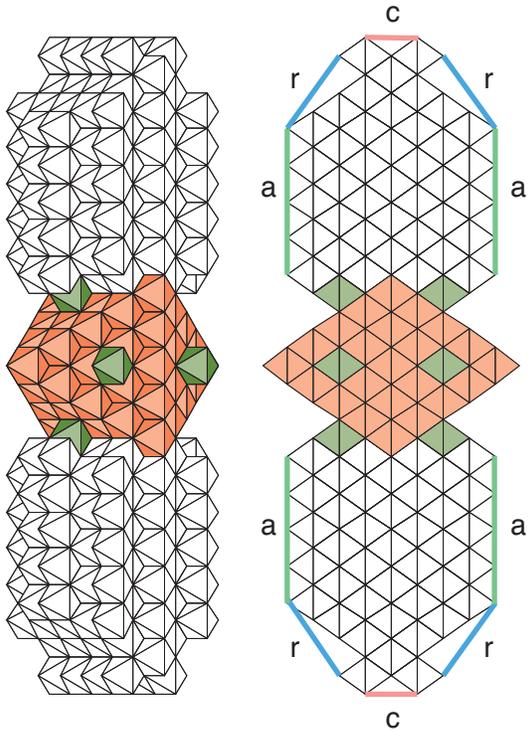
1. Dana & Ford, *ibidem*, Fig. 963, p. 638



Staurolite twin¹

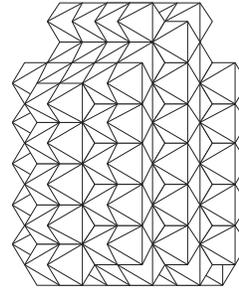
An additional pair of spokes has been added here to produce a three-way crossing which occurs in nature.

1. Dana & Ford, *ibidem*, Fig. 423, p. 185

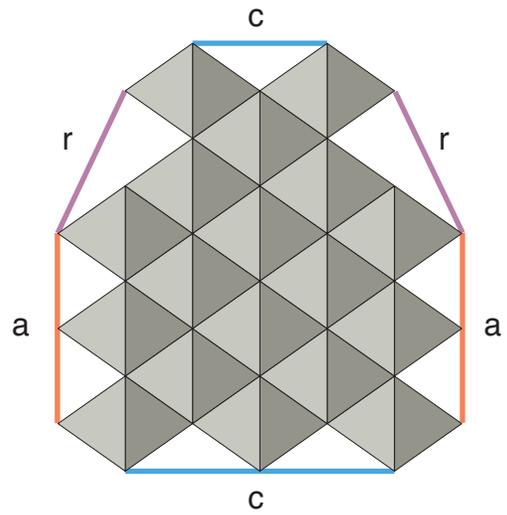


Staurolite twin with r-faces¹

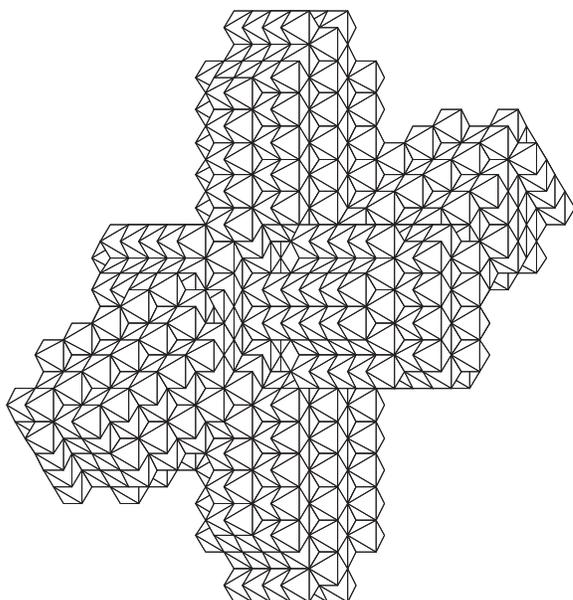
1. Dana & Ford, *ibidem*, Fig. 961, p. 638



Staurolite spoke with r faces, oblique view
Prism faces *b* and *m* with *c* face on bottom and *r* and *c* faces at top.



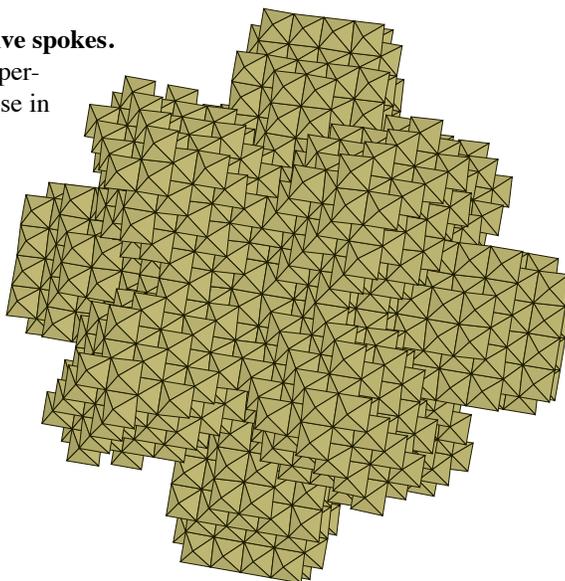
Staurolite spoke with r-faces, b-axial view



Staurolite twin combining right angle and sawhorse spokes¹.

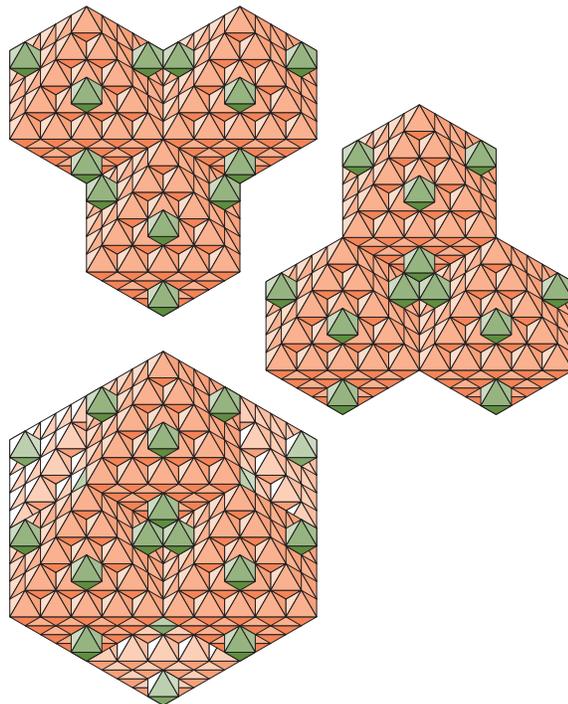
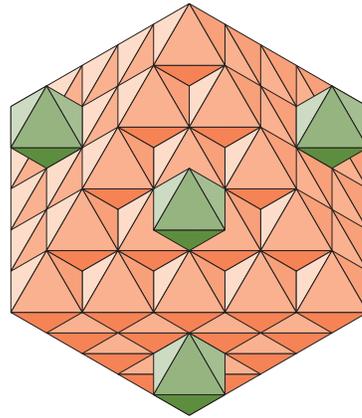
Dana & Ford, *ibidem*, Fig. 467, p. 191

Staurolite stellar sixling having twelve spokes.
This twelve spoked twin is viewed in perspective. The spokes are the same as those in the figure on the left.

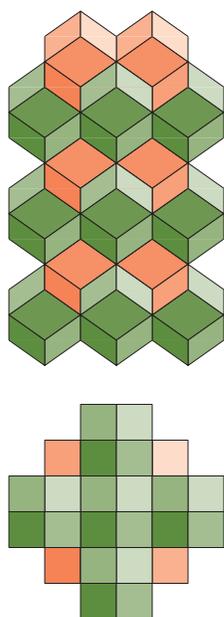


Phillipsite¹

Despite its assignment to the monoclinic class, Phillipsite occurs in a number of symmetrical forms: cruciform fourling twins and rhombic dodecahedral twins. The latter can be built of identical regular octahedra arranged so that they form rhombic dodecahedral subunits and six of these subunits in crystalline association with their centroids in positional relationship as the vertexes of a regular octahedron. And so the position of the epn is established here by the symmetrical requirements of the twins. For phillipsite, the hub unit of the staurolite model becomes the modeling unit for the rhombic dodecahedral twin. The hub unit has the rhombohedral planes while including the fewest octahedra. It is a 5-octa with a 1-octa on each face at the facial centroidal position. The rhombic dodecahedral planes are defined by an edge of the 5-octa and an edge of the 1-octa on each of the faces which define the 5-octa edge.

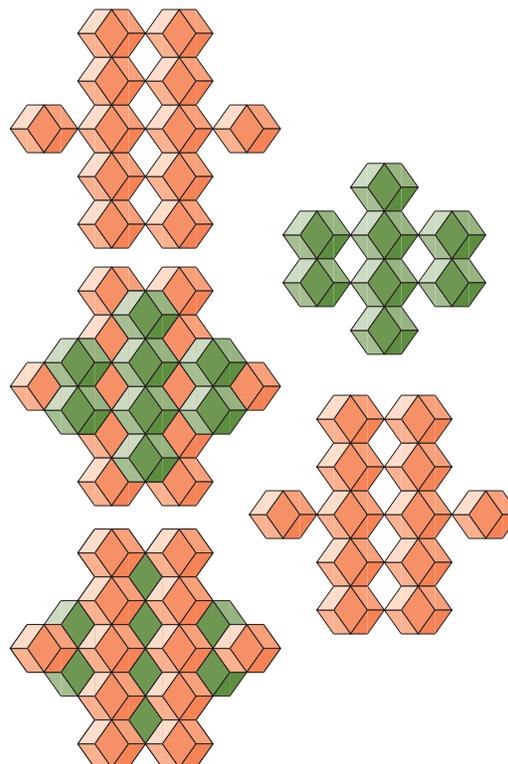


1. Dana & Ford, *ibidem*, Fig. 480, p. 193 & Fig. 426, p. 185

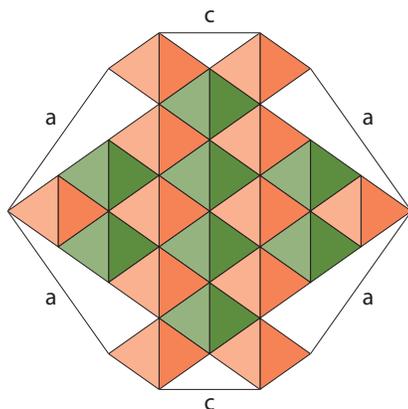


Phillipsite, cross-shaped spoke¹
 Prism faces are defined by rhombic dodecahedral faces (octahedral edges); axial (*bottom*) and radial (*top*) views

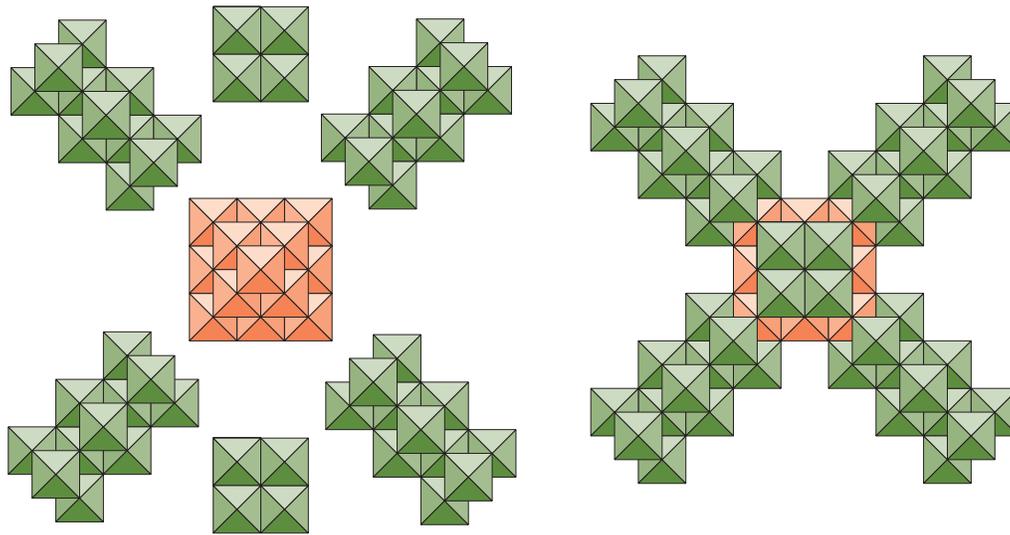
1. Dana & Ford, *ibidem*, Fig. 479, p. 193



Phillipsite: b-axial view of cruciform fourling¹
 The above figure shows the assembly of the twin as minimally formed by rhombic dodecahedra. The assembly grows on the left through the addition of the layer shown on the right. The figure below left shows the twin minimally defined by octahedra.



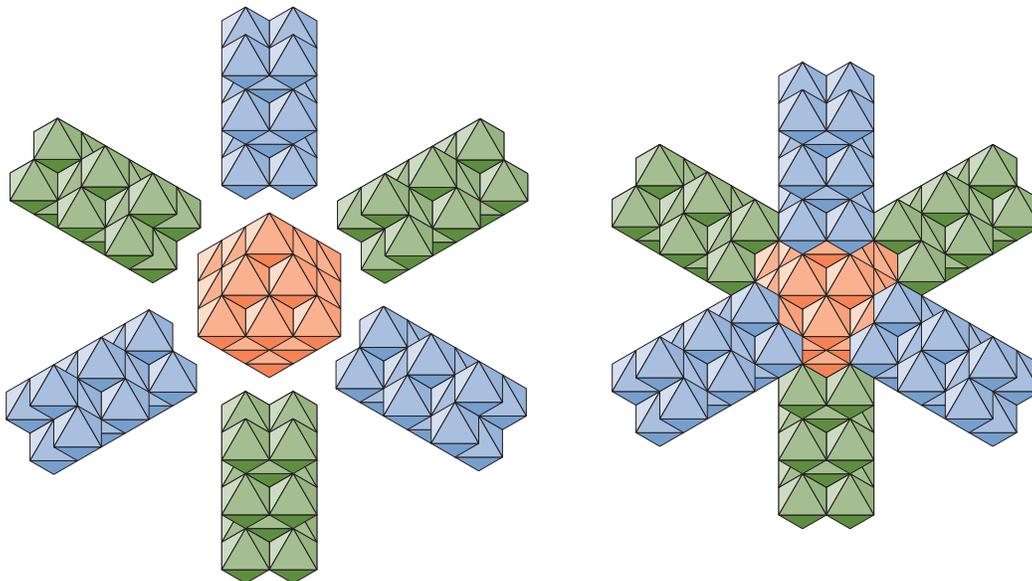
1. Dana & Ford, *ibidem*, Fig.478, p. 193



Phillipsite twin¹

Two views of the same phillipsite twin are depicted here. The spokes are square in cross-section and are vertexially axised. The prisms are defined by octahedral edges. The views above are octahedrally vertexial; the views below are octahedrally facial. The figures on the left are of the spokes and hubs prior to assembly. The assemblies are on the right.

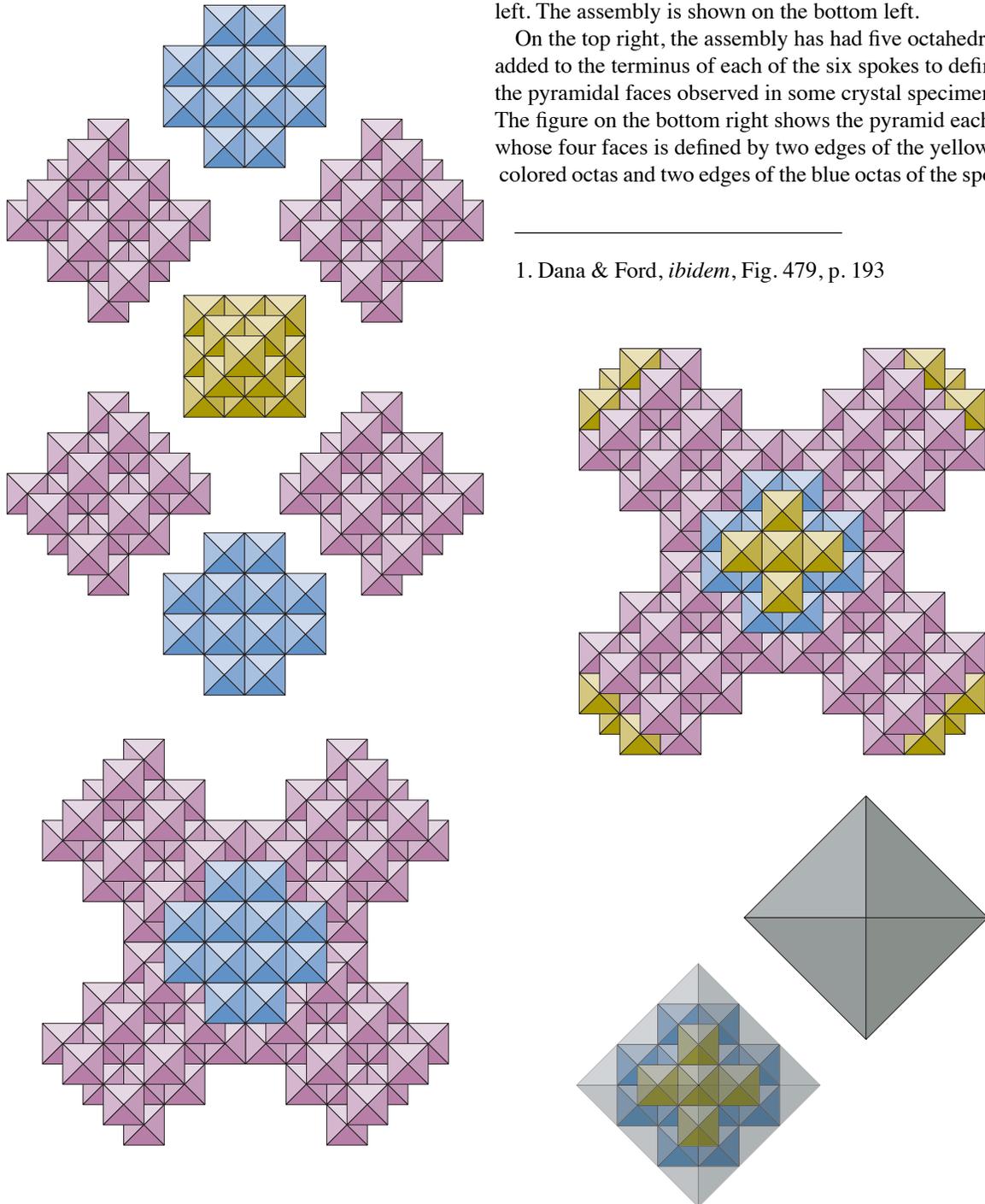
1. Dana & Ford, *ibidem*, Fig. 972, p. 647



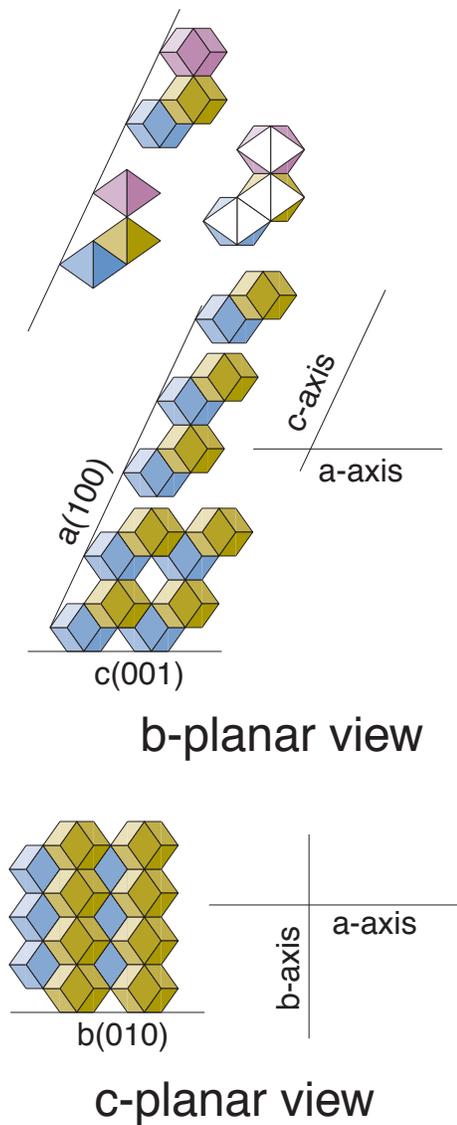
Three-way cruciform penetration twin in phillipsite¹

The six spokes surround the hub in the figure on the top left. The assembly is shown on the bottom left.

On the top right, the assembly has had five octahedra added to the terminus of each of the six spokes to define the pyramidal faces observed in some crystal specimens. The figure on the bottom right shows the pyramid each of whose four faces is defined by two edges of the yellow colored octas and two edges of the blue octas of the spoke.



1. Dana & Ford, *ibidem*, Fig. 479, p. 193



Crystalline faces of phillipsite.

The figure shows the manner in which the crystalline faces of phillipsite are defined by rhombic dodecahedra. There are two viewing directions here. At the top the view is perpendicular to the b -plane. At the bottom, the view is perpendicular to the c -plane.

The relationship of the a -plane to the octahedron is shown at the top. This is compared with the relationship of the a -plane to the rhombic dodecahedron, with the octahedral group superimposed upon the dodecahedral group.

Two pairs of facially-joined dodecahedra are joined so as to produce the a -plane. They are joined by a like pairing to produce a c -plane.

The a -plane is defined by octahedral vertexes while the b -plane and the c -plane are defined by octahedral edges. In producing the same crystalline faces with rhombic dodecahedral CFUs, the a -plane is defined by dodecahedral 4-vertexes and the b -plane and c -plane are defined by dodecahedral faces.

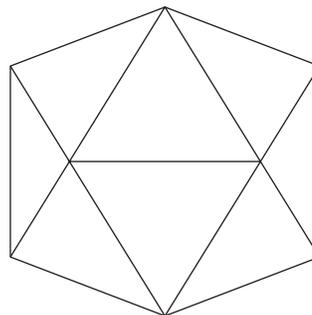
QUASICRYSTAL

An epn of any atom of any group of any assembly in a crystal has an orientation which is identical with that of any other epn in that crystal. That is not true for the quasicrystal. To produce the quasicrystalline forms using identical regular octahedra requires that one octahedron be rotated with respect to another. The octahedra must still be joined by their polar edges, and they must be in structurally stable assemblies.

Fivefold forms

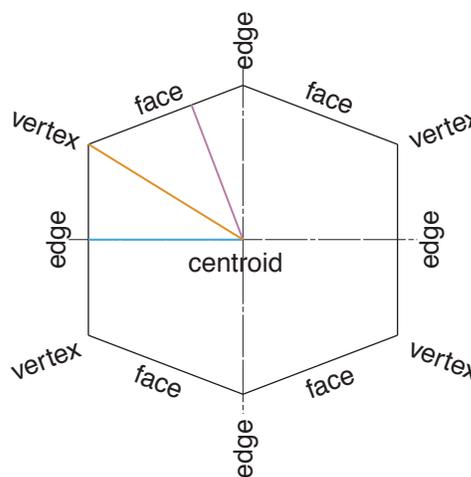
Icosahedron

A rigid regular icosahedron may be constructed using rigid equilateral triangular panels joined by hinges. Each of the eight faces of the regular octahedron is an equilateral triangle. Each face is defined by three edges. If the edges are polar, then one octahedron can be joined to another octahedron by a pairing of polarly attractive edges. The join is a hinge which permits rotation only about the shared edge. This pair can be added to so that a rigid icosahedron is produced in which each of the twenty panels is a regular octahedron which is polarly joined to three neighboring octahedra by the three edges defining one of its faces.



Geometry of the icosahedron.

The top figure shows an edgial view of the regular icosahedron. The bottom view shows the perimeter with topographic labels. Each of three radii are shown in color.



- facial radius
- vertexial radius
- edgial radius

Geometry of the icosahedron

The icosahedron has twenty faces which are equilateral triangles. It has twelve vertexes and thirty edges. The icosahedron is viewed in the direction of an edgial diameter in the next figure.

For an edge length of s , the radial distances of the topographical features from the centroid of the icosahedron can be calculated.

In the figure, this radius projects as its true length for the two edges which are projected at their true lengths, one on the left and one on the right. The same is true for the two edges which project as points at the top and bottom of the figure. All these edges are labeled. The

edgial radius is $r_{edge} = s \frac{1 + \sqrt{5}}{4}$.

There are four vertexes which are labeled in the figure. Each lies on the same plane as the centroid and its radial distance is

$$r_{vertex} = s \sqrt{\frac{5 + \sqrt{5}}{8}}.$$

There are four faces whose planes are parallel to the viewing direction and which are viewed edge on in the figure. The shortest distance between a face and the centroid is perpendicular to the face and intersects the face at its centroid. This radial distance is

$$r_{face} = s \sqrt{\frac{7 + 3\sqrt{5}}{24}}.$$

The three radial directions which are marked in the figure lie on the same plane. The angle between the vertexial radius and the facial

radius is $r_{vertex} \wedge r_{face} = \text{atan} \frac{1}{\sqrt{\frac{7 + 3\sqrt{5}}{8}}}$.

The vertexial radius and the edgial radius make an angle which is equal to

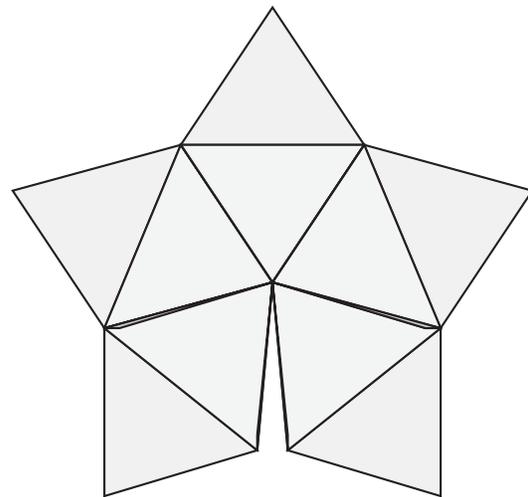
$$r_{vertex} \wedge r_{edge} = \text{atan} \frac{1}{1 + \sqrt{5}}.$$

The facial radius and the edgial radius make an angle which is

$$r_{face} \wedge r_{edge} = \text{atan} \frac{1}{\sqrt{\frac{7 + 3\sqrt{5}}{2}}}$$

Icosahedral association of regular octahedra

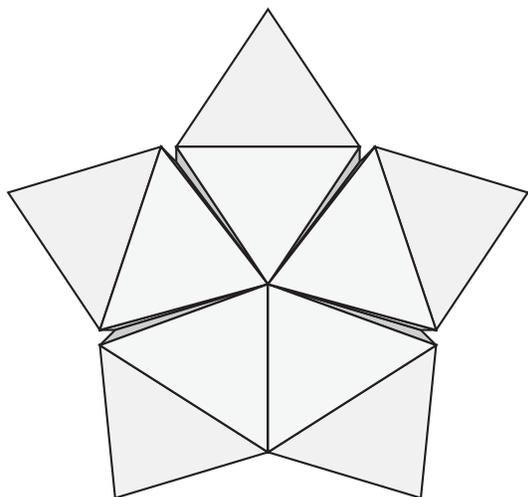
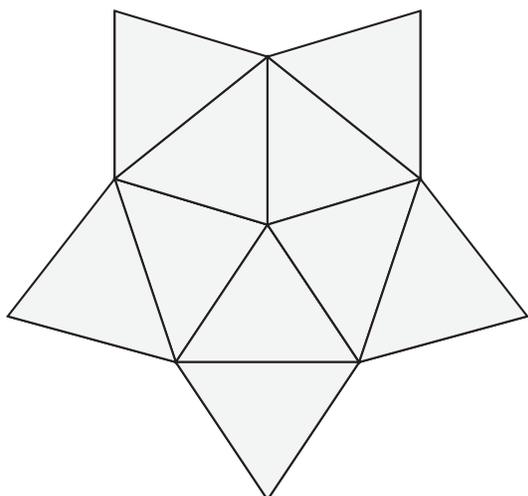
For the regular octahedron, the angle between faces at a vertex is $\text{atan} \sqrt{8}$. When five regular octahedra are joined face to face at a common vertex, the result is shown in the next figure. There remains a gap of $360^\circ - 5 \text{atan} 8$, which is approximated by $7^\circ 21' 22''$.



Five octahedra joined facially.

The figure shows five regular octahedra joined facially so that each of the octahedra shares a vertex in common with the others/ It is seen that there remains a gap so that the ring is incomplete.

Twenty regular octahedra can form a regular icosahedron when they join so that each contributes a face to a regular icosahedron. The relationship between the five octahedra at an icosahedral vertex is depicted in the next figure.

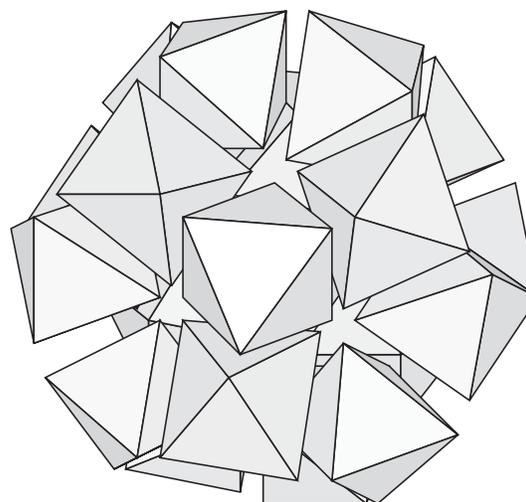
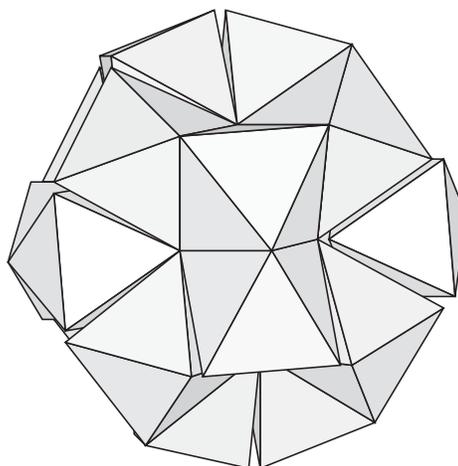


Two views of five octahedra from the icosahedral assembly below.

The upper view is of the inside and shows the join edges; the upper is of the outside and shows the separation of the outer edges.

The top portion of the figure is a view from the inside of the icosahedron in the direction of a vertexial radius. It shows that the edges of the octahedra are in contact, so that there is a join between adjacent octahedra. The lower view of the same five octahedra as seen from the outside in a direction opposite to the same vertexial radius shows the separation of the outer edges.

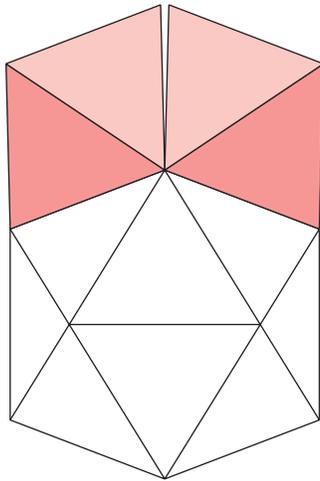
The full assembly of the icosahedral assembly of regular octahedra is shown in the next figure. In the upper view, the octahedra are in contact and appear as they would in the assembly. The lower view shows the twenty octahedra in the same orientation, but they are displaced radially to allow them to be more easily differentiated.



Twenty octahedra forming a regular icosahedron.

The lower view is an exploded view. Both are viewed in the direction of a face of the inner icosahedron.

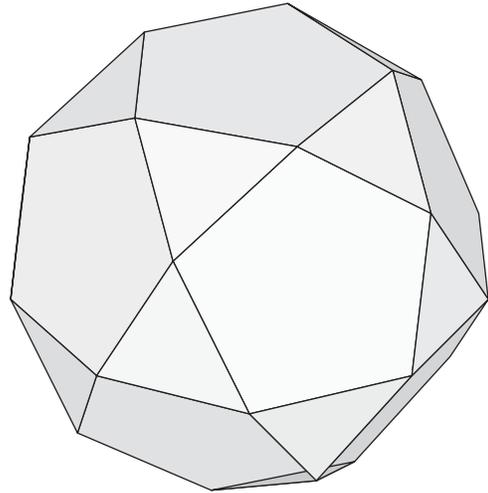
Each of the octahedra of the icosahedral assembly is a panel. Each of the edgial joins between a pair of panels is a hinge, but the hinges are stabilized by the other panels so that the resulting assembly is a rigid structure. In the figure, an edgial view of the icosahedron is shown with two of the octahedra at an edge. Each edge of the icosahedron is a join between two octahedra. The view shows the gap between the faces of the adjoining octahedra.



Icosahedral assembly: gap between octahedra at edge.

Icosidodecahedron

The face that each octahedron contributes to the icosahedron is turned towards the center of the assembly. It is paired with a parallel outward face of the same octahedron. Each of these outward faces defines a facial plane of a regular icosahedron. Each of the edges of each of the outer octahedral faces helps to define one of twelve facial planes of a regular pentagonal dodecahedron. Each dodecahedral face is defined by an edge of five different octahedra. The polyhedron which includes the twenty triangular faces of the icosahedron and the twelve pentagonal faces of the dodecahedron is called an icosidodecahedron.



Icosidodecahedron

Octahedral atoms form icosahedral assemblies

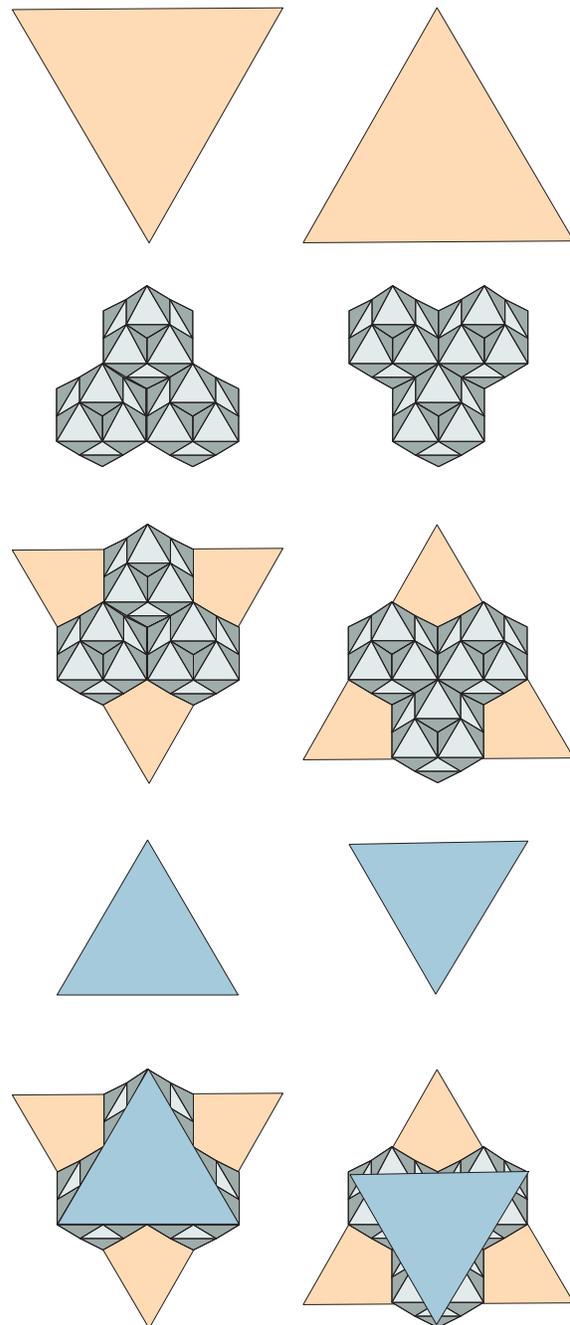
Each of the octahedra in the depicted icosahedral assemblies can be replaced by an atom or group of atoms of whatever complexity. Its volume must be contained within an octahedral volume. It must have He-octa edges which are colinear with the three edges of a face of the octahedral volume. These edges can join with identical edges of identical groups to form an icosahedral assembly.

Buckminster fullerenes

A number of Icosahedral groupings have been discovered which are composed of C-atoms. These are called *Buckminster Fullerenes*. A description of some of the assemblies follows.

An icosahedral assembly of C-atoms

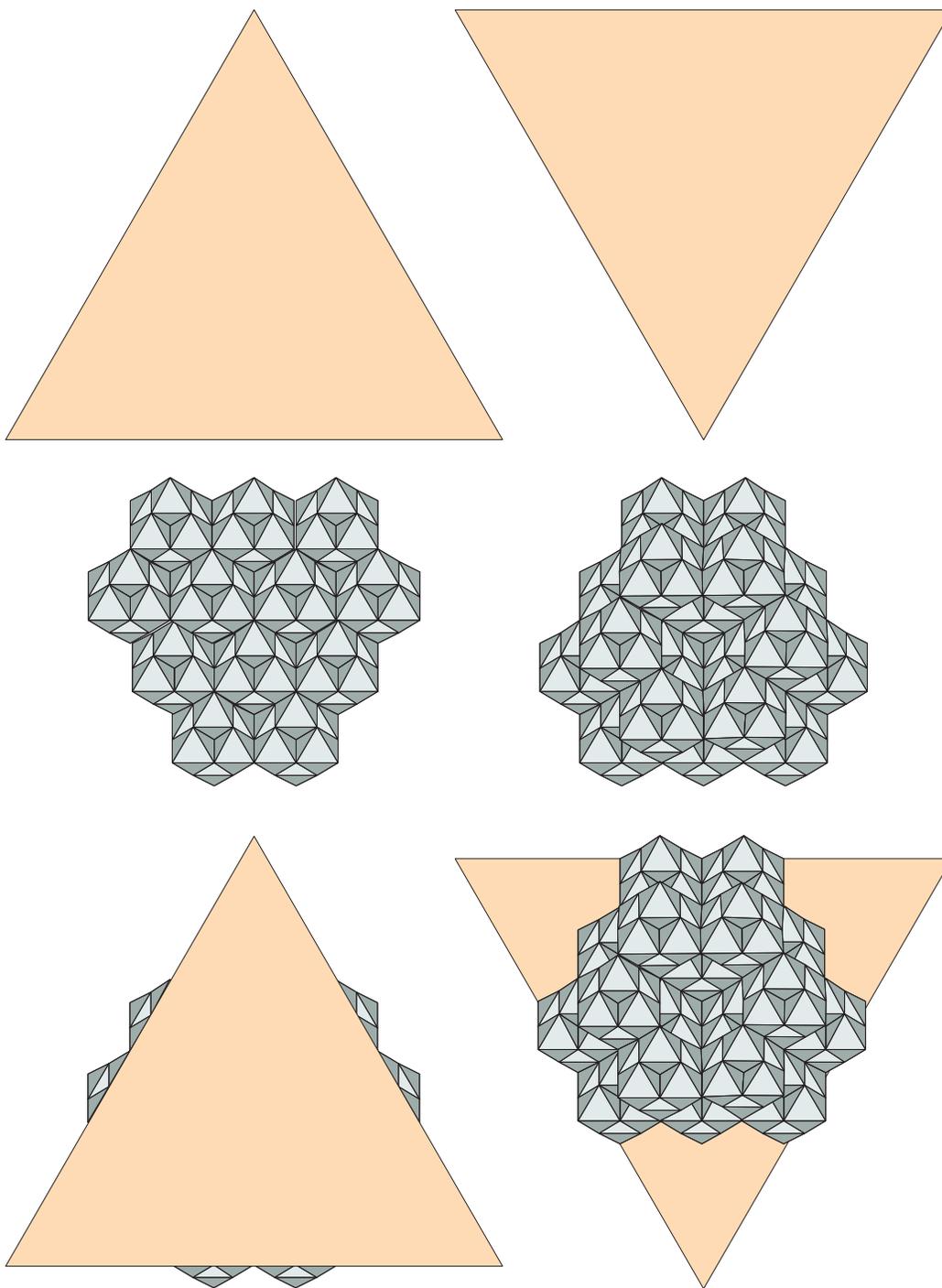
A C-atom is shown in the next figure with the two triangular faces it can form if it is the panel of an icosahedral assembly. The C-atom acts as the larger panel when its central tetrahedral void faces outward from the icosahedral centroid. The left column of figures shows the icosahedral face at the top. The next drawing is the C-atom as it would appear looking towards the icosahedral centroid. The third drawing shows the C-atom atop the icosahedral face. The fourth drawing is the icosahedral face that would result from using the upper face of the C-atom as a panel. In the bottom drawing the two faces sandwich the C-atom. The second column shows the same large icosahedral face at its top. The C-atom is inverted from the C-atom depicted on its left. The next drawing of the right column shows the inverted C-atom atop the large triangular face. The edges which are used to join the C-atom to other C-atoms to create this large triangle are colinear with the edges of the large triangle in this drawing. The small triangle is next in this column. In the last drawing of the column the C-atom is sandwiched between the two triangles. The edges of the small triangle on the left sandwich are colinear with the edges of the C-atom which are used to join to other C-atoms to form an icosahedral assembly. The two triangles have



Icosahedral faces defined by C-atom.

edge lengths which are in the ratio of 3 He-octa edges to 2 He-octa edges.

An icosahedral assembly of C_6 -rings



Icosahedral face defined by C_6 ring.

An icosahedral assembly of C_6 -rings is formed in a similar manner. In the next drawing the C_6 -ring is shown under the panel in the left column, and over the panel in the right column. The view at the bottom of the left column is how the panel would appear looking radially out from the centroid of the icosahedron. The drawing at the bottom of the right column is how the panel would appear looking in toward the centroid of the icosahedral assembly. The size of the triangular face is six He-octa edges.

An icosahedral assembly of C_3 -tetrahedra

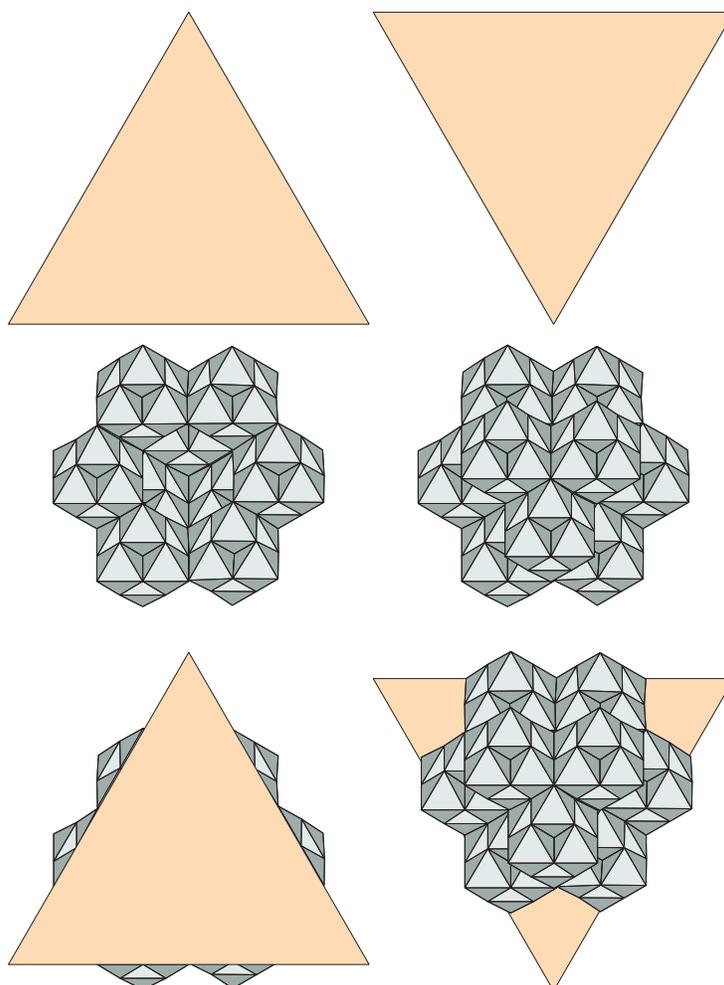
Another C-atom group can form an icosahedral assembly. The group is composed of three C-atoms. Each C-atom supplies a face of a reg-

ular tetrahedron. The fourth face is open. A He-octa of each of two C-atoms combine to form the hinged edge of the icosahedral panel. The resulting icosahedral panel has an edge length of four He-octa edges.

An icosahedral assembly of C_4 -tetrahedra

The C_4 -tetrahedron has a C-atom panel for each face. This unit can make an icosahedral assembly. The join between icosahedral panels is provided by a He-octa edge of one of the C-atom panels of the C_4 tetrahedron. This is one of the ways in which a C-atom can make a panel of an icosahedron and has been depicted previously.

Icosahedral face defined by C_3 tetrahedron



Icosahedral assemblies with identical facial panels

A consideration of icosahedral assemblies which are composed solely of C-atoms suggests the listing in the next table. The number

Table 14: Icosahedral assemblies

Atoms	Facial panel	Description
20	C-atom	
40	C ₂ -octa	Mg-octa
60	C ₃ -tetrahedron	Graphite CFU
80	C ₄ -tetrahedron	Diamond CFU
120	C ₆ -ring	Benzene ring

of C-atoms in each assembly is an integral multiple of twenty. The one with the fewest atoms contains just one atom per facial panel¹. The most common assembly contains sixty atoms.

Icosahedral assemblies with more than one type of facial panel

Seventy atom assembly

A seventy atom icosahedron might be assembled from ten C₄-panels and ten C₃-panels. They would supply forty plus thirty C-atoms to give the seventy C-atoms required. Although these panels might be distributed in an irregular manner, they could be distributed regularly. One set could be in two five-panel groups at opposite vertexes with the other set supplying the ten equatorial panels.

Seventy-six atom assembly

Seventy-six atoms can be obtained from six-

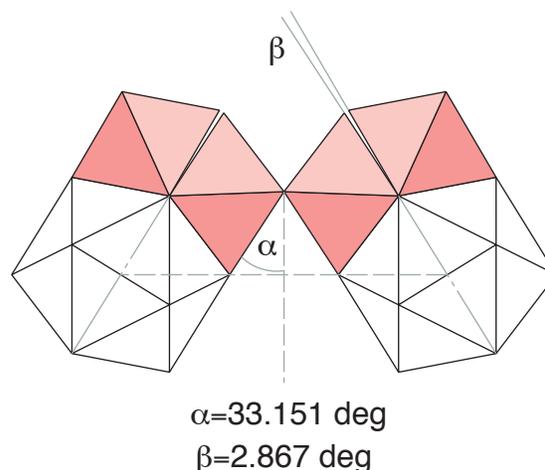
1. A *New York Times* article describes the twenty C-atom assembly as “the smallest of the buckyball family”. See “A Prodigious group and Its Growing Pains” by Kenneth Chang in the Science Times section of the *New York Times* of 10 October 2000.

teen C₄-panels and four C₃-panels. The sixty-four atoms of the C₄-panels plus the twelve atoms of the C₃-panels gives seventy-six C-atoms. These could be symmetrically distributed if the four C₃-panels were paired at diametrically opposed icosahedral edges.

Seventy-eight atom assembly

Two C₃-panels could occupy a pair of opposed icosahedral faces for six C-atoms. Eighteen C₄-panels could complete the seventy-eight atom icosahedral assembly.

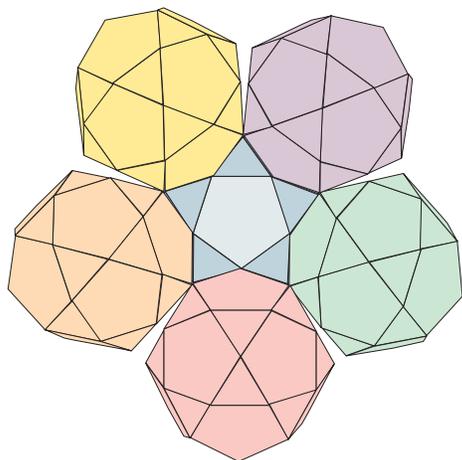
Icosidodecahedral joins



Icosahedral geometry: octal edgial contact between icosahedral assemblies.

Each dodecahedral plane is defined by an identical regular pentagonal array of five octahedral edges. A pair of identical icosahedral assemblies of regular octahedra may join so that a pentagonal array of octahedral edges of one assembly is congruent with an array of the other assembly to produce a rigid polarly attractive join. Again, each edge-to-edge join is stabilized by the other edge-to-edge joins. The geometry of the edge-to-edge join between a pair of octahedra belonging to adjoining icosahedral assemblies is shown in the figure. The two icosahedral centroids are joined by a line which is colinear with a vertexial radius of each assembly.

Because each of the pentagonal edgial arrays is rotated 36° to the array which is diametrically opposite, the move from one position to another requires a rotation of 36° between the joining units so that the octahedral edges at the join congrue. In the next figure, this rotation is seen in each of the five icosidodecahedra which have been joined to the central icosidodecahedron.



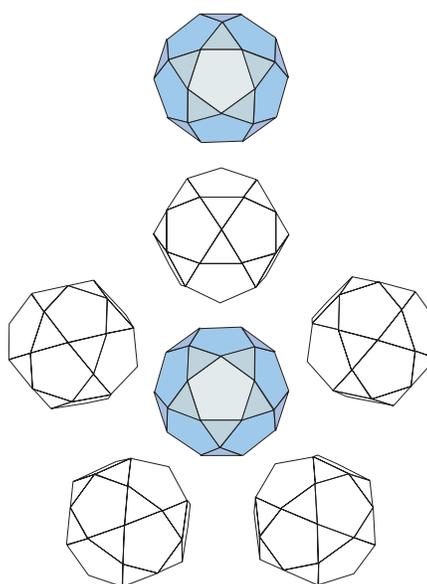
Icosidodecahedral hub showing five units joined to a central unit.

Orientations of the icosidodecahedron

When icosidodecahedra join pentagonal face to pentagonal face, there are twelve possible sites on a given reference unit. The joining unit is rotated 36° relative to the base unit about the axis joining their centroids. This axis is perpendicular to the facial join. It follows that the units joined in a given join direction alternate between two orientations. It is seen also that the pentagonal faces are arrayed as six pairs whose face normals are colinear and pass from facial centroid to facial centroid through the icosidodecal centroid. Each unit of each pair has the same orientation. This orientation differs from each of the other pairs. Thus, there are six possible orientations for the units joined to the reference unit. There is the orientation of the reference unit itself. There are, then, no more than seven possible orientations in an assembly of icosidodecahedra joined

pentagonal face to pentagonal face.

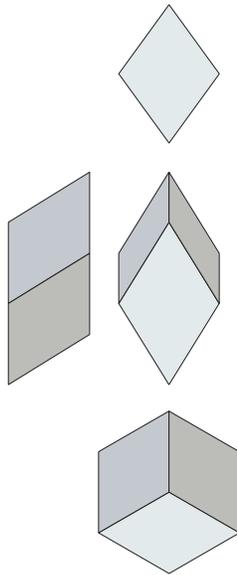
In the figure, an icosidodecahedron viewed normal to a pentagonal face is surrounded by icosahedra in the six other orientations. Together, these are the seven possible orientations.



Orientations of the icosidodecahedron.

The acute Penrose rhombohedron

Each icosahedral face connects three icosahedral vertexes. The three move directions through these vertexes provide the directions for the edges of a rhombohedron each of whose rhombic faces has an acute angle which is exactly the $\arctan 2$. This shape is known as an *acute Penrose rhombohedron*. This shape can act as the unit cell for the five-fold figures that result from the joining of icosidodecahedra. The figure here shows the principal views of the rhombohedron. The top right view shows the angle between the faces at an edge to be 72° or its supplement.



Acute Penrose rhombohedron: principal views.

The view on the left is along an edgial diameter. The top view on the right is parallel to the planes of four of the faces and shows the angle between the faces at an edge to be 72° or its supplement. The middle figure is normal to a face and shows its true shape. The bottom figure

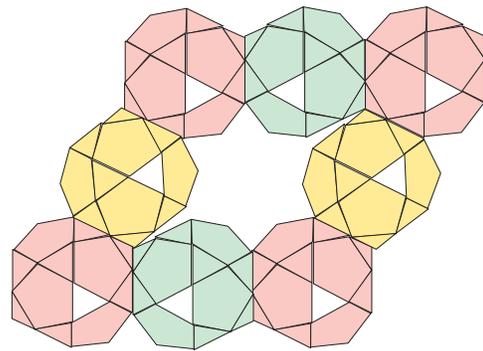
The edges of the rhombohedron have the same length. They are of two types. One type ends at the three-fold axis of symmetry; the other type does not. The former are in two sets of three. The others join the ends of the opposed axial sets and are six in number.

These comprise the twelve edges of the rhombohedron.

The vertexes are of two types. Two are on the axis of three-fold symmetry. Six others are in sets of three at one third and two thirds of the distance between the vertexes on the threefold axis. The view along the three-fold axis is at the bottom of the righthand column.

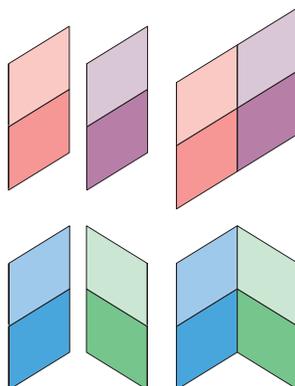
Rhombohedral assembly of icosidodecahedra

To realize the acute Penrose rhombohedral shape with the icosahedral assemblies, it is necessary to have assemblies of the same orientation at each of the rhombohedral vertexes. That requires mid-edge units to connect them to restore the orientation. (Twice 36° is 72° which for a pentagonal array means congruency.) In the figure the units are tinted according to their orientations. The red tinted are each at a vertex. The mid-edge units are differently oriented.



Face of an acute penrose rhombohedron defined by icosidodecahedra.

Rhombohedral joins



Rhombohedral joins.

Rhomboheda join face to face in one of two ways. The rhombohedra here are viewed edgially. In the top row, the two rhombohedra on the left have the same orientation. They are shown joined on the right. This is the simple crystalline join. The two rhombohedra on the left of the bottom row have different orientations. The resulting join is shown to the right. This is a twinned crystalline join.

The five-fold forms are modelable using this form with these two joins.

Crystalline join

A rhombohedron can be joined to an identical rhombohedron in identical orientation so that a face of one is congruent with a face of the other. This join is shown in the top row of the figure. This is a typical join for an untwinned crystal.

Twin join

A rhombohedron can be joined to an identical rhombohedron so that the face of one is congruent with the face of another while the two have different orientations. This is a twinned structure. It is shown in the bottom row of the figure.

Icosahedral assembly of acute Penrose rhombohedra.

Twenty acute Penrose rhombohedra can be joined face to face so that they share a common vertex. For each rhombohedron, the common vertex is on its three-fold axis. The axis is normal to a face of a regular icosahedron.

In the figure, each of the yellow rhombi is the projected face of a rhombohedron viewed parallel to four of its faces. Each of the five pairs of blue rhombi belong to a rhombohedron which is face joined to the yellow rhombohedron above it. Each of the green rhombi are face joined to each of the two adjacent blue rhombohedra.

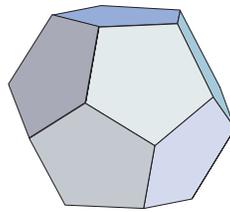
The outermost vertexes of the twenty rhombohedra are at the vertexes of a regular pentagonal dodecahedron. They define the twelve

faces of the dodecahedron. The five yellow rhombohedra share an edge which is an axis of fivefold symmetry. This axis is perpendicular to a dodecahedral face at the facial centroid.

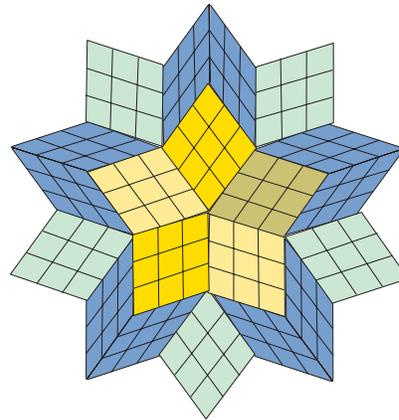
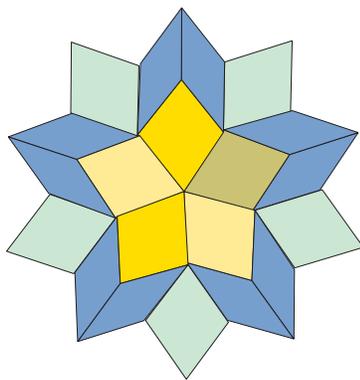
Crystalline expansion of five-fold forms with acute Penrose rhombohedral unit cells

Crystalline expansion of the rhombohedron

The crystalline expansion of the twenty rhombohedra maintains the geometry of the assembly while revealing the twinning. The figure shows twenty compound rhombohedra in the same relationship as the simple rhombohedra shown previously. Each of the compound rhombohedra is composed of twenty-seven simple rhombohedra.



Pentagonal dodecahedron

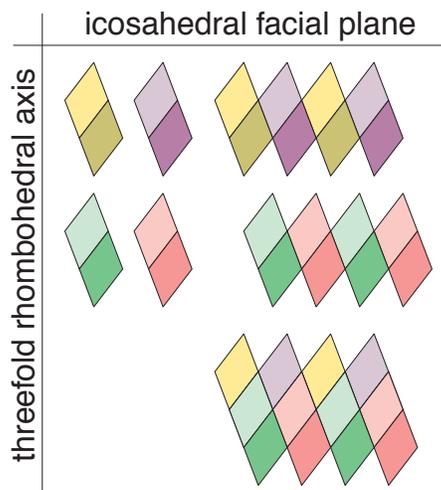


Twenty acute penrose rhombohedra joined facially with a common vertex.

The figure shows two assemblies of acute penrose rhombohedra. The one on the left is composed of simple rhombohedra; the one on the right is composed of compound rhombohedra. In each case, there are twenty rhombohedra which share a common vertex.

Crystalline expansion of the icosahedron.

The icosahedral plane is defined by vertexes on the threefold axis of the rhombohedra. The threefold axes of each rhombohedron is perpendicular to the icosahedral plane. A rhombohedron in a layer parallel to the icosahedral plane shares an edge with as many as six adjacent rhombohedra. It is facially joined to as many as three rhombohedra in an adjacent layer. The rhombohedra in the icosahedral plane are in the same orientation.

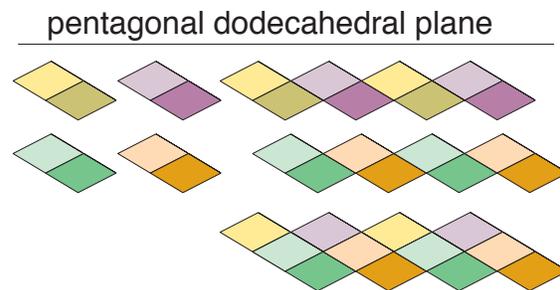


Icosahedral plane.

This is the arrangement of the acute Penrose rhombohedra at an icosahedral surface. The rhombohedra are viewed parallel to a pair of opposed faces. The threefold axis of each is perpendicular to the icosahedral surface. In the two upper rows, the units on the left are individual rhombohedra. They are arranged on the right in edge to edge contact. The bottom row shows them joined facially.

Crystalline expansion of the pentagonal dodecahedron

The pentagonal dodecahedral plane is defined by vertexes of the rhombohedra which terminate the minor diameters of the rhombohedral faces. The rhombohedra are in layers which are parallel to the dodecahedral plane. The layer is parallel to the major diameter of each of four faces of the rhombohedron. Each rhombohedron in the layer shares an edge with as many as six adjacent rhombohedra in the layer. Each rhombohedron is facially joined to as many as three rhombohedra in each adjacent layer.



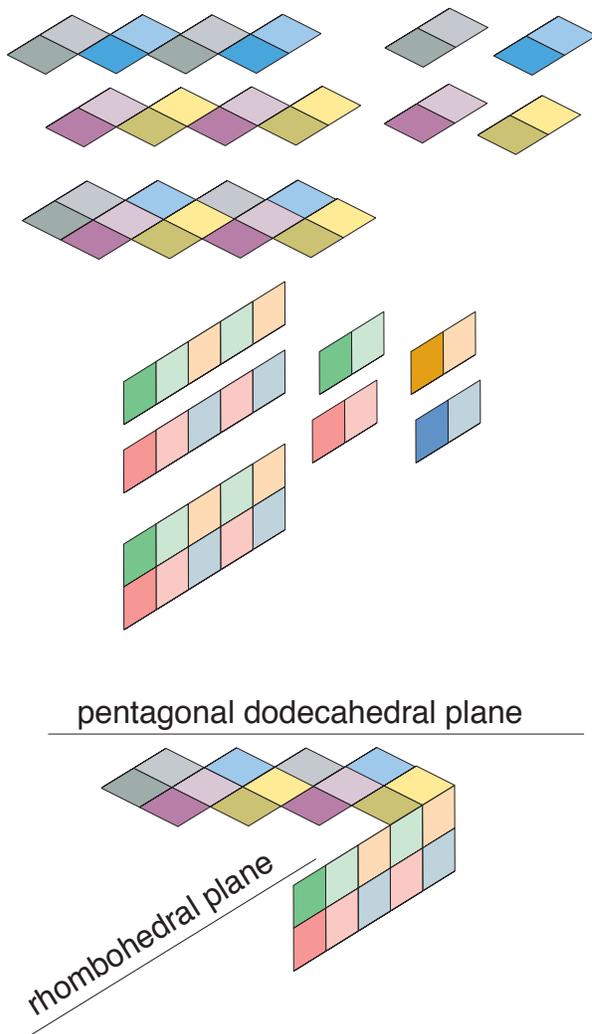
Pentagonal dodecahedral plane.

This is the arrangement of the acute Penrose rhombohedra at a pentagonal dodecahedral surface. Each rhombohedron is viewed parallel to a pair of opposed faces. In the top two rows, the two units on the left are individual rhombohedra. Their arrangement in the assembly is shown on the right, where the rhombohedra are in edge to edge contact in two lines parallel to the pentagonal plane. The lines are shown in facial contact in the bottom row.

Join between rhombohedron and dodecahedron

In the next figure, the arrangement of the Penrose rhombohedra are shown for each of two crystalline regions. The upper group shows the arrangement within the region of the pentagonal dodecahedral plane. The middle group shows the arrangement in the region of

the rhombohedral plane. The threefold axes of these rhombohedra are parallel to a vertexial radius of an icosahedron. In each of the two regions, the rhombohedra are in the same orientation and the facial joins are crystalline. At the junction of the two regions the joins are twins. This is seen in the bottom grouping.

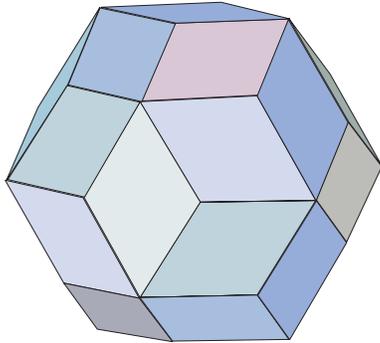


Junction of dodecahedral and rhombohedral planes.

The arrangement of the acute Penrose rhombohedra at the pentagonal dodecahedral plane is shown at the top. Next, their arrangement at the rhombohedral plane is shown. The arrangement of the rhombohedra at the junction is shown at the bottom.

The join the of the rhombohedra at the junction of the two planar regions is of the twin type. Within each region, the join is crystalline.

The triacontahedron



Triacontahedron.

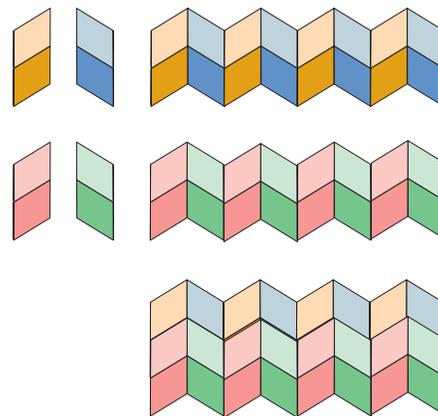
The triacontahedron has thirty faces which are identical rhombi, one for each of the edges of the icosahedron. It has twelve five-fold vertexes, one for each vertex of the icosahedron. It has twenty threefold vertexes, one for each face of the icosahedron.

The triacontahedron is a fivefold form related to the icosahedron.

- Each of the thirty identical rhombuses which constitute its faces is normal to a radius which is colinear with an edgial radius of a concentric icosahedron.
- A facial radius of the icosahedron is colinear with the radius which intersects each face of the triacontahedron at its centroid.
- The major diameter of each triacontahedral face is terminated at each end by a fivefold vertex which lies on the same line as a vertexial radius of the icosahedron.
- Each of the major diameters of the triacontahedral faces can be colinear with an edge of a concentric icosahedron.
- The minor diameter of each face is terminated by a threefold vertex which lies on the same line as a facial radius of the icosahedron.

Crystalline expansion of the triacontahedron.

The triacontahedron can be formed by an assembly of acute Penrose rhombohedra. The triacontahedral plane is defined by threefold vertexes of the Penrose rhombohedra. These rhombohedra are facially joined in crystalline layers which are perpendicular to the triacontahedral plane and run parallel to the major diameter. They are facially joined as twins to rhombohedra in adjacent layers. In the figure, the arrangement of the rhombohedra within the layer which is parallel to the triacontahedral plane is shown. The development of the two layers are depicted in the upper rows. The bottom row shows the arrangement of adjacent layers. The twin joins within the layers parallel to the triacontahedral plane are evident in the upper rows; the crystalline joins in the layers perpendicular to the triacontahedral plane are evident in the bottom row.

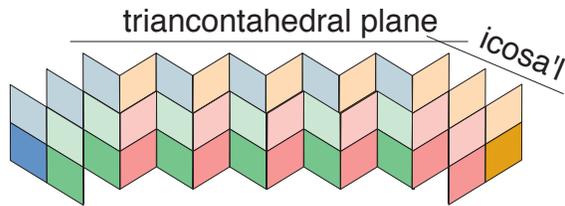


triacontahedral plane

Triacontahedral plane.

The acute Penrose rhombohedra which form the triacontahedral plane are oriented so that their facial join planes are perpendicular to the triacontahedral plane. Each of the upper rows has a pair of individual rhombohedra in the orientations which occur in the assemblies to the right. The combined assemblies are at the bottom. The join rhombohedra in the row is that of twins; the join between rhombohedra of adjacent rows is crystalline.

Triacontahedral and icosahedral planes



Relationship between the triacontahedral plane and adjoining icosahedral planes.

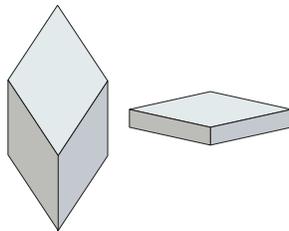
The view is normal to the minor diameter, parallel to the major diameter of the triacontahedral face.

The region of the triacontahedral plane is flanked by a pair of icosahedral planar regions. The view is parallel to the major diameter of the triacontahedral face. The two orientations of the rhombohedra of the triacontahedral region are seen in the icosahedral regions, within each of which the rhombohedra are identically oriented.

The obtuse Penrose rhombohedron

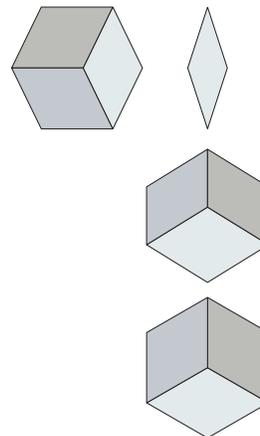
The obtuse Penrose rhombohedron has faces which are geometrically similar to the acute Penrose rhombohedron.

Where the faces of the two rhombohedra are identical, the length of the three fold axis of the acute rhombohedron is over four times that of the obtuse rhombohedron.



The Penrose rhombohedra

The two Penrose rhombohedra viewed perpendicularly to their threefold axes.



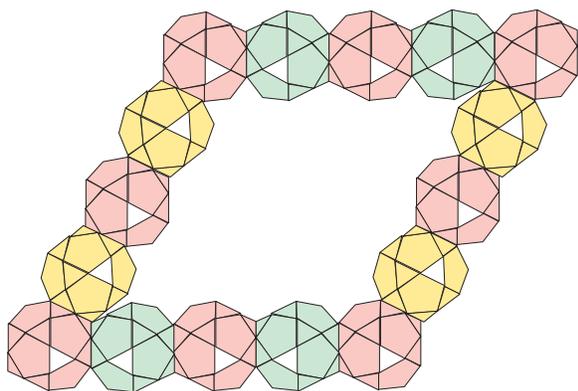
Obtuse Penrose rhombohedron.

In the right column: View parallel to four faces, top; view of true face, middle; view parallel to threefold axis, bottom.

The view on the left is normal to the view to its right. The edges parallel to the top of the page are projected in their true length.

Face of obtuse Penrose rhombohedral assembly of icosidodecahedra

When icosidodecahedra assemble to form the edges of an obtuse Penrose rhombohedron, the resulting edge length is twice the length of the edge of the acute Penrose rhombohedron. This is so that the icosidodecahedra which define one edge of the rhombohedron does not obstruct the formation of another edge. Extending the edge of a rhombohedron composed of icosidodecahedra requires the addition of two units. This assures that the vertexial units are in the same orientation.

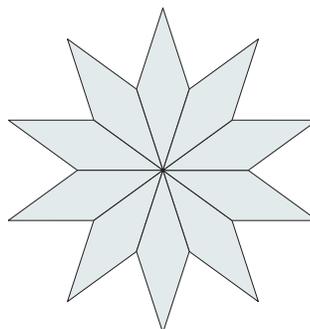


Face of obtuse Penrose rhombohedron defined by icosidodecahedra.

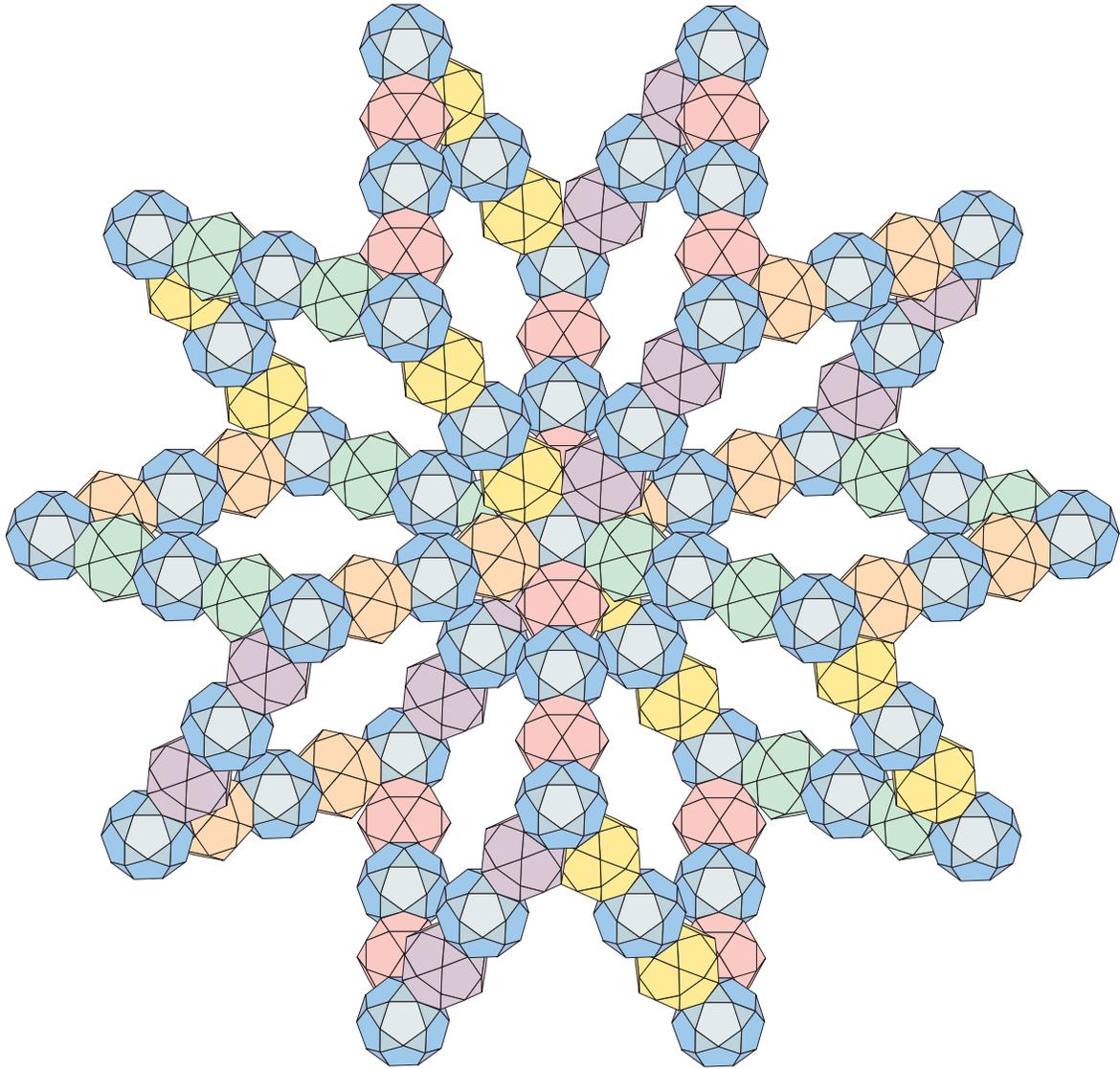
The icosidodecahedra with a common orientation have a common color.

Tenfold star of obtuse rhombohedra

In the obtuse rhombohedron, the angle that each pair of faces makes at a mid-edge is 36° . When the obtuse rhombohedron is the unit cell for a quasicrystalline form, ten of the unit cells can join face to face so that they share an edge. This gives the appearance of a tenfold star. Each of the joins between adjacent rhombohedra is of the twin type.



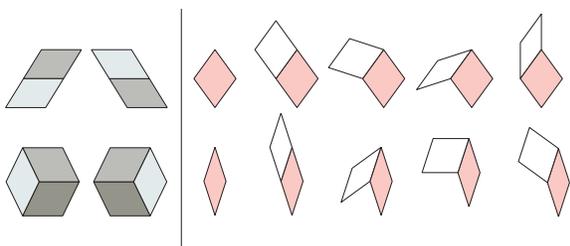
Tenfold star of obtuse Penrose rhombohedra.

Tenfold star of icosidodecahedra**Decagonal assembly of icosidodecahedra.**

The arrangement of icosidodecahedra in an assembly akin to the tenfold star is shown in the figure at the top of the next page. Each of the icosidodecahedra is colored according to its orientation. There is a central icosidodecahedron.

Joins between Penrose rhombohedra

There are two possible facial joins between a pair of Penrose rhombohedra. They differ by a rotation of 180 degrees about the normal to the join faces. In the figure, the red-tinted rhombuses are the projections of the reference rhombohedron and the white-filled rhombuses are the projections of the joining rhombohedra. These are the possible facial joins for the Penrose rhombohedra in the reference projections. The gray-shaded rhombohedra on the left are views of the reference rhombohedra normal to the viewing direction on the right. Both the acute rhombohedron and the obtuse rhombohedron can be in either of the two orientations shown and still project as the red-tinted rhombuses.



Facial joining of Penrose rhombohedra.

In the top row, the reference unit is the acute rhombohedron; in the bottom, it is the obtuse rhombohedron.

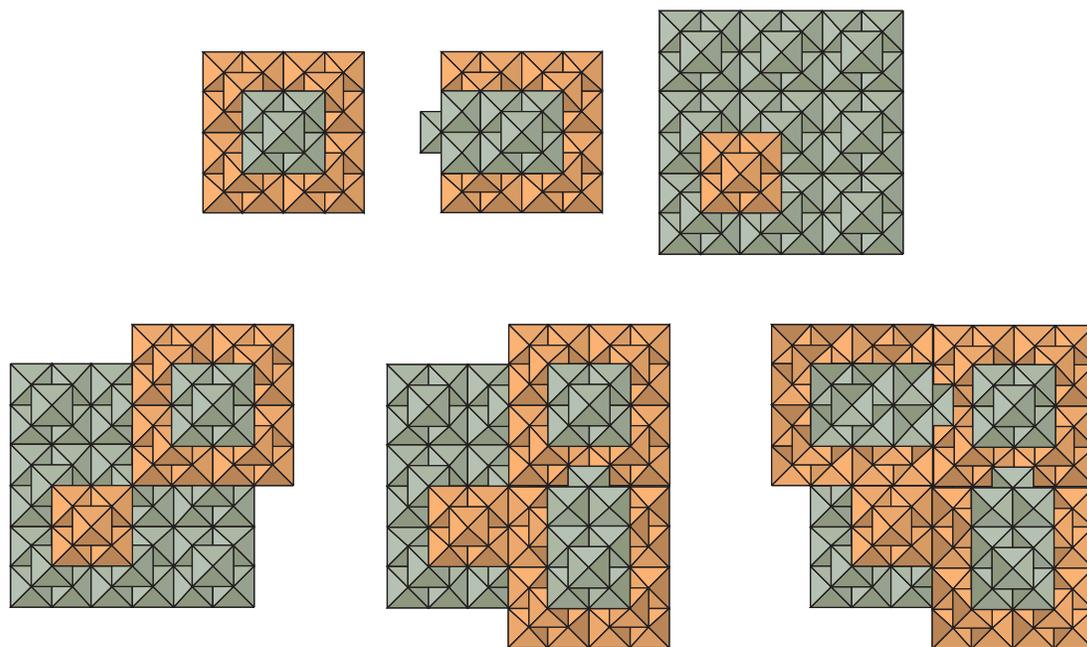
Icosahedral alloy $^1\text{Mg}_{32}(\text{Al,Zn})_{49}$

The alloy $\text{Mg}_{32}(\text{Al,Zn})_{49}$ is of particular note in the study of quasicrystals. Efforts were made to assign the atoms to places within a Penrose rhombohedron because that form is useful for analyzing quasicrystals with fivefold symmetry. But that symmetry is due to the icosahedral assembly of regular octahedral subassemblies. The icosahedra assemblies define the Penrose rhombohedral unit cells. It is the icosahedral assembly, then, that must produce the atomic census of the alloy.

The seventy-one atoms of the alloy must be apportioned to the twenty octahedral assemblies which form the icosahedral assembly. Al-atoms and Mg-atoms occupy equivalent volumes. The volume is much less than that required for a Zn-atom. So, the Zn-atom is the likely base for the octahedral assembly. Using twenty Zn-atoms leaves twenty-nine Al-atoms and thirty-two Mg-atoms to be distributed among the twenty icosahedral assemblies. That requires that three of the smaller atoms be included with each of the Zn-atoms and leaves one atom to be allocated to one of the twenty icosahedral assemblies.

In the top row of the figure, the three types of atoms are shown in a view parallel to the vertexial growth axis. The Mg-atom is on the left, the Al-atom is in the middle, and the Zn-atom is on the right. In the bottom row, the left group is a Zn-atom to which a Mg-atom has been joined. The join is such that the He-octa of the Mg-atom fills the Fe-octa Se-octa void of the Zn-atom. Adding an Al-atom to the left group so that its He-octa occupies the Ge-octa void of the Zn-atom produces the middle group of the bottom row. To this group a second Al-atom is added so that its He-octa occupies the Kr-octa void of the Zn-atom.

The icosahedral face produced by these Zn-Mg-Al panels has an edge length of four He-octas. This is the same size face that is produced by the C_3 -tetrahedron.



Facial panel for $Mg_{32}(Al,Zn)_{49}$ icosahedral assembly.

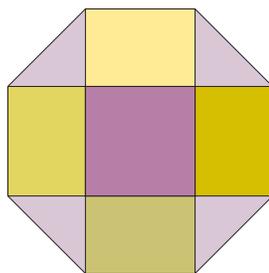
The top row shows the three atoms which form the assembly.

The bottom row shows the formation of a $ZnAl_2Mg$ assembly which is a possible panel assembly.

Eightfold forms

Rhombicuboctahedron

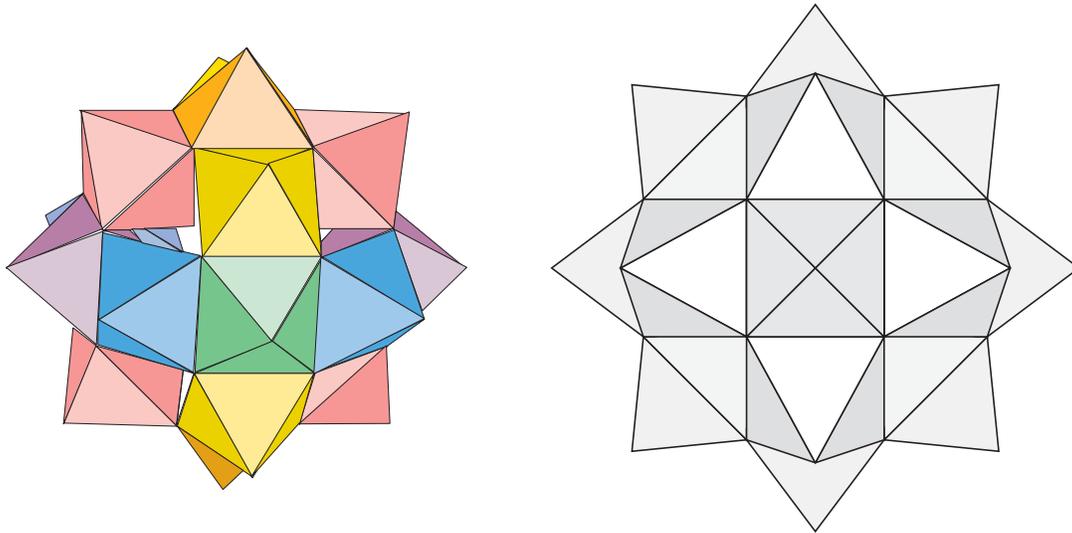
The rhombicuboctahedron has eighteen faces which are squares and eight faces which are equilateral triangles. It has twenty-four vertices. The square faces are arrayed so that they may be seen as three mutually perpendicular rings. When each of the rings is viewed parallel to the planes of the square faces, their edges define a regular octagon. The square faces



make an angle of 45° where they meet. This can be seen in the figure, where the perimeter is defined by the edges of the square faces which are normal to the plane of the projection. The view is normal to a square face which is common to two of the rings.

Rhombicuboctahedral assembly of regular octahedra

Eighteen regular octahedra joined edge to edge at an edgial equator will produce a stable rhombicuboctahedron. The edgial equator of each octahedron is a square and these account for the square faces of the rhombicuboctahedron. The eight triangular faces are defined by the unpaired equatorial edges of the octahedra.



Rhombicuboctahedral assembly

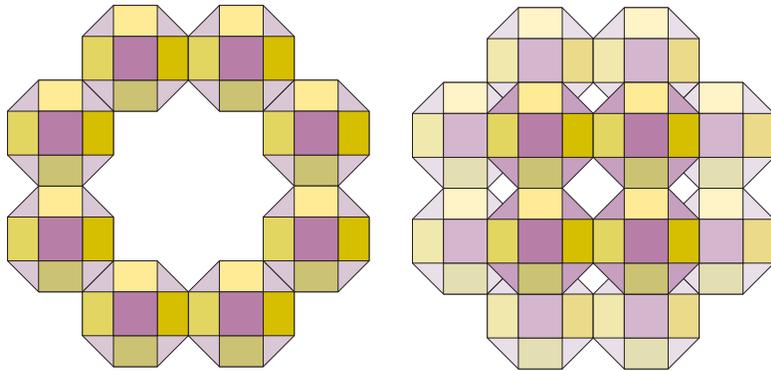
The figures show two views of a rhombicuboctahedral assembly of eighteen regular octahedra. The view on the left is a perspective view, that on the right is an orthographic projection.

The square faces are arrayed as three mutually perpendicular and intersecting regular octagonal prisms. The octahedra which occupy the faces at the intersections of the octagonal arrays are edgially joined to each of four neighboring octahedra. There six of these positions. The other twelve share an edge with each of two intersectional octahedra. Each square face is matched with a diametrically opposite face. The octahedra in the two positions are in the same orientation. There are nine rotational orientations for the eighteen octahedra, so the octahedra are not in crystal-line order. If each of the octahedra were replaced with a compound octahedron of six

units each, and the outermost vertexial unit were removed from one octahedron and the innermost from its opposite, then none of the joins of the rhombicuboctahedron is disturbed and each square facial position is occupied by an identical assembly of five octahedra. This permits the rhombicuboctahedron to be joined face to face with an identical assembly so that the outermost vertexial subocta of one of the octahedra fits crystally into the position of the removed subocta on the opposed face of the other assembly and this produces an edgial join between the pair. The pair will be identically oriented.

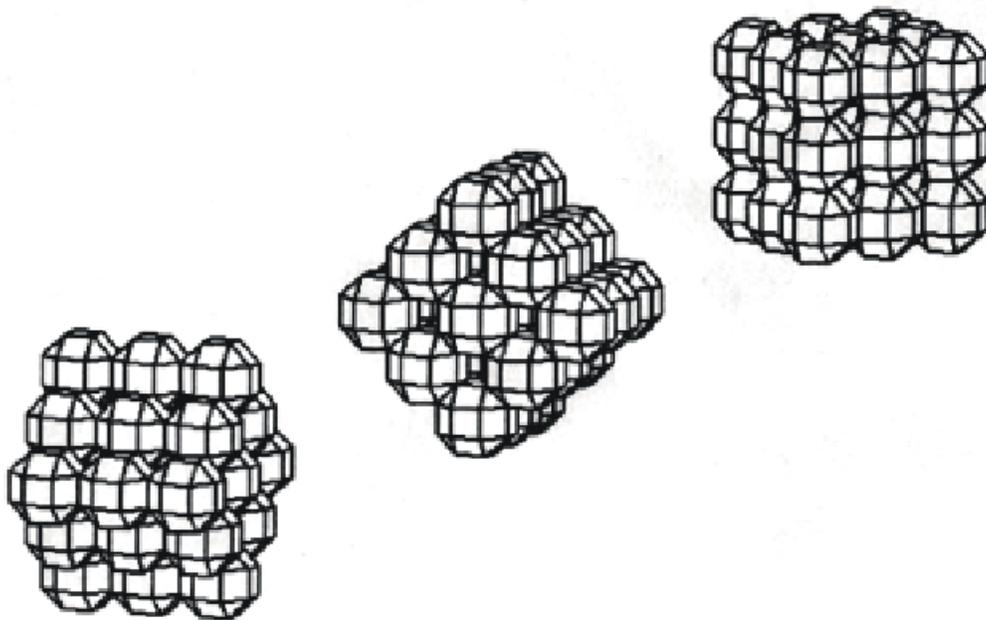
Ring of rhombicuboctahedra

Eight rhombicuboctahedra can assemble square face to square face to form an octagonal ring. Two of these rings can be stacked so that each unit of the first ring is joined to the unit of the ring above it by a square face. A ring of four rhombicuboctahedra can be made and place atop the joined rings and another below the joined rings. Together, these assembled rings form a larger compound rhombicuboctahedron. Each of the simple units occupies one of the twenty-four vertexes of the compound assembly. Twenty-four of these assemblies could be joined in similar fashion to produce a larger compound rhombicuboctahedron..



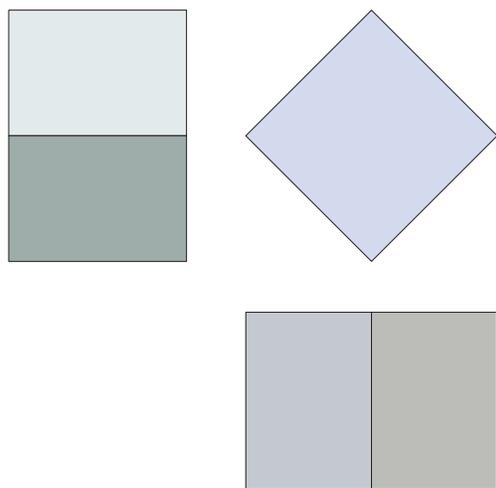
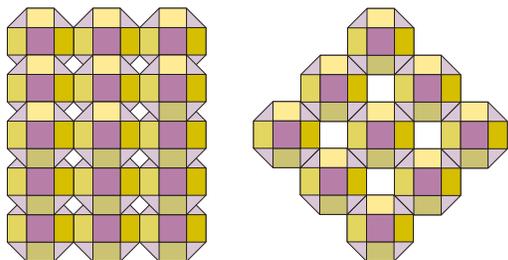
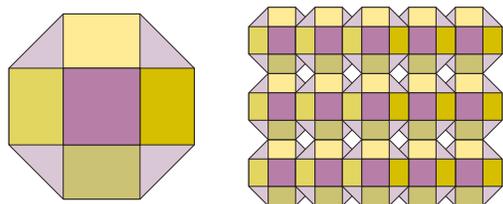
Cubes of rhombicuboctahedra

Each pair of opposed intersecting faces combine with four non-intersecting faces to define a cube. The effect of developing these cubes by joining rhombicuboctas only on the faces of one of the described cubes is seen in the next figure.



Three cubal assemblies of rhombicuboctahedra.

The figure shows three cubes of different orientation that are formed by rhombicuboctahedra each of which is identically oriented to each of those in each of the three cubes



Rhombicuboctahedral cubic assemblies.

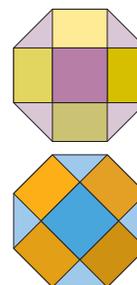
The rhombicuboctahedron depicted in the upper left is the unit which forms the three assemblies adjacent to it. Each is a cube whose faces are not parallel to the faces of the other two cubes. The shaded drawings at the bottom are projections of cubes which are in the same orientation as the assemblies above.

Each of the cubes is composed of identical subunits in identical orientation. But, the cubes produced are differently oriented. The three cubes are in the orientations required to produce the **quantum polyhedron**¹, in which the

three cubes have a common centroid. Although each of the three cubes can be rotated so that its join directions are parallel to those of either of the others, to produce the quantum polyhedron requires the use of the three sets of join directions. The quantum polyhedron is polycrystalline; each of the cubes is crystalline.

Pseudo-rhombicuboctahedron

If an octagonal array of square faces of the rhombicuboctahedron is taken as a reference, then the other square faces are in groups of five on either side of the equatorial faces. Each of these groups is a mirror image of the other. One group can be rotated 45° to the other and joined to the equatorial group in this new position. This figure is stable and the square face positions can be occupied by the same octahedral groups as for the rhombicuboctahedron. To join the units in the directions of the rotated faces will require a rotation between the units.



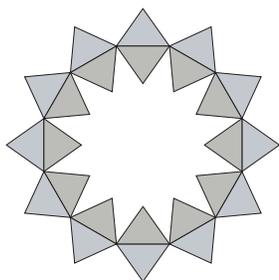
Pseudo-rhombicuboctahedron.

The upper drawing is the top view of the pseudo-rhombicuboctahedron. The lower drawing is the bottom view. The bottom face and the four faces to which it is joined are rotated one-eighth turn to the top face and the four faces to which it is joined.

1. *Scientific American* Feb 93 The Artist, the Physicist and the Waterfall p. 30

Twelvefold forms

A twelvefold assembly is possible if a regular dodecahedral ring can be formed using regular octahedra. Such a ring is depicted in the next figure. The two edges of each of the edg-

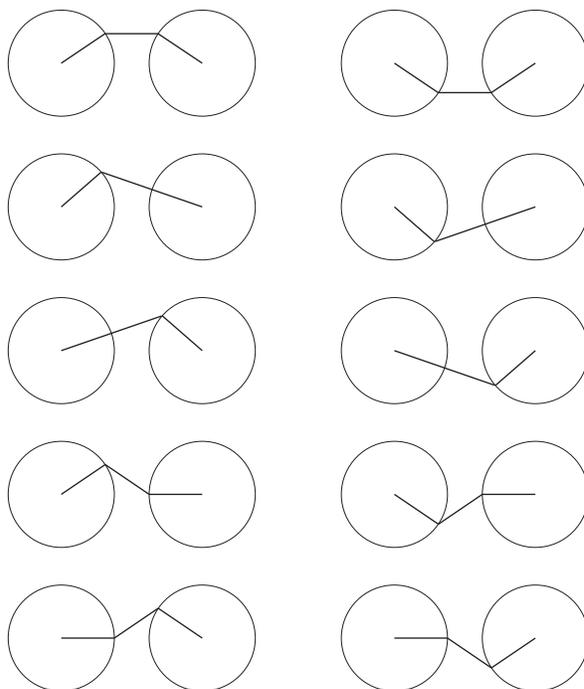


Dodecahedral ring of octahedra.

ially view octahedra which are shared by adjacent octahedra of the ring lie an edgial equator. The edges on this equator define a square. This ring must be angularly stabilized by additional octahedral units. Two adjacent panels which are in turn adjacent to stabilized panels will themselves be stabilized. In the next figure, the instability of three adjacent unstabilized panels is seen in the next figure. The three panels are represented by line segments. The line segments within the circles are attached to stabilized panels and that hinged joint is at the center of the circle. The other end of the panel must lie on the circle. The distance between the circles is fixed. The top left drawing shows the desired symmetry. The remaining drawings show the extremes of the dispositions that the three panels can assume within these constraints. The panels within the circles are limited to a rotation between the situations shown in the second and third rows respectively. In these positions the other two panels are colinear. The bottom two rows show the arrangement between the panels when one of the end panels is midway between its rotational limits.

Stabilizing rings

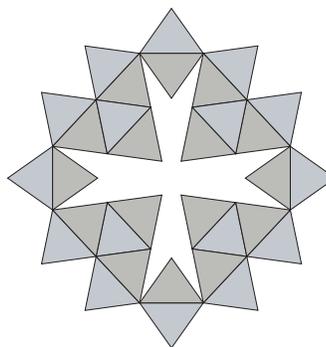
The stabilizing ring assemblies for the dodecahedral ring are of two kinds. These are



Disposition of three rotatable edges.

The edges within the circles rotate about the centers of the circles. These centers are fixed relative to one another.

fourfold and threefold. The fourfold is a dual ring which has a square panel for its hub that is

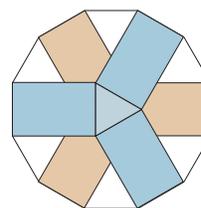


Stabilizer ring for dodecahedral ring.

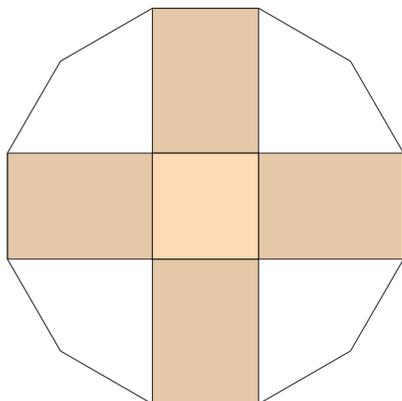
The leftmost and rightmost octahedra are members the dodecahedral ring.

an edgial equator of an octahedron. Each edge of this equator is joined to one of the octahedra of the dodecahedral ring by a rectangular

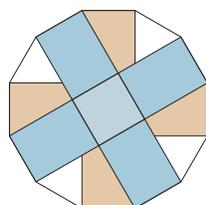
assembly of octahedra. In the next figure, one ring of the dual ring assembly is viewed parallel to its axis. The leftmost octahedron and the rightmost octahedron are on the dodecahedral ring. The octahedra at top and bottom lie on the axis of the dodecahedral ring. The next figure shows a view of the assembly normal to the dodecahedral ring which shows equators of its constituent assemblies.



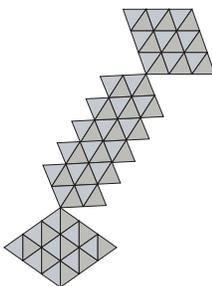
Tripod stabilized dodecahedral ring.



The fourfold stabilizer can be split in half and the halves rotated so that they stabilize different dodecahedral panels. This is shown in the next figure where each half has been colored to differentiate it.

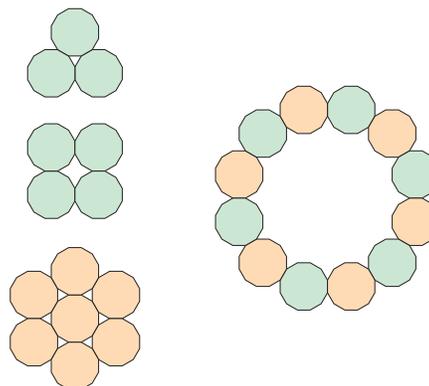


The threefold stabilizing assembly has a face of a regular octahedron for a hub. Its legs are rectangular and join to the dodecahedral ring in a manner which is similar to the fourfold stabilizing assembly. The two tripods are rotated one-sixth of a turn so that every other panel of the dodecahedral ring is stabilized.



Dodecahedral ring assemblies

The dodecahedral rings of identical assemblies can form planar twelfold assemblies. Each dodecahedral unit will lie one of the vertices of a regular dodecagon. This is seen at the bottom of the next figure where alternate assemblies have the same color.



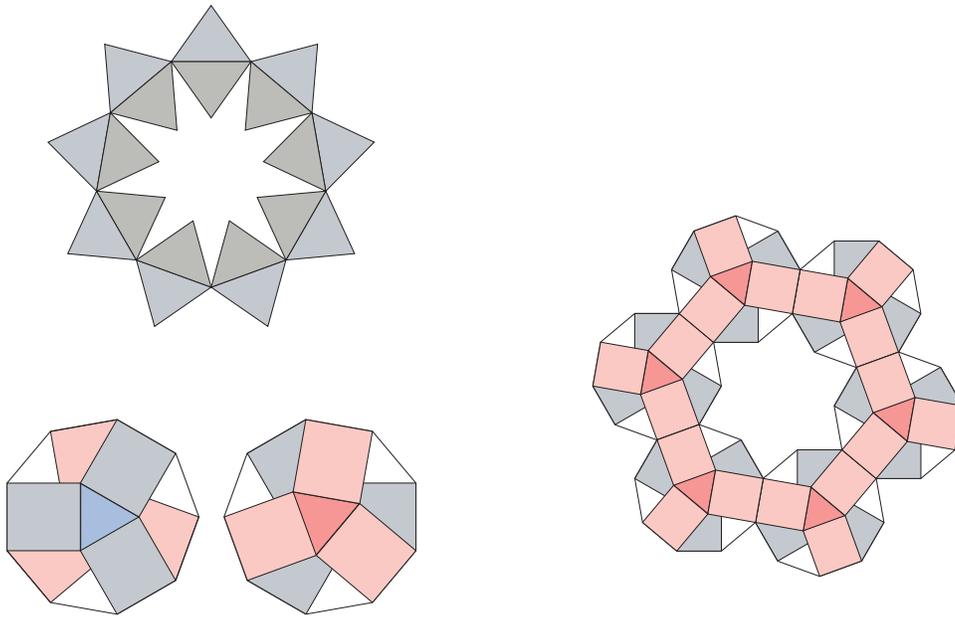
Dodecahedral ring assemblies.

In each of the assemblies the dodecahedral rings lie on the same plane. The joins are square face to square face.

Rings could be joined parallel to the axis of symmetry to form a cylinder.

The figure shows other facially joined dodecahedral rings of three, four, and seven units. The units are at the vertexes of an equilateral triangle, the vertexes of a square, and the vertexes of a regular hexagon. The drawings suggest that the dodecahedral ring assembly is capable of complex structures.

Eightenfold forms



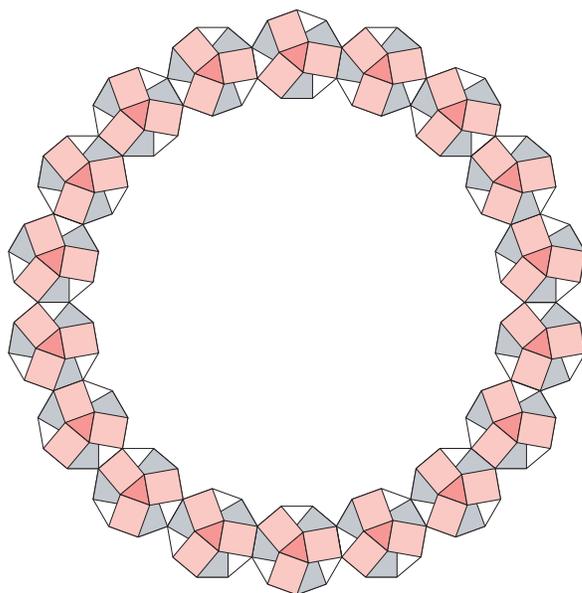
Nonahedral ring assembly

Regular octahedra can form a structurally stable unit consisting of a ring of nine edgially joined regular octahedra and a pair of stabilizing tripodal octahedral assemblies. The equators of the stablized ring project as a regular nonagon, and the square equators are the faces of a regular nonahedral ring.

Nonahedral ring assemblies

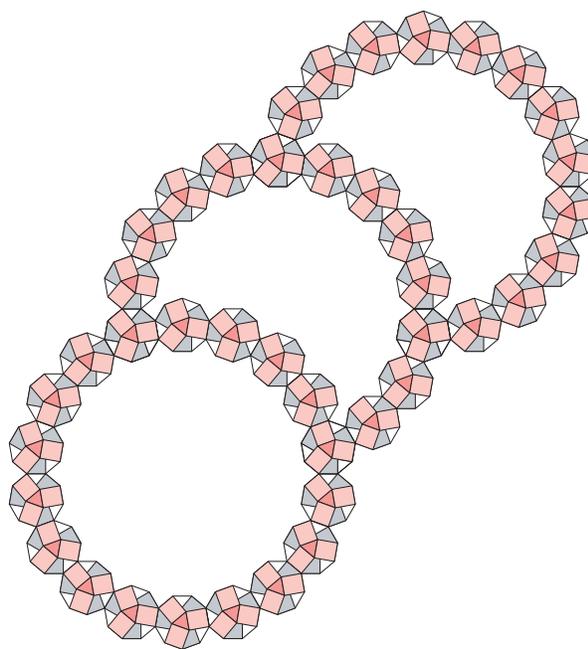
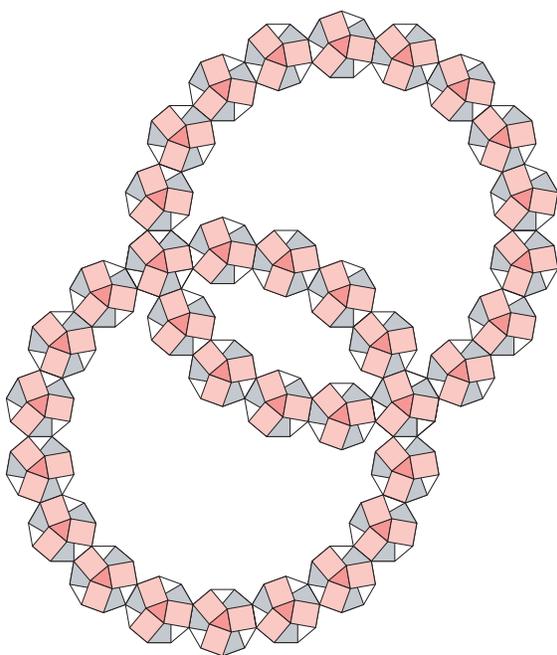
The nonahedral rings can assemble into a hexagonal ring where each nonahedral unit is at the vertex of a regular hexagon. The units are joined facially.

Tubulin



Tubulin

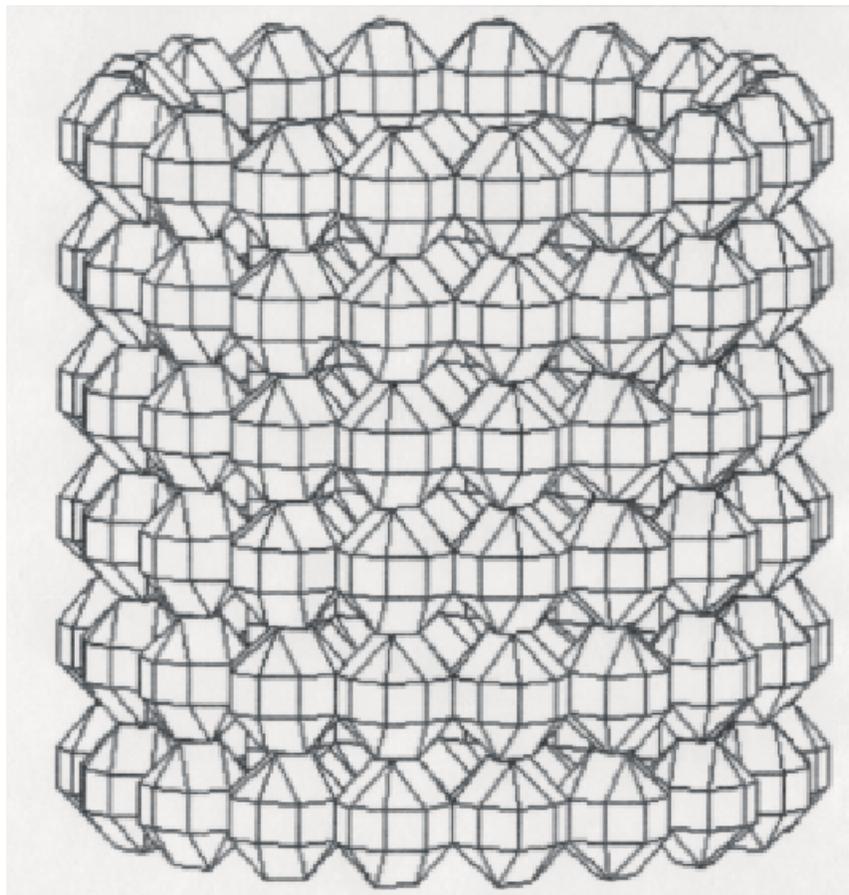
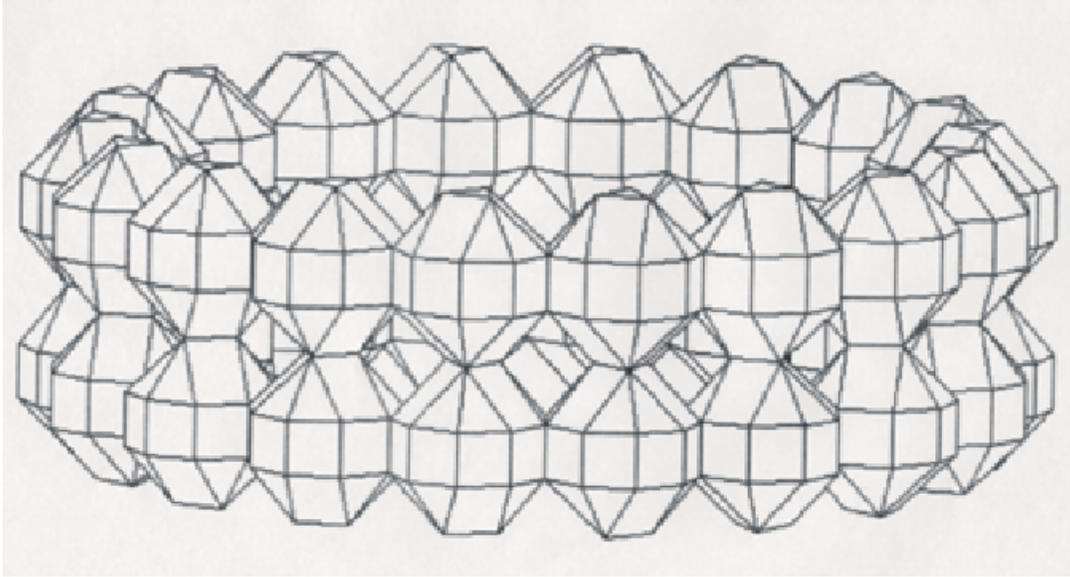
Another ring which they can form is composed of eighteen nonagonal units. This ring has the same symmetry as a ring shown in an article about the centromere and the nonagonal units permit the formation of interpenetrant rings. Two full rings are shown in the next figure which hold two units in common. In the next figure, one full ring has portions of another ring attached to it. This added portion has a portion of a ring attached to it.



Tubes of nonagonal rings.

The rings of eighteen nonagonal units can be structurally connected parallel to their axis of symmetry to form tubes. The triangular faces of the units are the join surfaces. In tubulin, the individual units will be complex associations of proteins. But, the underlying order will be

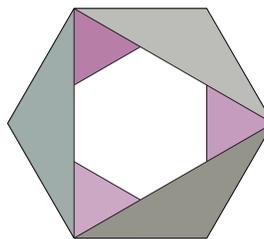
as octahedral regions in the same orientation as the simple units depicted here. In the figure with two rings stacked one above the other, the view is nearly normal to the stack axis. In the next figure there are six rings in the stack. The view is, again, nearly perpendicular to the stack axis.



Quasicrystalline rings

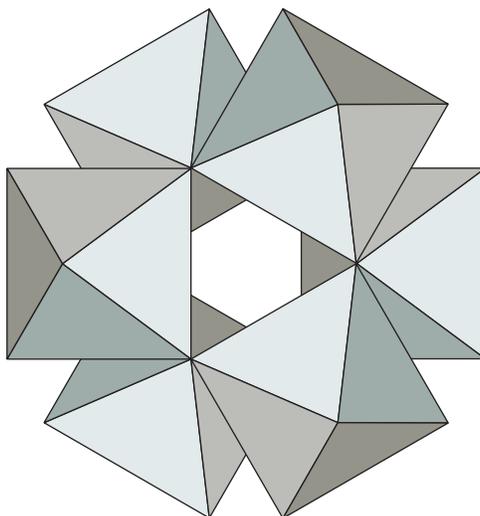
Double threefold ring

A structurally stable double threefold ring can be created using six regular octahedral panels which supply the equatorial faces of a regular octahedron. The remaining two faces of the octahedron could be closed by additional octahedral panels. The octahedra of each panel have the same orientation. Panels which are diametrically opposite have octahedra in the same orientation. There are three sets of diametrically opposite panels for the open ended assembly, and there are four sets of diametrically opposite panels for the eight panel assembly.



Double threefold ring.

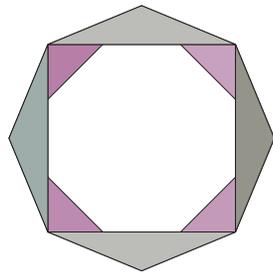
The six equilateral triangular faces are arranged as the equatorial faces of the regular octahedron.



Double threefold ring of octahedra.

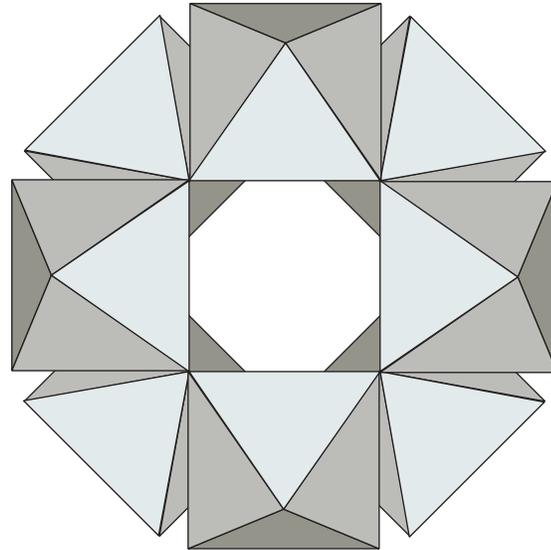
Each of the six octahedra acts as facial panel to produce a stable structure.

Double fourfold ring



Double fourfold ring.

The eight faces are equilateral triangles.



Double fourfold ring of octahedra.

Each of the eight octahedra acts as a facial panel to produce a stable structure.

A structurally stable double fourfold ring can be formed of eight regular octahedral panels. Each of the faces is an equilateral triangle. The octahedra of each panel are in the same orientation. The orientation of the octahedra in each panel is unique to that panel. No two panels have octahedra in the same orientation.

The open faces of the assembly are squares. These could be closed with panels composed of identical octahedra, but the inner vertex of the panel assembly would have to be truncated so that the opposed panels do not obstruct one

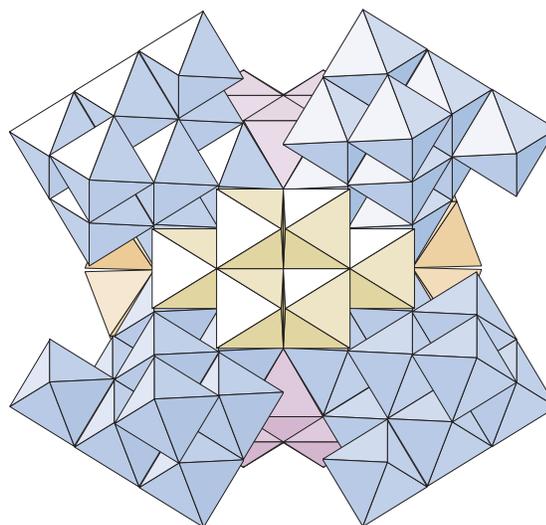
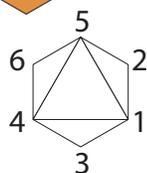
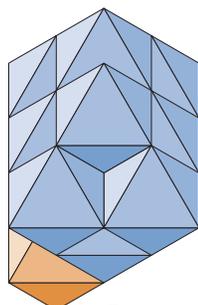
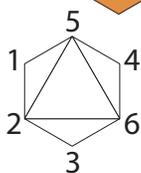
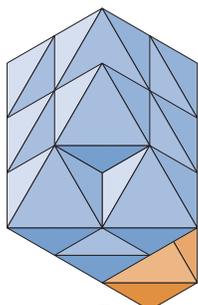
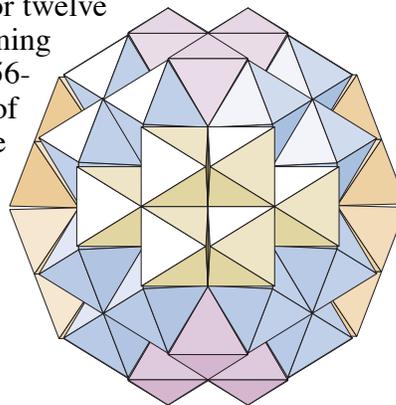
another.

Assemblies of double fourfold rings.

The octahedral panels of a double fourfold ring which is rotated 45° about the axis of symmetry will be oriented so that it can be joined to an unrotated ring. Each of the octahedral panels of the original ring has a counterpart in the rotated ring which is in the same orientation and which is capable of forming a join with it. The panels are at opposite ends of the same diameter.

Ti_8C_{12} icosahedral array

The regular icosahedron has thirty edges each of which lies on a diameter which bisects it and to which it is perpendicular. Three such diameters can be selected which are mutually perpendicular. The three axes have two edges each for six edges. The two faces which define these edges are each contributed by the 123-face of a C-atom. There are six edges times two faces per edge for twelve faces each of which is a C-atom. The remaining eight faces are each supplied by either the 256-face or the 145-face of a Ti-atom. The length of the edge of the icosahedron is twice the edge length of the He-octa. This icosahedral edge length is one half that of the icosahedron which can be built of twenty C_3 units. The latter may be the C_{60} -fullerene.



Ti-atoms with join faces topmost

The Ti-atom has two faces which have the same form as the 623-face of the C-atom—the 526-face and the 541-face. The Ti-atoms depicted above have these faces uppermost. These faces act as panels for the Ti_8C_{12} icosahedron. The Ti-octa of each atom is colored orange here.

Edgial view of Ti_8C_{12} icosahedral array

At the top of the figure is a C_{12} icosahedron viewed edgially. In the figure below it, the blue colored C-atoms have been replaced with blue colored Ti-atoms. An equivalent replacement of four C-atoms on the far side of the assembly produces the Ti_8C_{12} icosahedron.

JOIN

Atomic joins

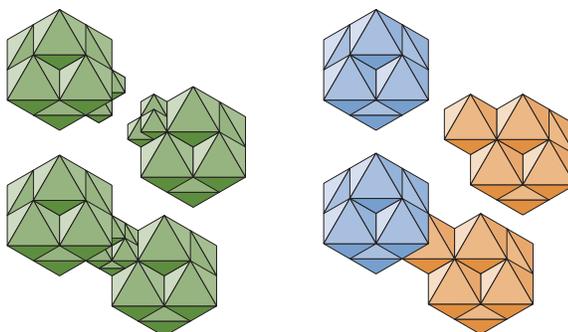
The crystalline atom is a structural association of identical octahedra identically oriented in precise positions. If the positions are changed or the parts removed it is no longer the same element. The parts and their relative positions determine how an element may join with another element to produce a group. The identity of the element is maintained in any molecular association. It gives up nothing; it gains nothing. It is in no way transformed. The concept of the ion is not applicable as a transformation of the crystalline atom. The concept of electron pairing is analogous to triplet pair-

ing. Shell completion is analogous to layer completion.

Atoms join so that each of the open edges which is paired by their contact is congruent with another to which it is polarly attracted.

Triplet pairing by atoms with odd atomic numbers

Odd numbered elements can join so that the single unpaired triplet of one is paired with that of the other so as to form a He-octahedron. For modeling purposes, a pair of Al-atoms can be shown using a Mg-atom and a Si-atom. The Si-octa of the Si-atom being shared by the two Mg portions of the paired Al-atoms. This type of join has been termed an "ionic bond".



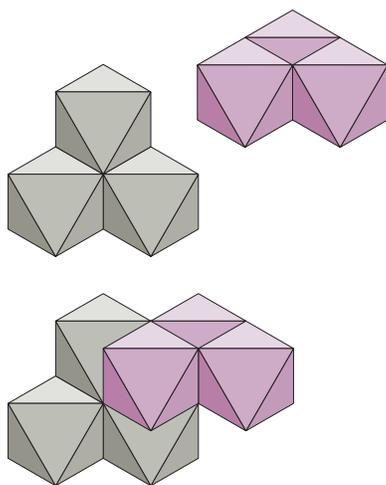
Triplet pairing join of Al-atoms.

On the upper left is shown two Al-atoms oriented for triplet pairing with the completed join below. On the upper right a Mg-atom is depicted with a Si-atom and the join between them is shown below. This SiMg group has the same conformation as the Al₂ group.

The Al₂ group could be described as one Al-atom giving up an electron to the other leaving one as a Mg-atom and the other as a Si-atom. No such transfer occurs.

Cleft pairing by atoms

Some of the elements have clefts. Clefts provide attachment locations. The atoms join so that a pair of He-octas of each forms a tetrahedral array. Each of the four He-octas provides a face enclosing a regular tetrahedral void. A pair of C-atoms joined in this way will each have a He-octa location occupied by a He-octa of the other. The join is specified as a C-Ne-join which means that the C-octa of one occupies the Ne-location of the other.

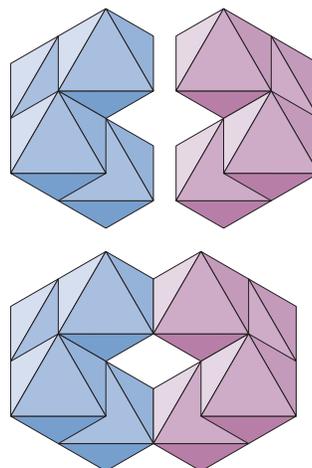


Cleft join of two C-atoms.

A pair of C-atoms is shown at the top. The atoms are shown cleftly joined at the bottom. A He-octa of each of the atoms occupies a position of the other atom that a He-octa would occupy in the formation of a higher numbered atomic element. The three positions for a C-atom are the O-void, the Ne-void, and the Mg-void.

Simple edge to edge

Atoms can join by simple edge pairing. Two O-atoms can form an O_2 group where the epn edges of the He-octa or O-octa of one atom are paired with the He-octa or O-octa of the other atom.

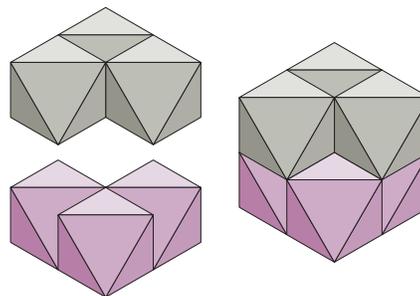


Edge pairing of two O-atoms.

Two O-atoms are shown at the top. The O-atoms join so that each has two He-octas joined edge-to-edge with two He-octas of the other. The result is an O_2 group.

Face to face

Two C-atoms can produce a Mg-atom form when joined like the epn triplet pairs in a He-atom.



Face-to-face join of two C-atoms.

Two C-atoms at the left join face-to-face to form a C_2 group which is the same shape as a Mg-atom.

Molecular arrangements

The crystalline atom imposes restrictions

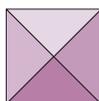
Crystals

Crystals formed from crystalline atoms require that there be only one orientation for the each epn of each of the atoms of each of the groups of each of the units which form the crystal.

Helixes

The helix requires a rotation between units. Thus, the rotation must be such that the rotation of the unit leaves the epns of the two units in the same orientation. This can happen only if the rotation matches the symmetry of the epn about an axis parallel to the helical axis.

A vertexial diameter of the epn is an axis of fourfold symmetry. It provides for 1/4 revolution and 1/2 revolution helical joins.



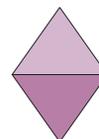
View parallel to vertexial diameter

A facial diameter of the epn is an axis of double threefold symmetry. It provides for 1/3 revolution helical joins.



View parallel to facial diameter.

An edgial diameter is an axis of twofold symmetry and provides for 1/2 revolution helical joins.



View parallel to edgial diameter.

Modeling tests the atomic forms

The atoms produced by the regular association of identical regular octahedral particles provide a periodicity of form which matches the periodicity of the elements. The forms of the atoms can be tested by fitting them together structurally in crystalline order to produce geometrically defined groups.

- Chains and angular relationships between portions of the same chain, as in the lipids, are useful in this regard.
- Associations between chains, as in the pleated sheets of proteins further test the validity.
- Rings of atoms or groups are especially useful, because the closure is an additional restraint. Rings are essentially a single chain. The carbon ring and the cyclic peptides are examples.
- Helixes, like rings, require a type of closure through rotation with a translation.
- The production of handedness in the peptides and in the helixes of the mineral crystals also try the atomic shapes.

Facially joined octahedra

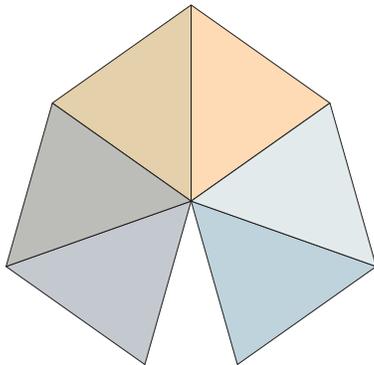
Three octahedra sharing a single edge

Three regular octahedra can be joined facially so as to share a common edge. The angular sinus is $2 \times \text{asin} \sqrt{2/27}$, which is approximately equal to $31^{\circ}35'11''$. This is calculated from the octahedral geometry as follows.

Let θ be one half of the sinus angle, s be the length of the octahedral edge, and x be half the distance between the octahedral vertexes at the mouth of the sinus. Then,

$$\theta = \frac{1}{2} \times (360 - 3 \times (180 - \text{atan} \sqrt{8})) = \text{asin} \sqrt{\frac{2}{27}}$$

$$x = s \times \frac{\sqrt{3}}{2} \times \sin \theta = s \times \sqrt{\frac{1}{18}}$$



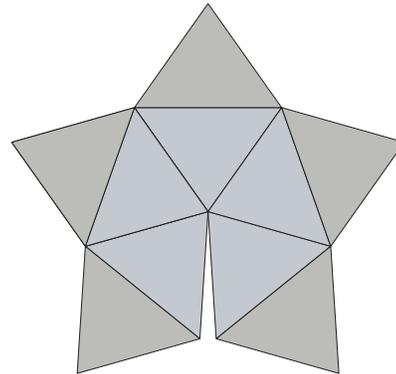
Three facially joined octahedra sharing a common edge.

Five octahedra sharing a single vertex

Five regular octahedra can be joined facially so as to share a common vertex. The angular sinus is $2 \times \text{asin} \sqrt{1/243}$, which is approximately equal to $7^{\circ}21'22''$. This is calculated from the octahedral geometry as follows.

Let θ be one half of the sinus angle, s be the length of the octahedral edge, and x be half the distance between the octahedral edges at the mouth of the sinus.

$$\theta = \frac{1}{2} \times (360 - 5 \times \text{atan} \sqrt{8}) = \text{asin} \sqrt{\frac{1}{243}}$$



Five facially joined octahedra sharing a common vertex.¹

1. N. Pangarov,, Twinned Crystals in electrical crystallization of silver, Figs. 28a and 28b, **Growth of Crystals**, vol. 10, N. N. Sheftal, editor, translated by J. H. S. Bradley, U. of London, Consultants Bureau, London.

ATOMIC GROUPS

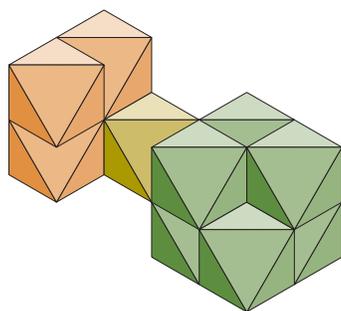
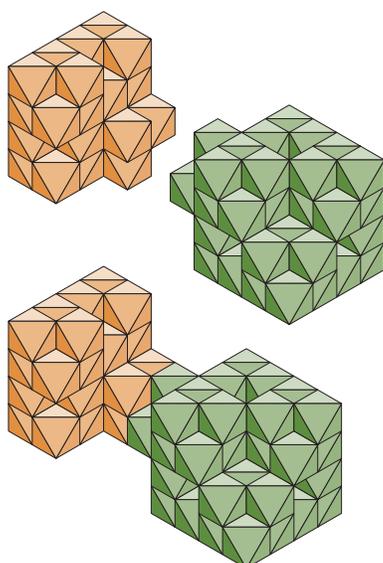
Introduction

The groups are ordered according to the Atomic Symbol of the lead element of the formula.

Al

AlN group

The AlN group results from the pairing of the N-triplet and the Al-triplet. The pair occu-

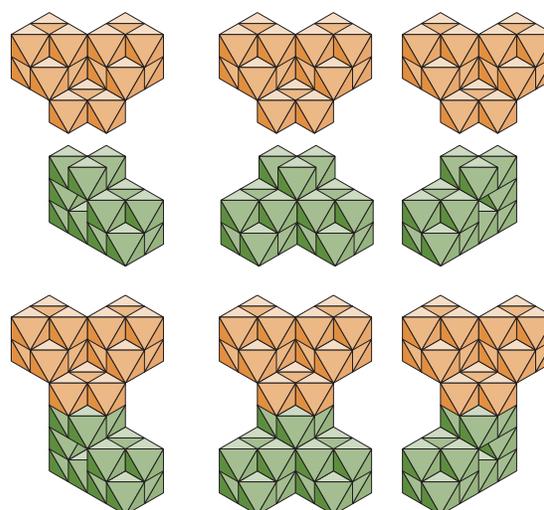


pies the O-octa space of the N-atom and the Si-octa of the Al-atom. Because of the threefold symmetry of the Al-atom about the join direction, the join produces just one configuration.

B

B₂ group

Two B-atoms can triplet-join in the three ways shown in the figure. The central column depicts a *planar* join in which the He-octas of the two B-atoms all lie on the same plane. The columns to either side of the central column depict a join in which the He-octas of the two B-atoms do not all lie on the same plane. In each column, the B-atoms are at the top and the completed assembly are at the bottom.



Three types of B₂ groups

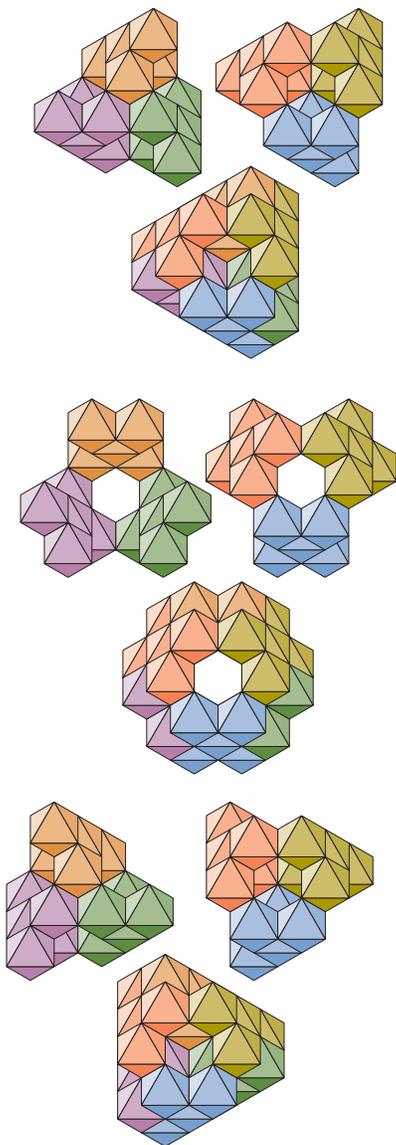
6B₂ group

Crystals of boron have been described as being composed of icosahedrally arrayed boron atoms, with the twelve atoms at the vertexes of the icosahedron. In light of the octahedral nature of the atom, a different structure is required.

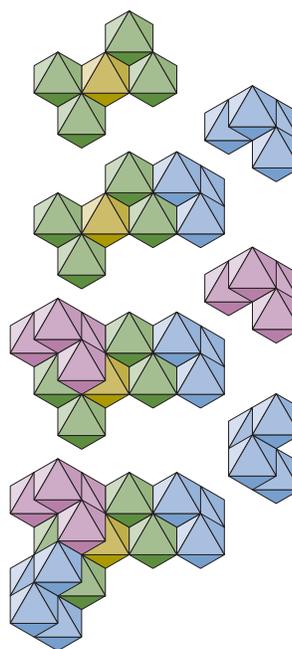
The first requirement of building structural units for the odd atomic numbered elements is the pairing of the triplet. As seen in the previous section, there are three possibilities of pairing two boron atoms. Six identical pairs fit

In the next figure, the bottom three B_2 units are depicted in the same relationship as they have in the $6B_2$ assembly. The top units are depicted in the same way. The assembly is then shown beneath these two insets.

B_2O_3 group

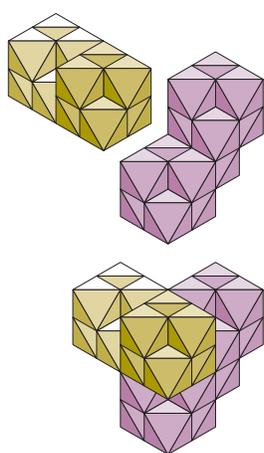


$6B_2$ assemblies

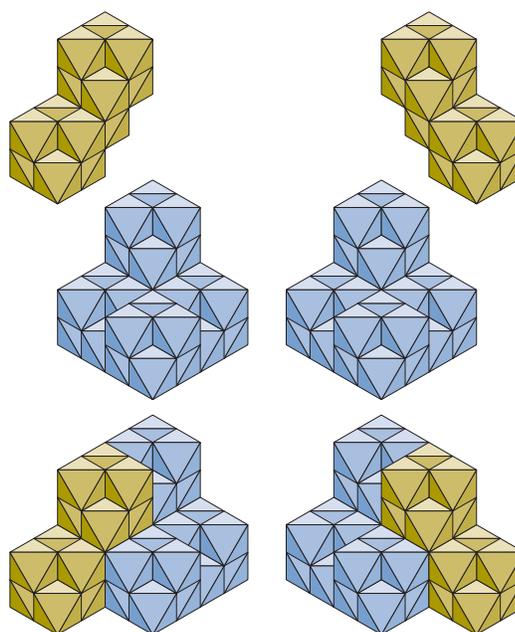


B_2O_3 group

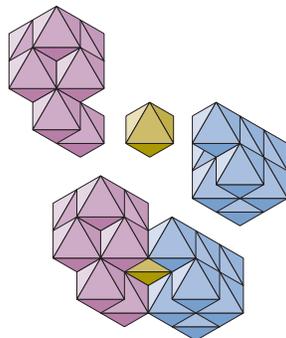
together so that the pairs are interlocking. If the B_2 groups are as the middle one in the previous figure, the $6B_2$ assembly has sixfold symmetry. The other B_2 groups produce assemblies which have threefold symmetry.

Be**Be₂ group.**

Two Be-atoms are in the top row in the orientations required cleftly join. The assembly has four He-octas in a tetrahedral array.

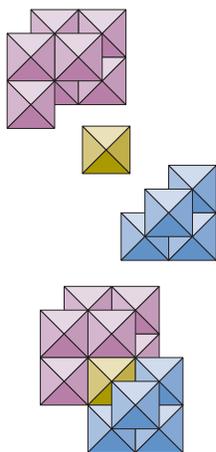
**BeO group**

Cl



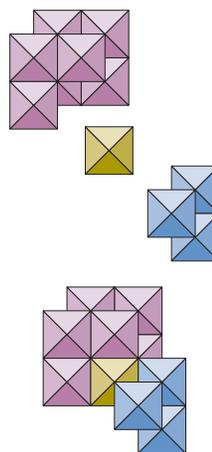
Cl₂ group

Two Cl-atoms can pair their triplets in only one way. It is depicted in the next figure. The group has a He-octa socket like the O₂ group. There are two clefts, one si-ne cleft in each of the Cl-atoms.



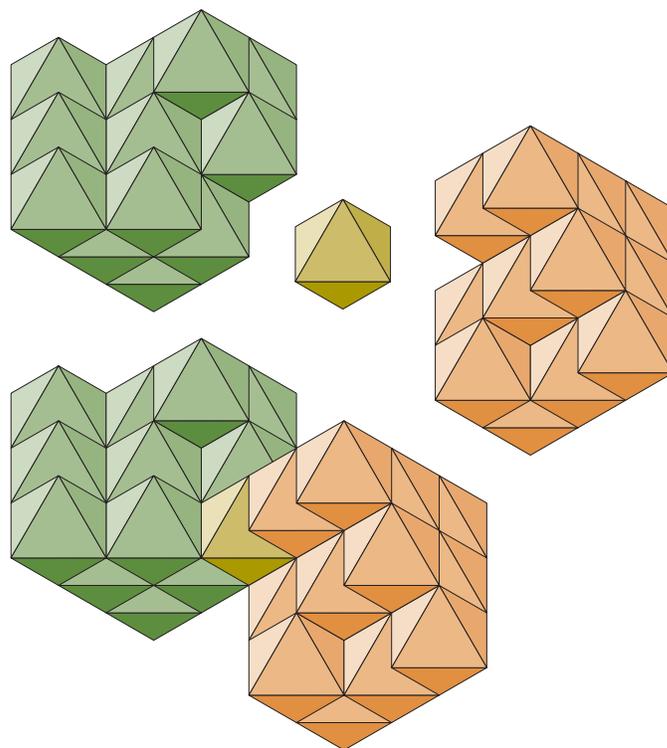
ClH₂O group

A Cl-atom triplet paired an H₂O-group



ClN group.

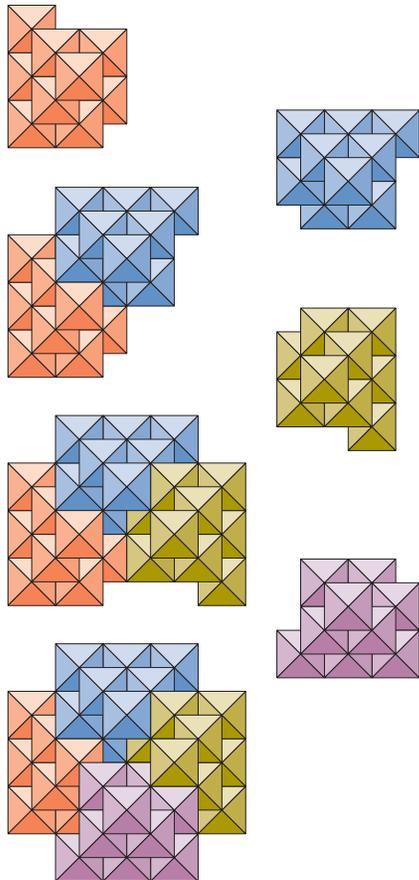
A Cl-atom triplet paired with an N-atom

Cu**Cu₂ group**

The pair of Cu-atoms combine by triplet joining and have the form of a Ni-atom and a Zn-atom which share the Zn-octa and which are so joined that the Ni 65-edge corresponds to the Zn 43-edge.

Fe

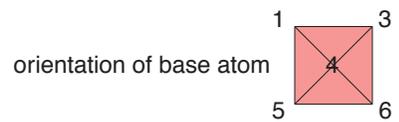
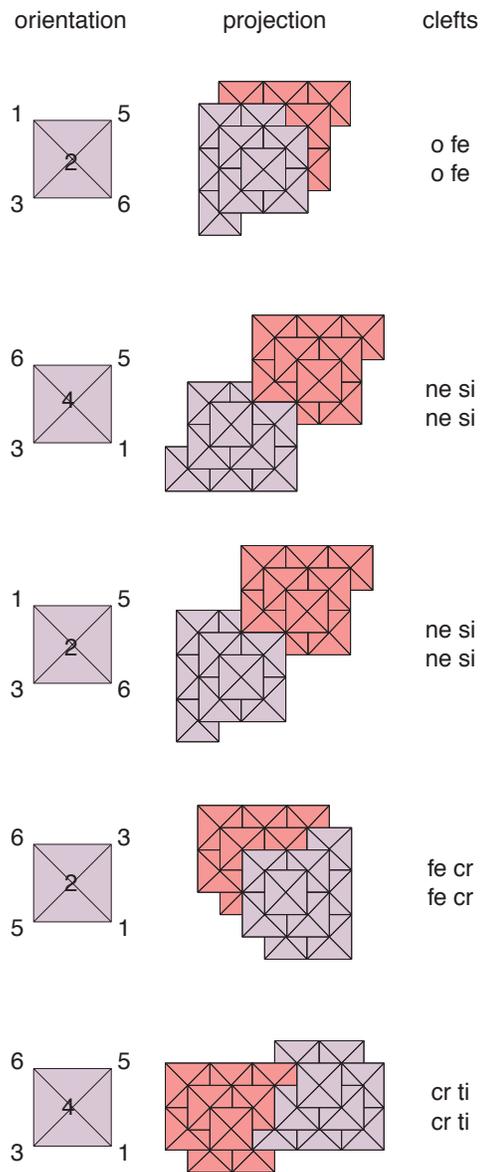
Fe helix



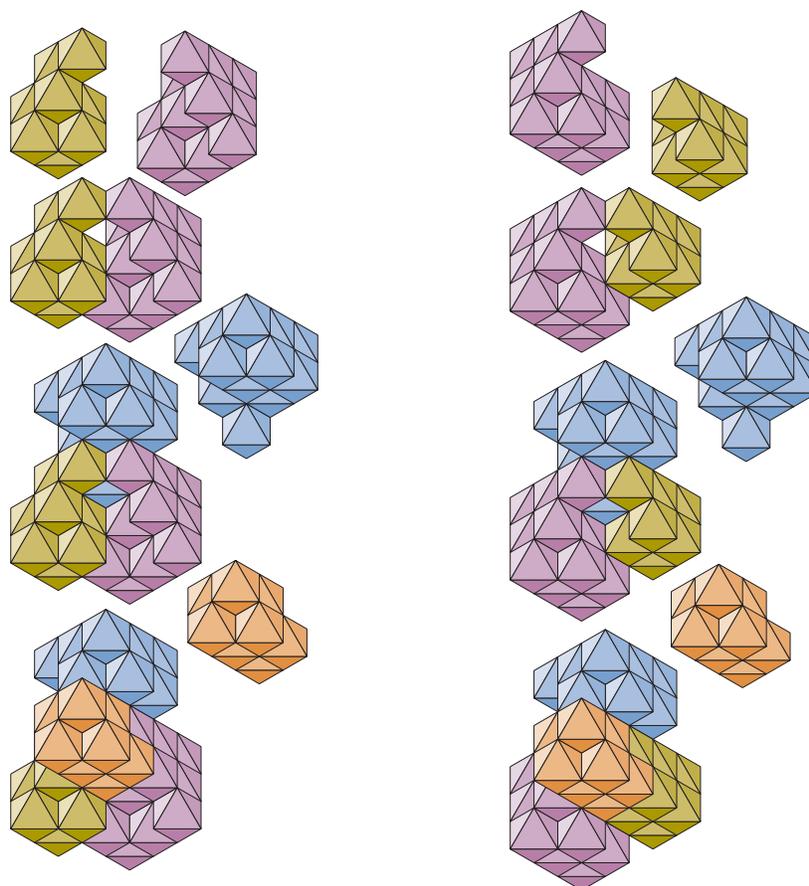
Fe helix

The helix uses lone Fe-atoms, 1/4 turn per atom. The join is Fe43fe-Fe41zn.

Fe₂ groups



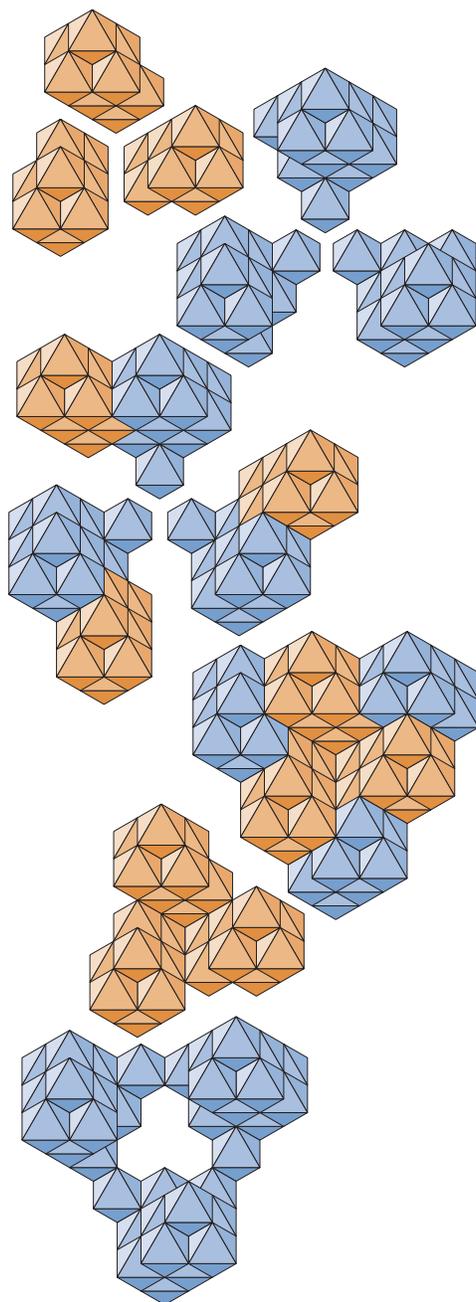
Fe₂ groups

FeS groups**Two 2FeS rings**

Two S-atoms and two Fe-atoms can form a ring which is similar to a ring formed by four S-atoms. There are two possible joinings which create two different rings. In the first ring which is shown in the figure on the left, the cleft join between S-atoms is BeS-BeS and between Fe-atoms the join pairs OFe-clefts.

To show the ring structure, the S-atom and the Fe atom at the top of the figure are juxtaposed in the positions they occupy in the assembly. The second Fe-atom is then inserted between them and is cleftly joined to each. The second sulphur atom completes the ring. The S-octa of each of the S-atoms and the Fe-octa of each of the Fe-atoms form a tetrahedral group.

The second ring which is shown on the right is similar to the first. The S-atoms here are joined by their SiS-clefts; the Fe-atoms are joined by their CFe-clefts. The assembly proceeds in the same manner as the previous ring.

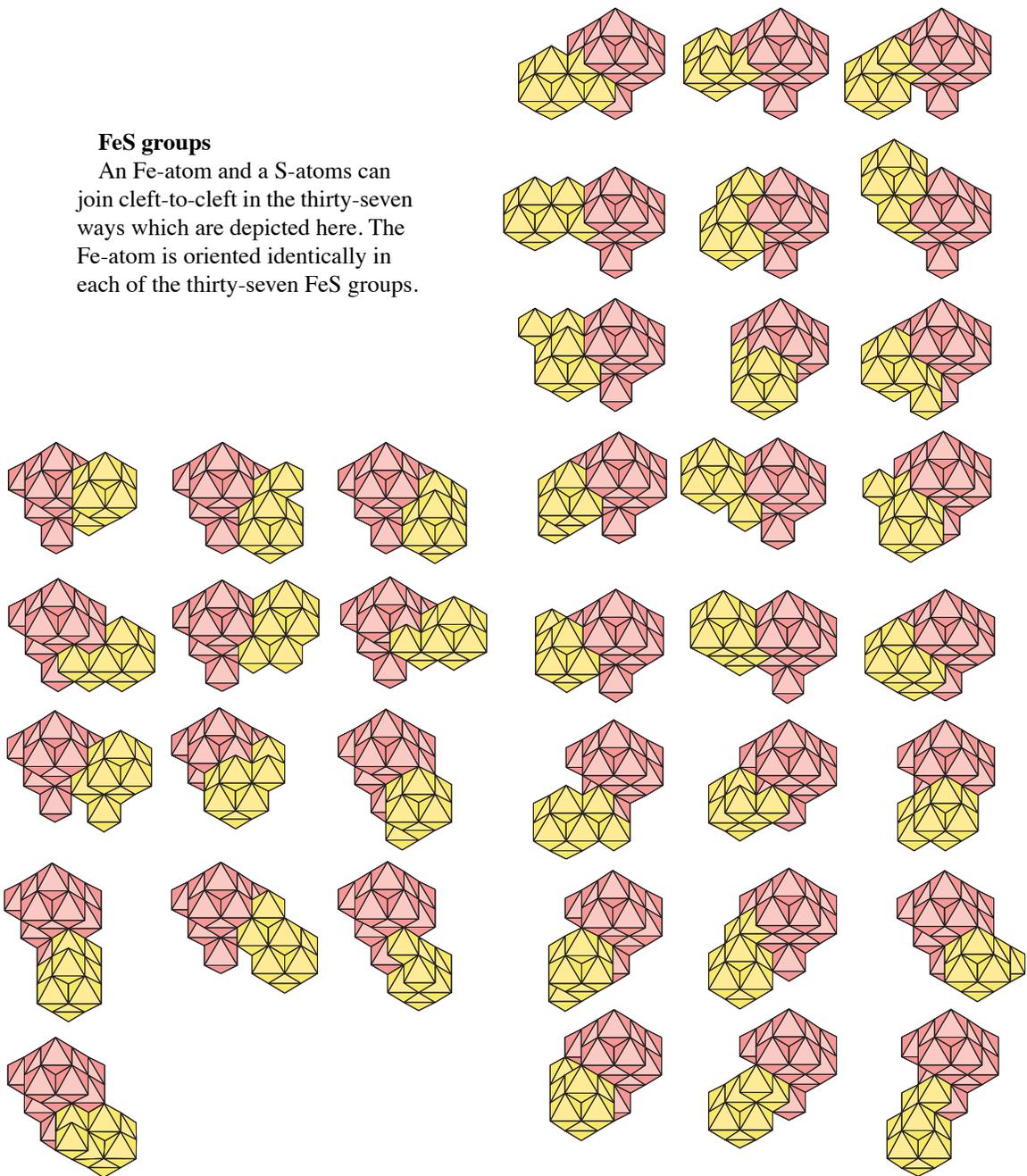


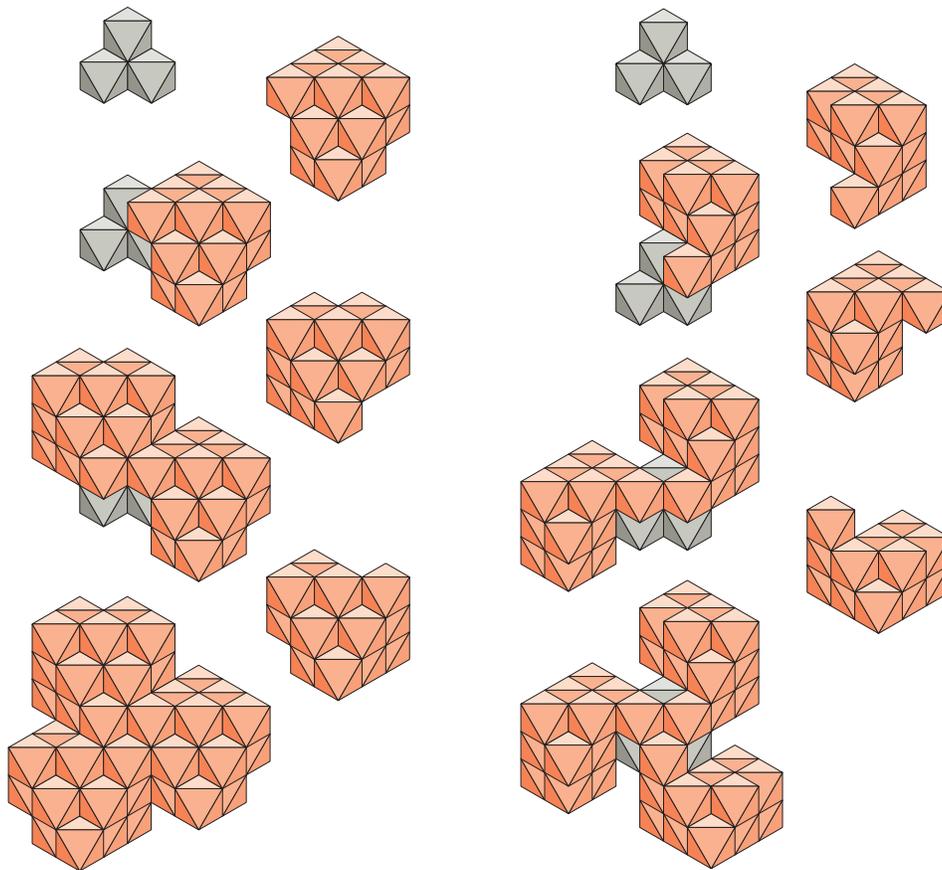
3FeS ring

The figure depicts the assembly of a ring of threefold symmetry composed of three FeS groups. The three S-atoms are colored orange and are depicted in a group at the top of the figure. Just below the group is a group of Fe-atoms colored blue. The FeS groups are shown next followed by the completed assembly. The last two depictions are of the S-atoms as they are in the assembly and the Fe-atoms similarly.

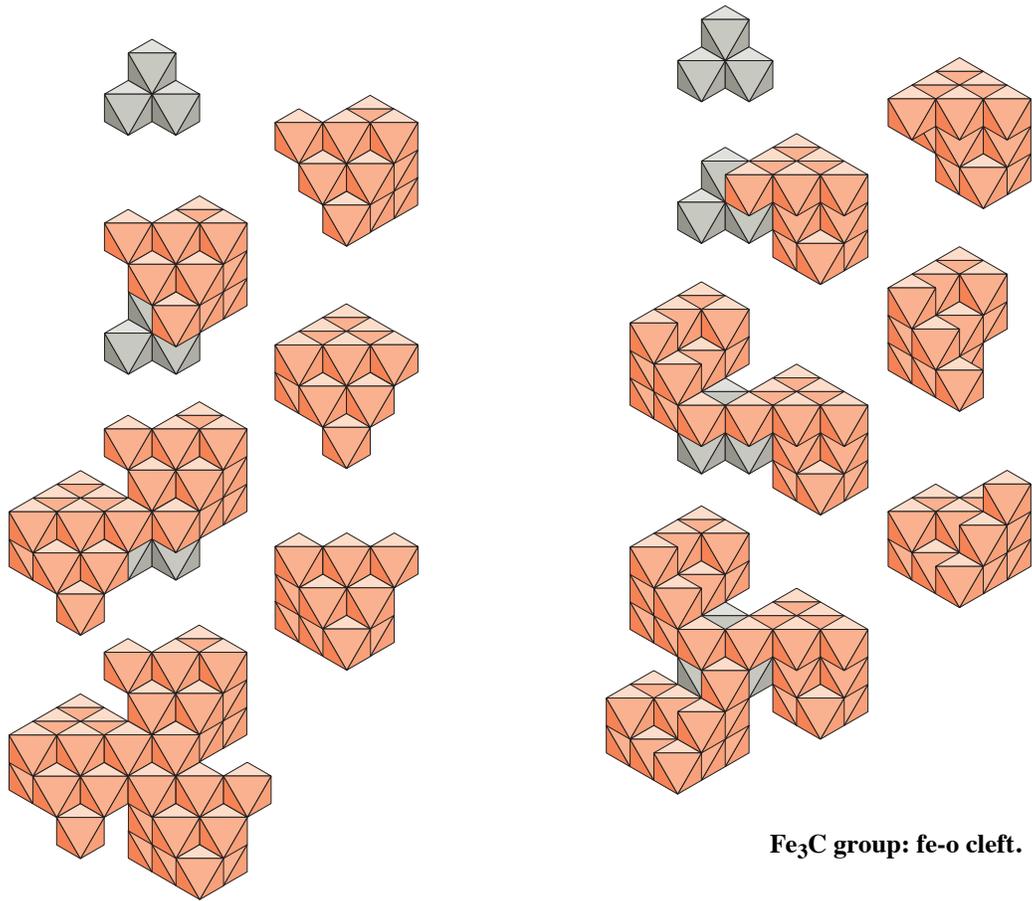
FeS groups

An Fe-atom and a S-atoms can join cleft-to-cleft in the thirty-seven ways which are depicted here. The Fe-atom is oriented identically in each of the thirty-seven FeS groups.

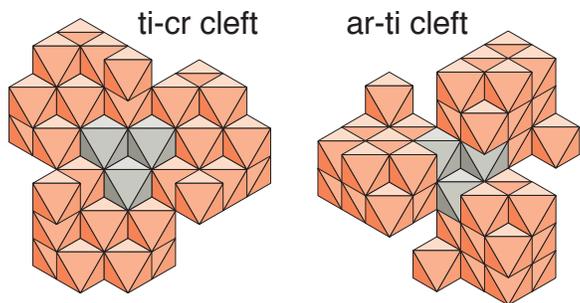
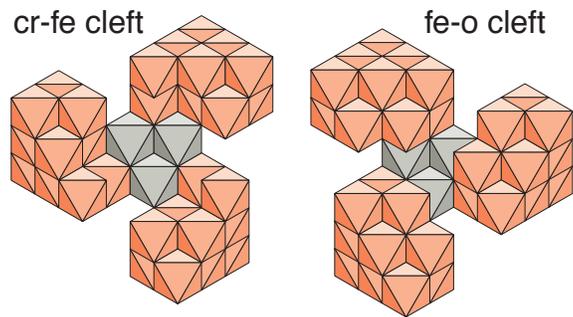


Fe₃C groups**Fe₃C group: ti-cr cleft.****Fe₃C group: cr-fe cleft.****Four Fe₃C groups**

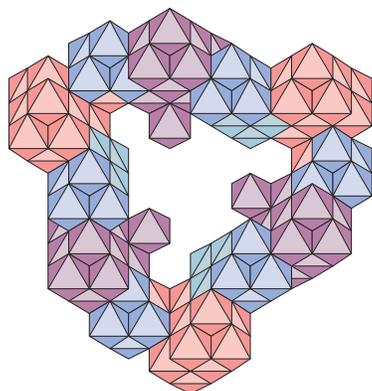
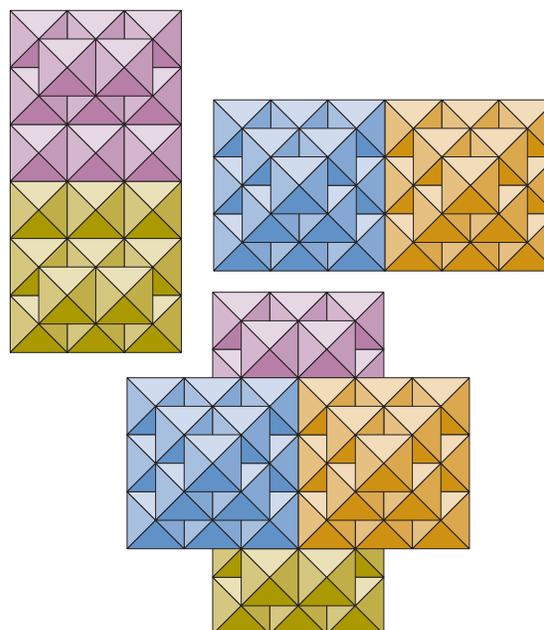
Three Fe-atoms can cleftly join to a C-atom so that each of the Fe-atoms is rotated 120° with respect to each of the other Fe-atoms. This group occurs in cementite. Four threefold assemblies of Fe₃C groups are depicted in two panels. The second panel shows the four assemblies obversely.



Fe₃C group: ar-ne cleft.



Fe₃C groups, obverse views.

3Fe₂O₃ ring**3Fe₂O₃ ring****Assembly of Ge₄ ring****Ge****Ge₄ ring**

Four Ge-atoms can form a ring in which each of the Ge-atoms is doubly cleftly joined to each of two other Ge-atoms of the ring. In the left column of the figure, the stages of the assembly of the Ge₄ ring are shown. The adding Ge-atoms are shown in the column on the right of the figure.

Ge₄ tetrahedron

Four Ge-atoms can join so that each of the atoms provides a face of a regular tetrahedron. This grouping is similar to the C₄ tetrahedron which is the cfu of diamond. Two Ge₄ tetrahedra cannot make the facial join that produces the diamond crystal. The figure shows two Ge₄ tetrahedra in the right column. The pairs of Ge-atoms on the left join to form the tetrahedra. The joining possibilities of the lower tetrahedron are higher those of the upper tetrahedron.

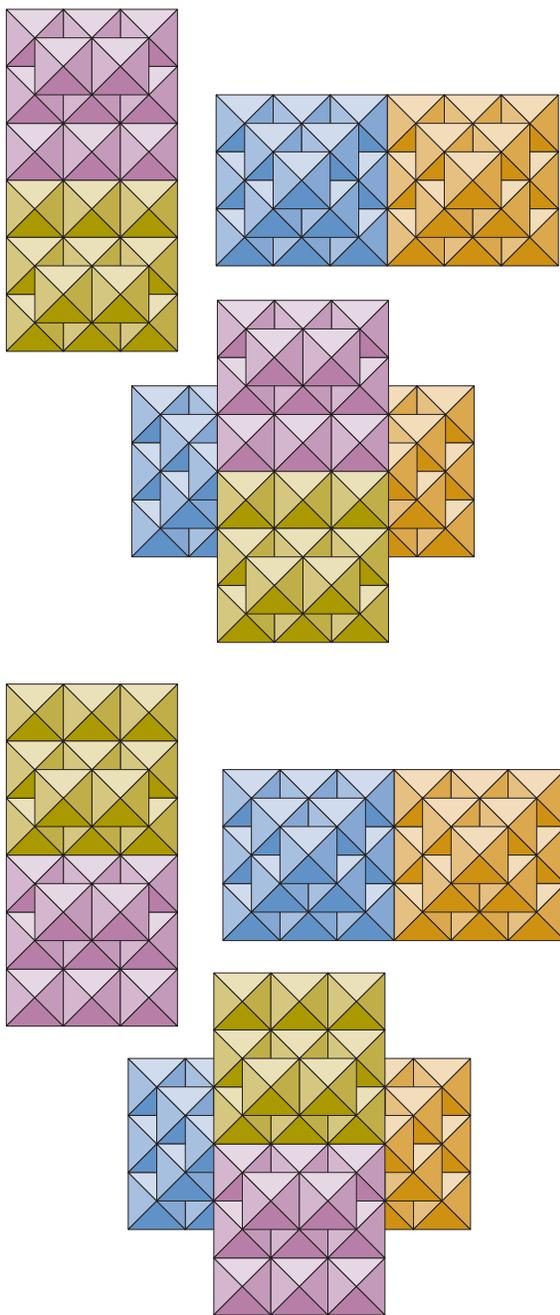
Joining Ge₄ tetrahedra

The next figure shows the assembly of four Ge₄ tetrahedra to form a symmetrical assembly. Each tetrahedron is doubly cleftly joined to two of the other tetrahedra in the assembly. The assembly shows that the tetrahedra can join to form a crystalline assembly.

The second depiction from the top is of two tetrahedral assemblies which are not structurally joined. The addition of the third tetrahedral assembly makes a structural join with each of first two tetrahedra. The fourth makes a structural join with the first two tetrahedra as well.

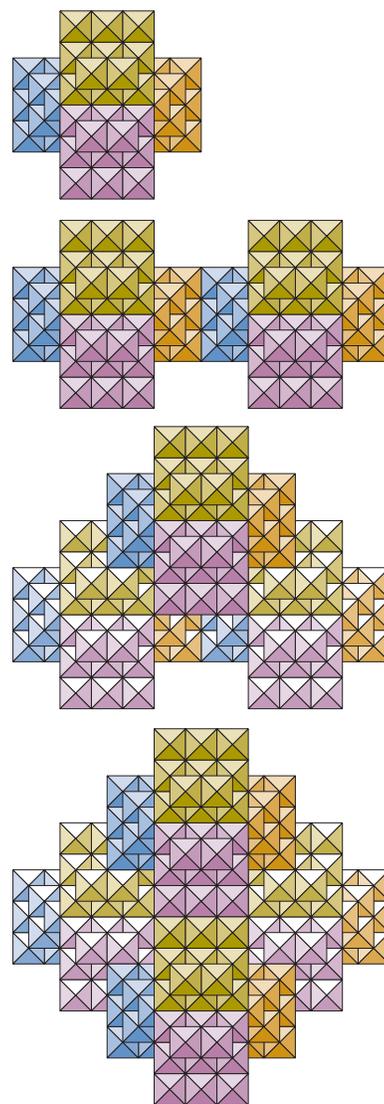
Crystal of Ge₄ tetrahedra

A crystal in which the Ge₄ tetrahedra are joined throughout by double cleft joins pro-



Assembly of two Ge_4 tetrahedra.

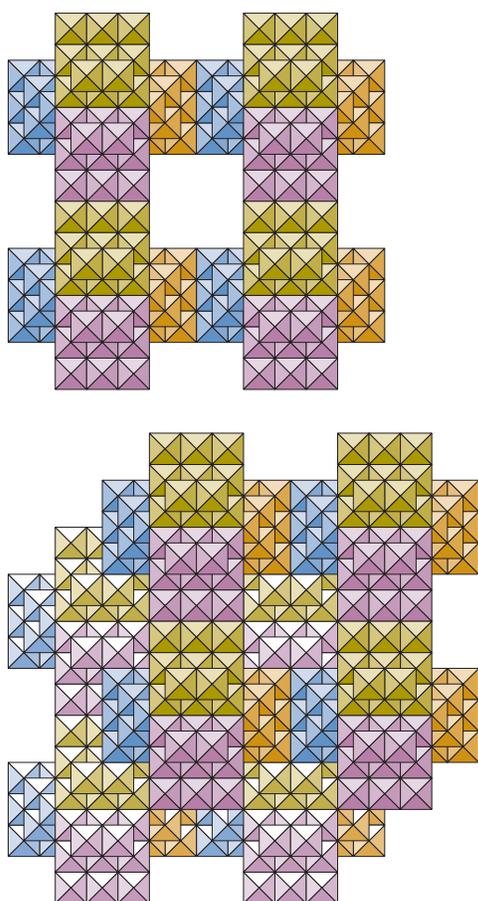
duces layers of tetrahedra in which each of the tetrahedra projects within a square of a check-



Joining of Ge_4 tetrahedra

erboard. This is seen in the next figure which shows just four of the tetrahedra. This pattern is extensible throughout the plane.

The next figure shows the relationship of two identical adjoining planes of tetrahedra. These two planes are offset from one another so that



Planar array of Ge₄ tetrahedra.

the centroids of the tetrahedra of one plane are midway between the centroids of diagonally adjacent tetrahedra of the other plane.

F

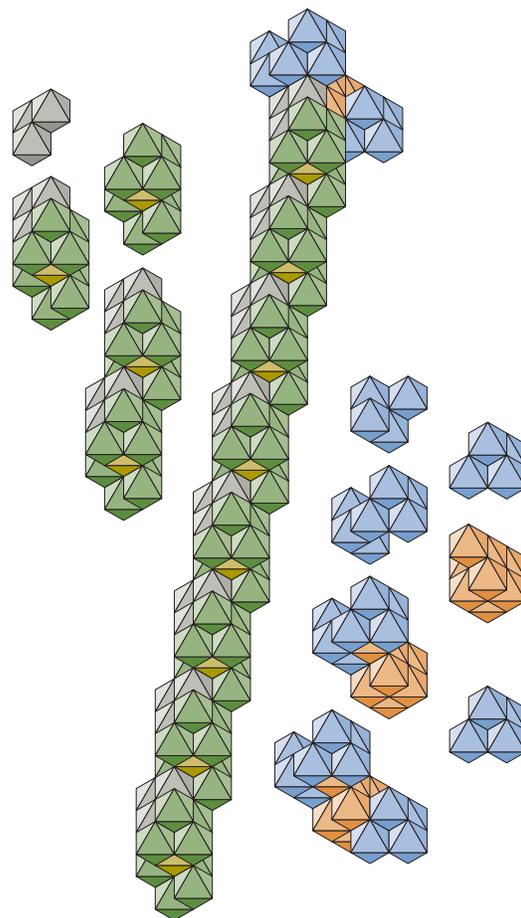
PFOS group

The PFOS group is depicted¹ as an eight C-atom chain with a pair of F-atoms attached to each of the C-atoms. The C-atom has three clefts. Two clefts are used by the joins with adjacent C-atoms of the chain. That leaves one

1. Rebecca Renner, Scotchgard Scotchd, *Scientific American*, March 2001.

cleft for attaching two F-atoms. This can be accomplished by adding the F-atoms as a triplet joined pair. One of the F-atoms is cleftly joined to the C-atom. The pair cannot be attached to a C-atom of the chain without obstructing the cleft of one of the adjoining C-atoms. Thus, the C-atoms cannot be in the usual chain formation found in a lipid.

If the C-atom is cleftly joined with a triplet joined pair of F-atom, the unit can produce a chain. This is shown in the figure. The paired



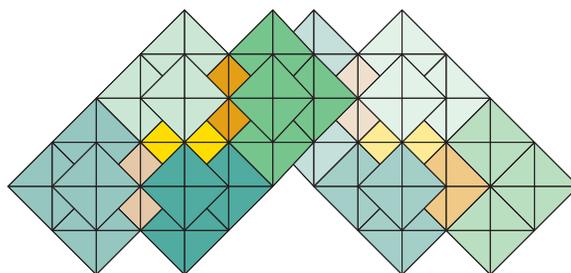
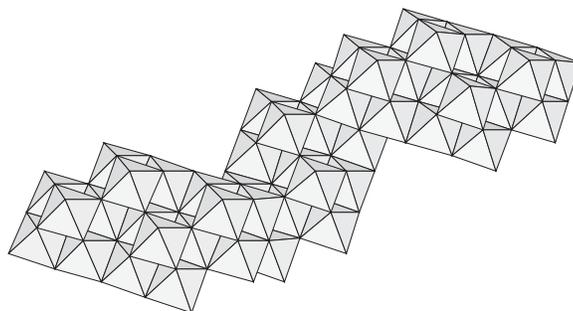
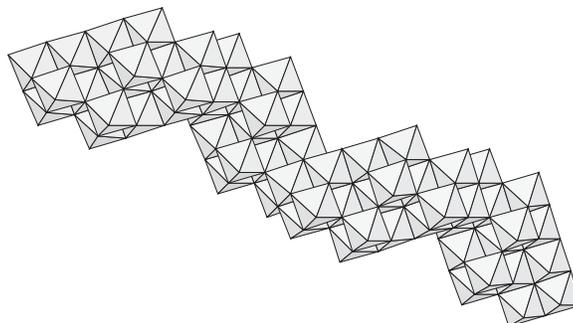
PFOS group.

The PFOS group runs diagonally through the center of the figure. To its left, the assembly of the chain unit is shown with a pairing of chain units. To its right, the assembly of the SO₃ terminus is shown.

F-atoms are linked by C-atoms, CFF-CFF-CFF-CFF-CFF-CFF-CFF-CFF.

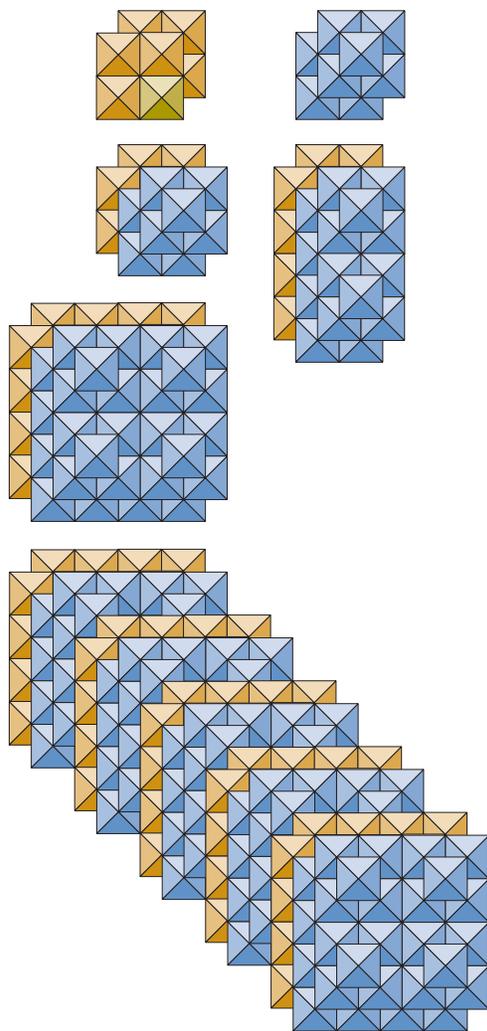
HF chain

HF chain
In the figure below the F-atoms are shown in green and the paired H_2 groups are shown in yellow or brown. Two perspective views of an extended chain are shown in the figures on the right.



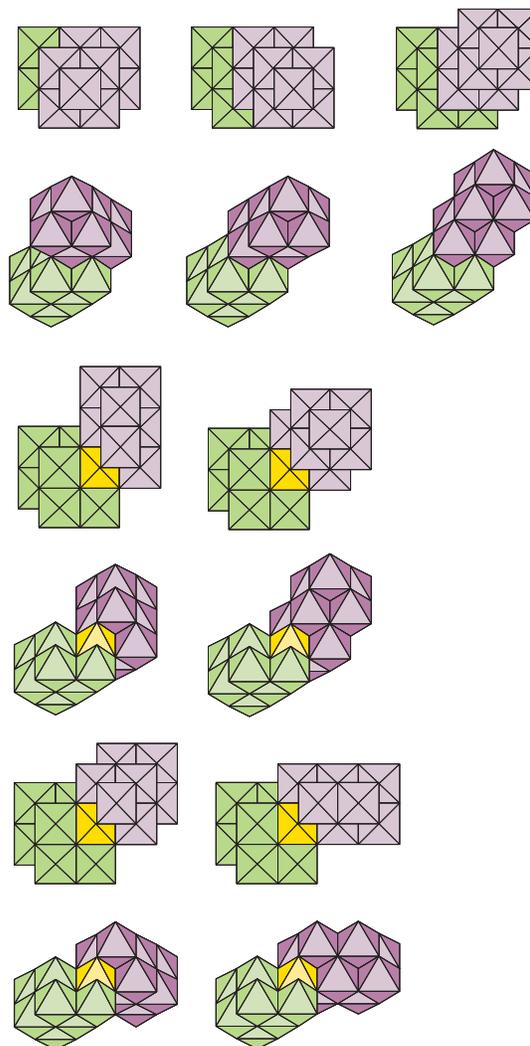
K

KCl group



KCl group.

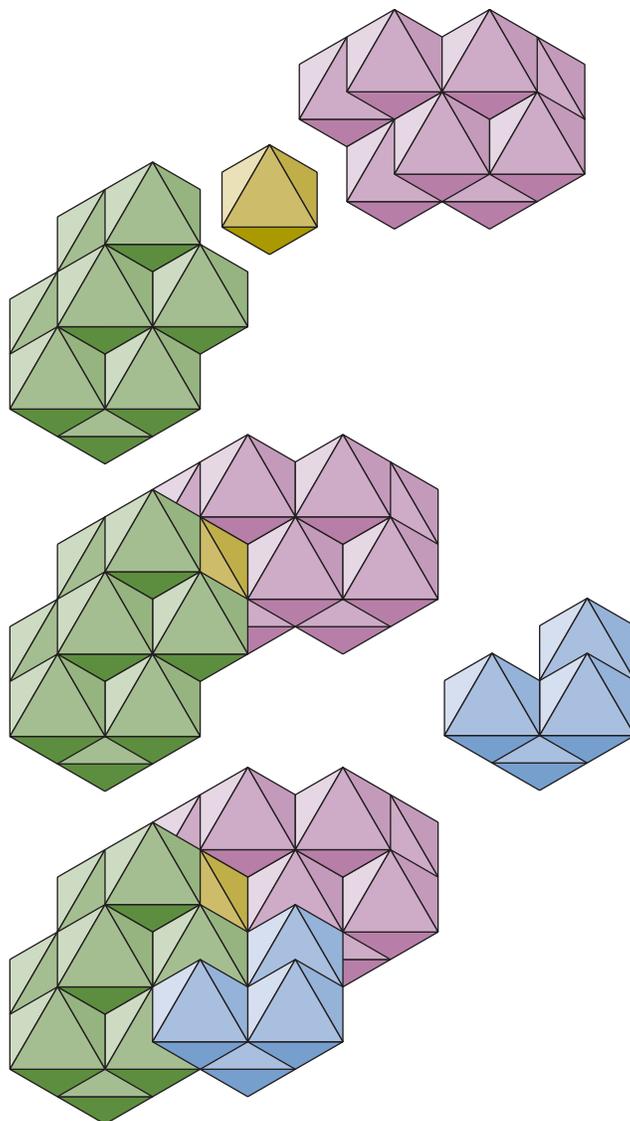
In the top row are shown a Cl-atom on the left and a K-atom on the right. Below the Cl-atom is a KCl group and to the right is a pair of KCl groups. Below the KCl group is a crystalline layer of four KCl groups. At bottom is a crystalline stack of five KCl layers. In the extended crystal, a K-atom in the layer at the bottom of the stack will have a K-atom in the top layer which differs in its position by a move normal to the two planes.



Seven possible KCl groups

The Cl-atom is maintained in its orientation throughout and the K-atom is triplet-joined. The K-triplet is placed in the four possible orientations relative to the remainder of the K-atom.

K₂O group

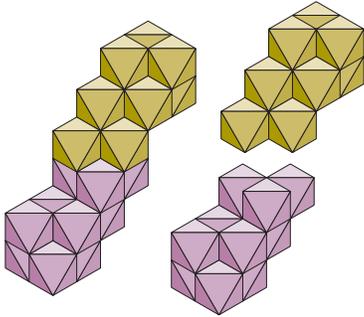


K₂O group

This is the group which shows up in the chemical analyses of minerals.

Li

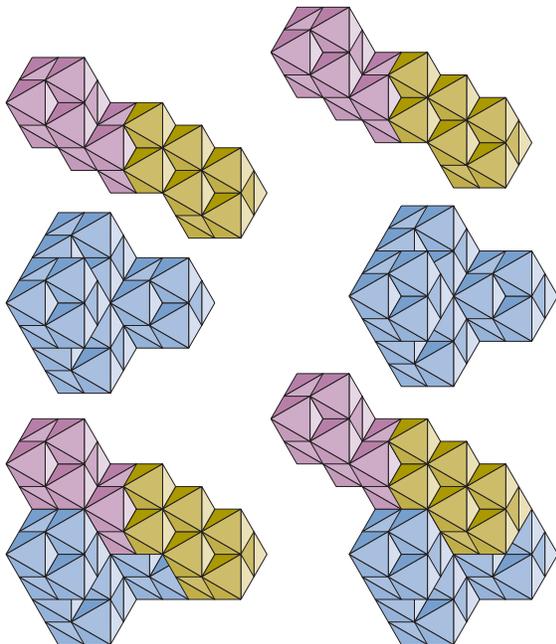
Li₂ group



Li₂ group.

On the right are two Li-atoms oriented to triplet join to form the Li₂ group on the left.

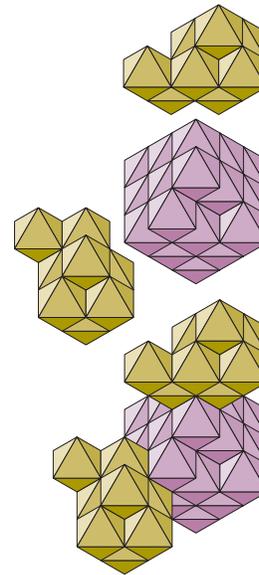
Li₂O group



Li₂O group.

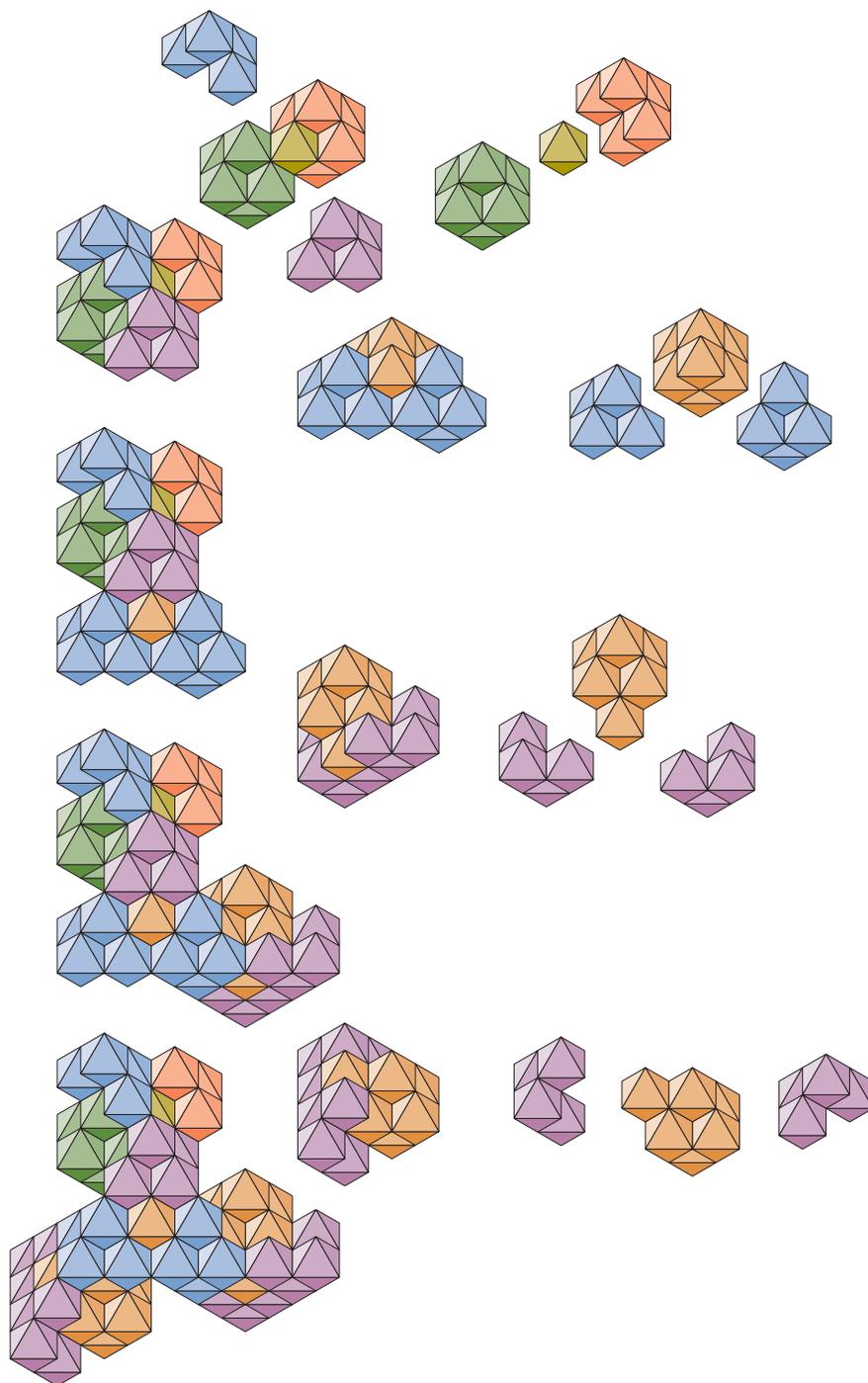
Mo

MoS₂ group



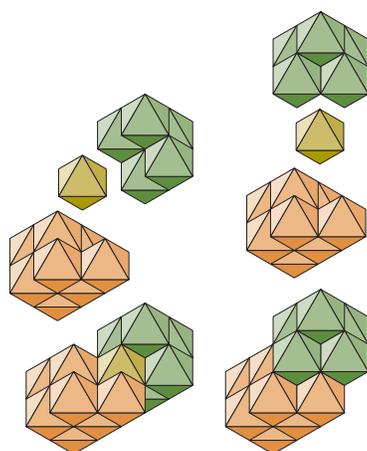
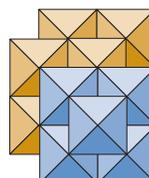
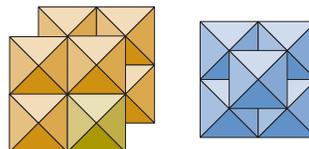
MoS₂ group

Na



NaAlO₃SiO₂

NaCl

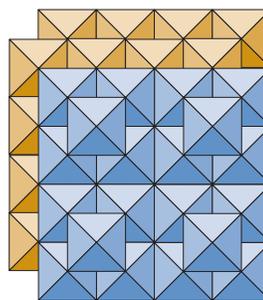
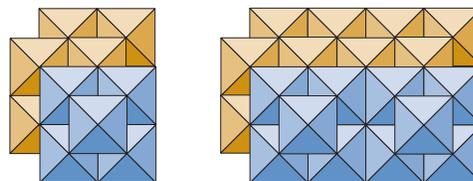


Two possible NaCl groups

A Na-atom is triplet joined to a Cl-atom to form a NaCl group. The triplet pair occupies the position of the Ar-octa for the Cl-atom and the Mg-octa for the Na-atom. Two such triplet pairings are possible and are shown in the figure.

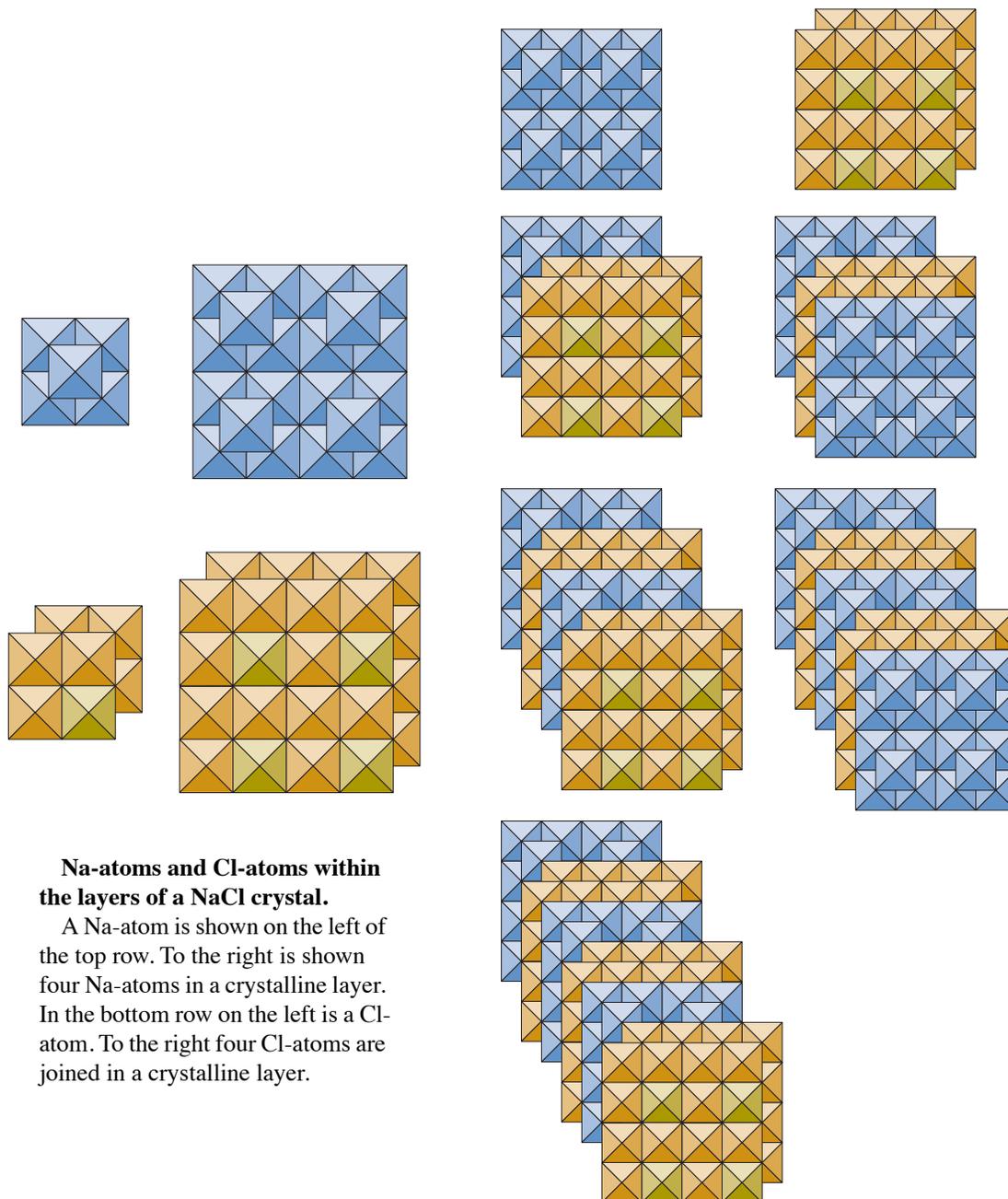
NaCl group.

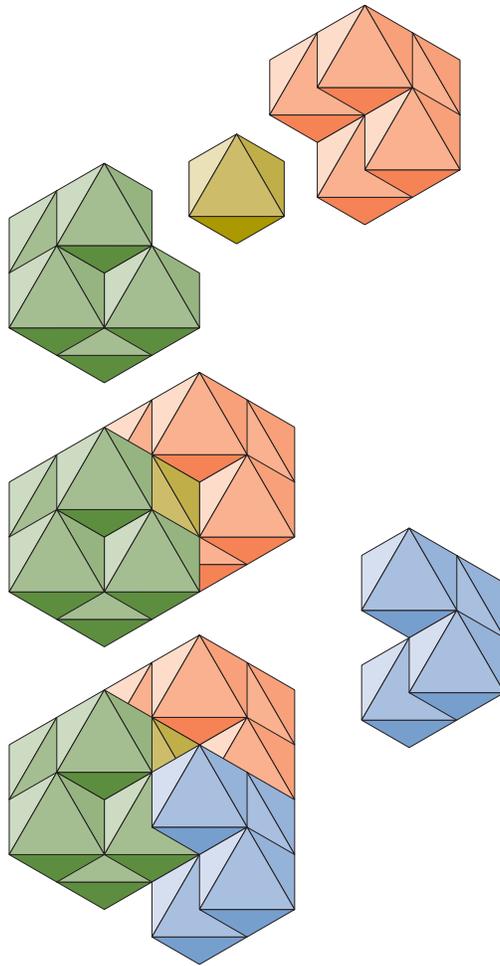
The Cl-atom is on the left in the top row and the Na-atom is on the right. The NaCl group is shown underneath. The Cl-atom is depicted as an Ar-atom and the Na-atom is depicted as a Ne-atom. The yellow colored octa represents the paired triplets.



NaCl atoms in crystalline layer.

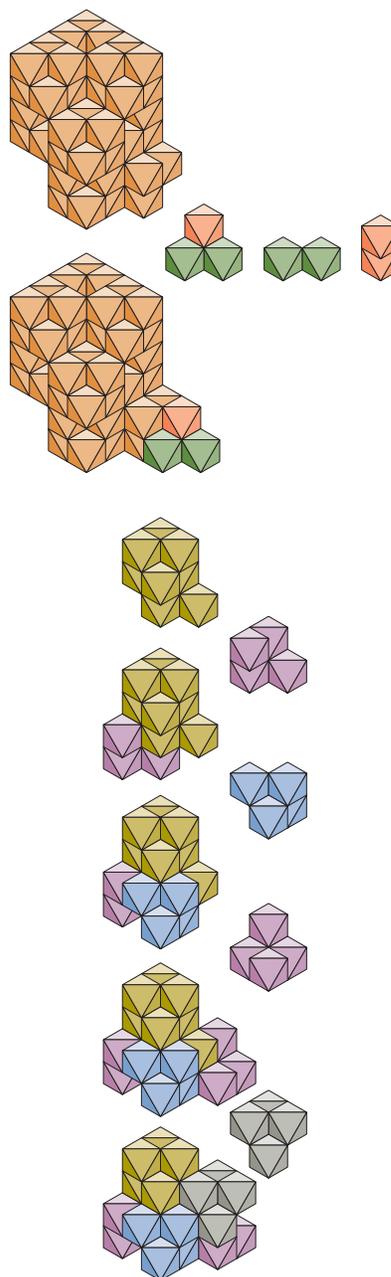
In the top row is a NaCl group on the left and a pair of NaCl groups on the right. The bottom figure shows four groups in a crystalline layer.



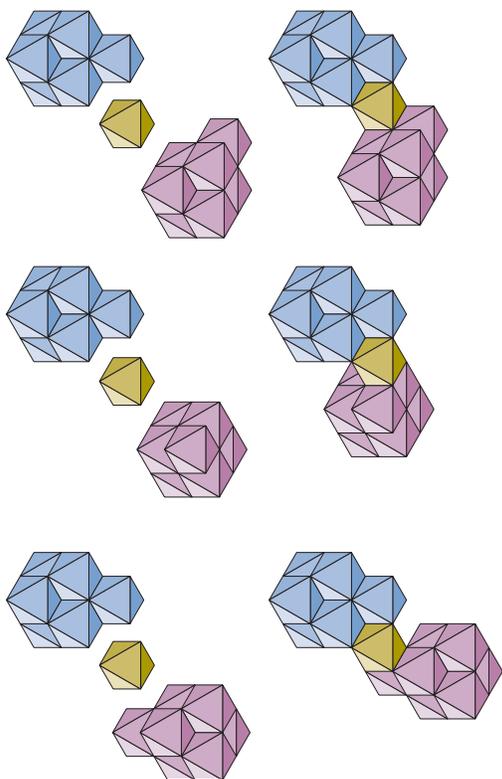
Na_2O  Na_2O group

P**H₂PO₄ group**

As shown at the top of the figure on the right, the P-atom colored orange joins with an H₂-group whose H-atoms are colored red or green. The resulting S-atom homomorph is colored yellow in the succeeding H₂PO₄ assembly. The four O-atoms are shown in the right hand column and the growing assembly is shown in the left hand column. The H₂PO₄ group has the same form as the SO₄ group.



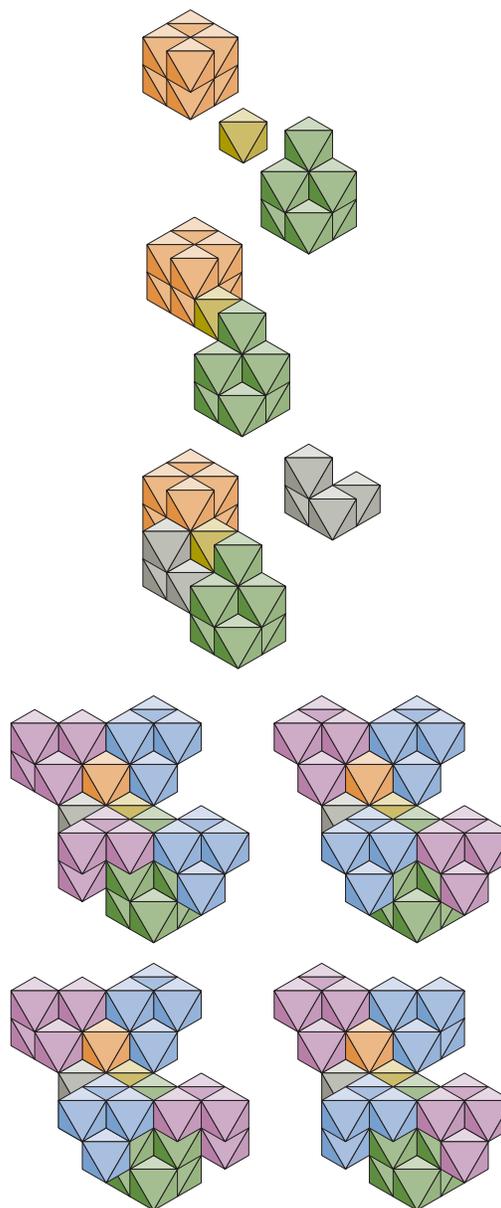
P₂ groups



P₂ groups

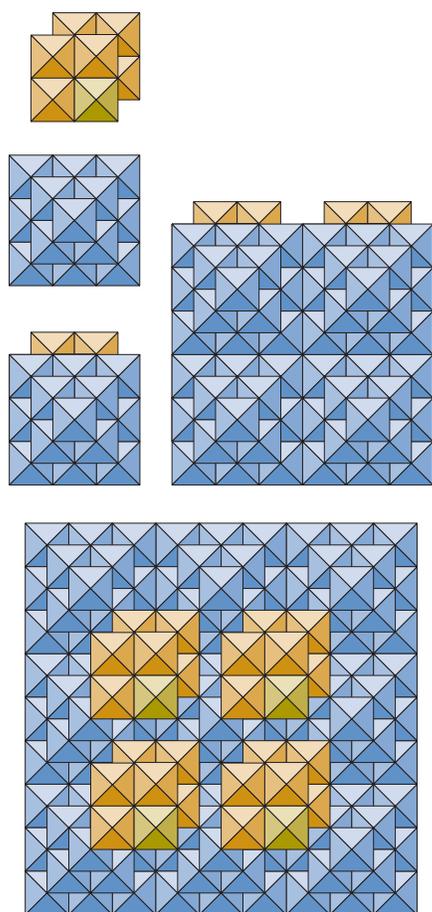
Two P-atoms can triplet join in the three ways shown here. A P₂-assembly is depicted in each of the three rows. Each depicts two Si-atoms joined by a He-atom which represents the paired triplets of the P-atoms.

P₂O₅ group



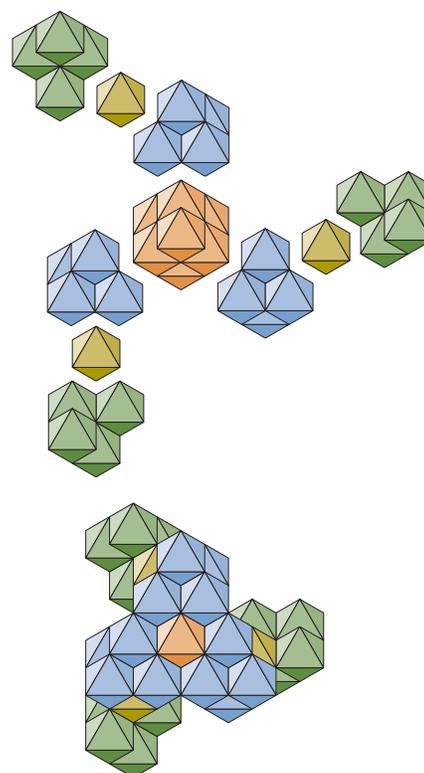
P₂O₅ groups

The figure shows four ways in which five O-atoms can join to a pair of triplet joined P-atoms. The O-atom depicted in gray is the same in each of the four P₂O₅-groups shown at the bottom of the figure.

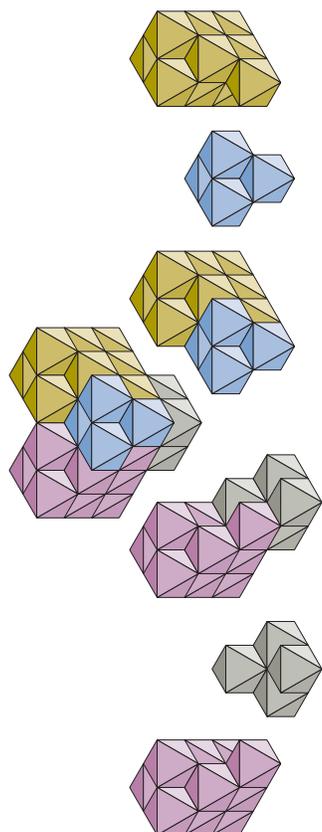
RbCl group**RbCl group.**

The RbCl group is formed when the Rb-triplet pairs with the Cl triplet. The triplet pair occupies the Ar-octa of the Cl-atom and the Sr-octa of the Rb-atom. In the crystalline layers of the crystals of NaCl and KCl, the Cl-atoms are in contact. As the figure shows, they do not touch in the RbCl crystal.

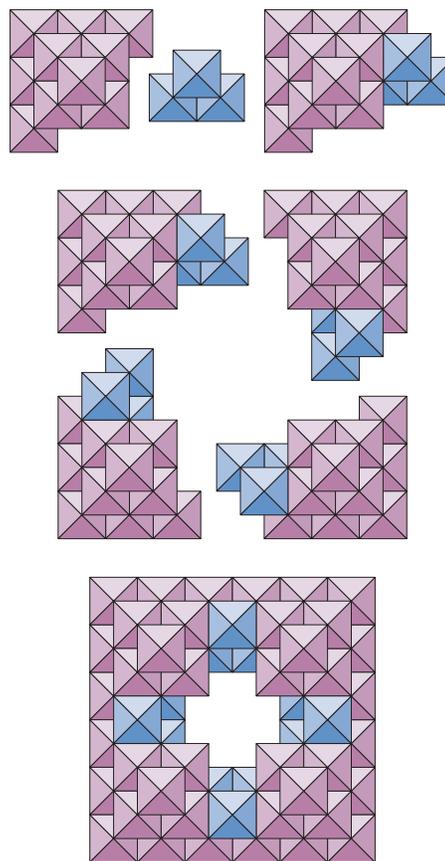
A Cl-atom is shown at the top of the figure. Below it is a Rb-atom and in the same column is the RbCl group. To the right of the group is a crystalline layer of four RbCl groups. At the bottom, a layer of Cl-atoms is joined to a layer of Rb-atoms.

SiF₆**SiF₆ group**

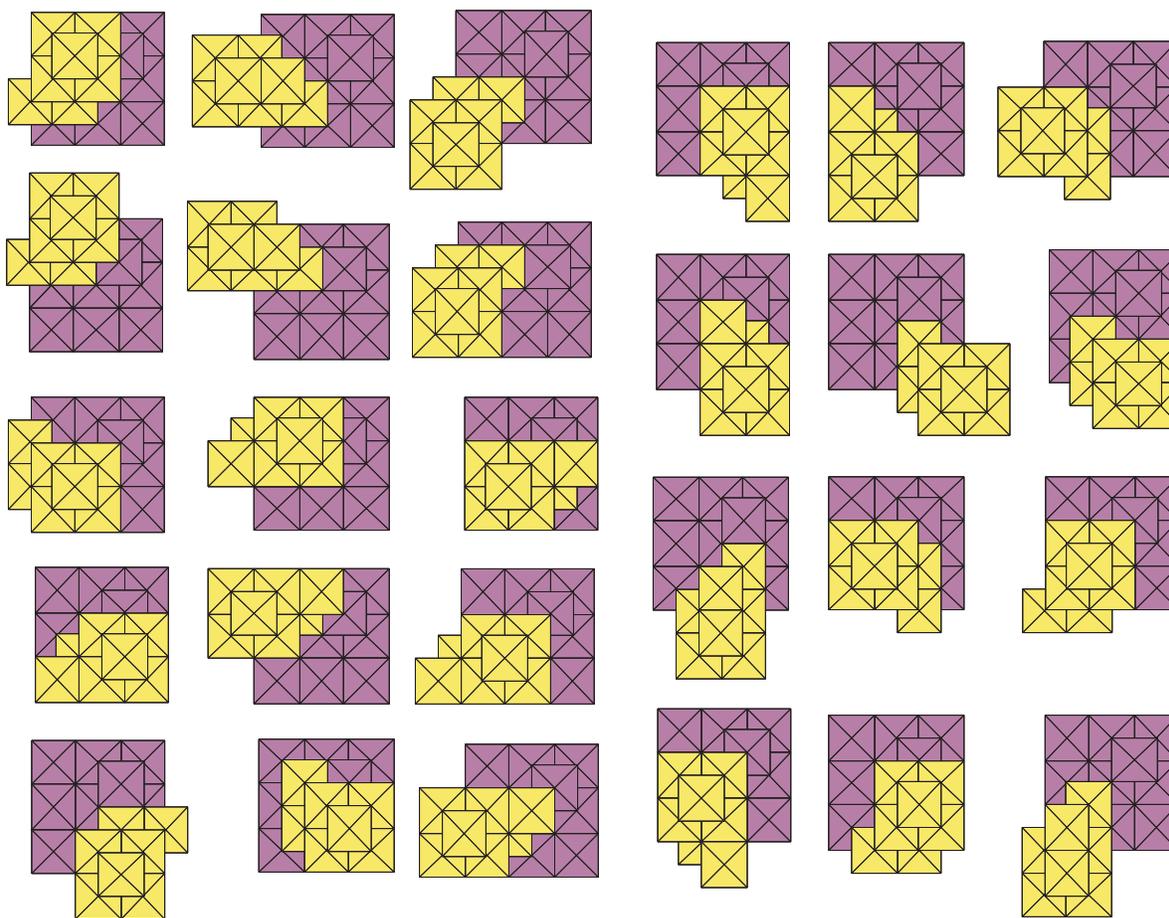
The Si-atom is colored orange, the O-portions of the F-atoms are colored blue or green and the paired F-triplets are colored yellow.

TiO group**Paired TiO groups**

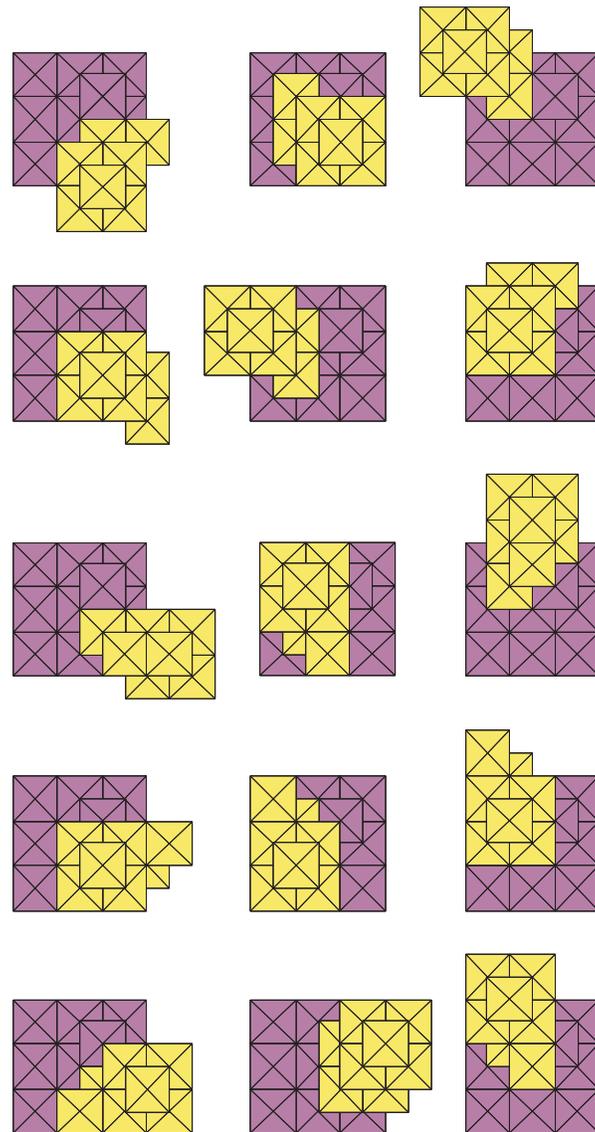
The figure shows the formation of an assembly consisting of two identical TiO groups. The assembly is to the left of center. The assembly of each of the TiO groups proceeds from either the top or the bottom towards the completed assembly.

Zn**ZnO group****Ring of four ZnO groups**

Four ZnO groups can form the fourfold ring shown here. The join between the Zn-atom and the O-atom is shown at the top of the figure. Four identical molecules oriented to form the ring are shown next. At the bottom is the completed ring.

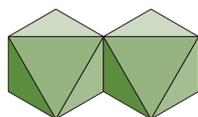
ZnS groups**ZnS groups plate II****ZnS groups plate III****ZnS groups**

The forty-two possible cleft joins between a Zn-atom and a S-atom are shown in the two plates above and in a third plate on the next page.



ZnS groups plate I

HYDROGEN

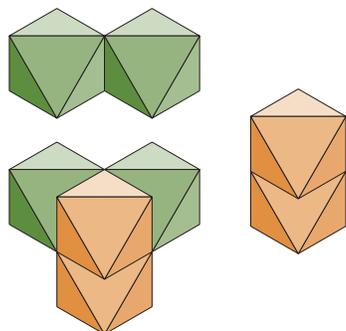


H atom

The H-atom is a pair of epns which share a common edge. The join is a hinge and the pair is free to swing between face-to-face contact at either extreme.

The hydrogen atom

The H-atom is an epn pair. This lacks structure, since the linked edges of the pair form a hinge. Two such pairs can form a tetrahedral group of epns, a face of each epn supplying a face of a central regular tetrahedral void. This is a structurally perfect association. It is the form of the H_2 group.



H_2 group

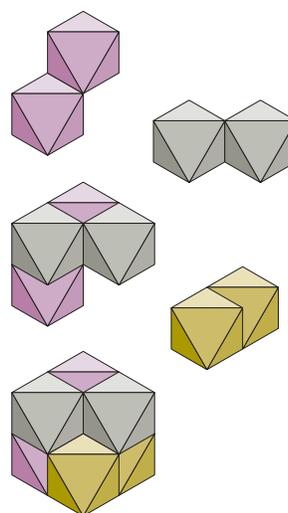
The H-atoms at the top and right cleft join to form the H_2 -group at the bottom.

The H_2 -group

The H_2 -group is identical to an epn triplet to which an epn has been added so as to provide the fourth face of the tetrahedral void. That is, it is edge bonded to each of the epns of the

triplet. The group has four faces which provide bonding sites for triplets as the single bonding face of the triplet itself. It is suitable for bonding with an N-atom to provide an association identical in appearance to an O-atom with an extra epn particle. Within a large group it could fill precisely the space occupied by an O-atom. The same is true for H_2P and S. It could combine with the unpaired triplet of any odd atomic numbered element to provide a shape identical to that of the next higher numbered element.

The H_3 group



H_3 group

Three H-atoms can assemble to form a homomorph to the He-atom. The pairing of the first two is mutually stabilizing.

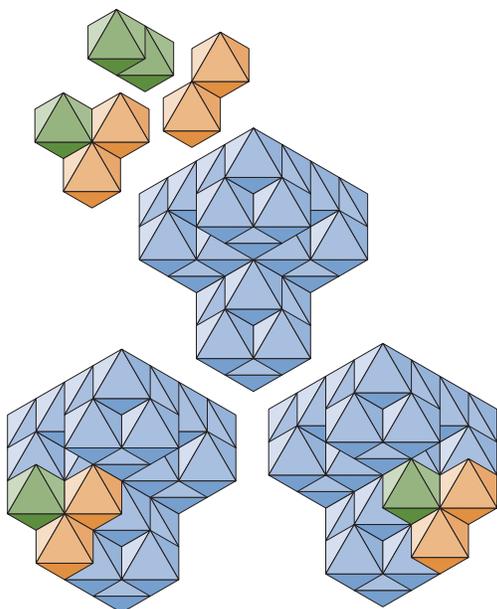
Three of the hinged epn pairs could combine to form a regular octahedron identical in

appearance to that of an He-octa. This would be an H_3 group. When an H_3 -group is combined with a C-atom it has the form of an O-atom.

Molecular hydrogen provides the material for making the O_2 -homomorphs NH_2O , CH_3O , CH_3CH_3 , NH_2NH_2 , and CH_3NH_2 .

H_2O groups

There are four positions on an O-atom where an H_2 -group can fill a triplet position. The four joins produce just two conformations. These mirror one another. In the figure, an H_2 -group



H_2O groups

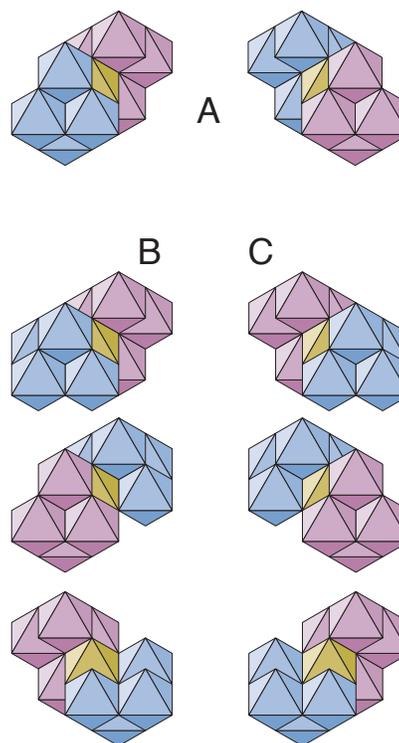
The formation of the H_2 group is depicted in the upper left. In the middle is an O-atom. At the bottom are shown the two possible types of H_2O groups wherein the H_2 group occupies one of four triplet positions.

occupies a position on the left of center of the H_2O group on the left while an H_2 -group occupies a corresponding position on the right side of the H_2O group on the right. One H_2O group mirrors the other. The left group will be called **L- H_2O** and the right group will be called **D- H_2O** .

H_2O pairs

H_2O groups can form pairs wherein the triplet-like H_2 molecule of each is paired to form a He-octa like assembly which fills either the Mg-void or the Ne-void of each of the O-atoms.

Three types of pairs can be formed wherein each of the remaining O-atom voids is independently fillable by a He-octa of another atom. The types are shown in the figure. Type A is a join between an L- H_2O and a D- H_2O . Type B is produced by a pairing of two D- H_2O groups. Type C is produced by a joining of two L- H_2O groups. Type C mirrors Type B.



H_2O pairs

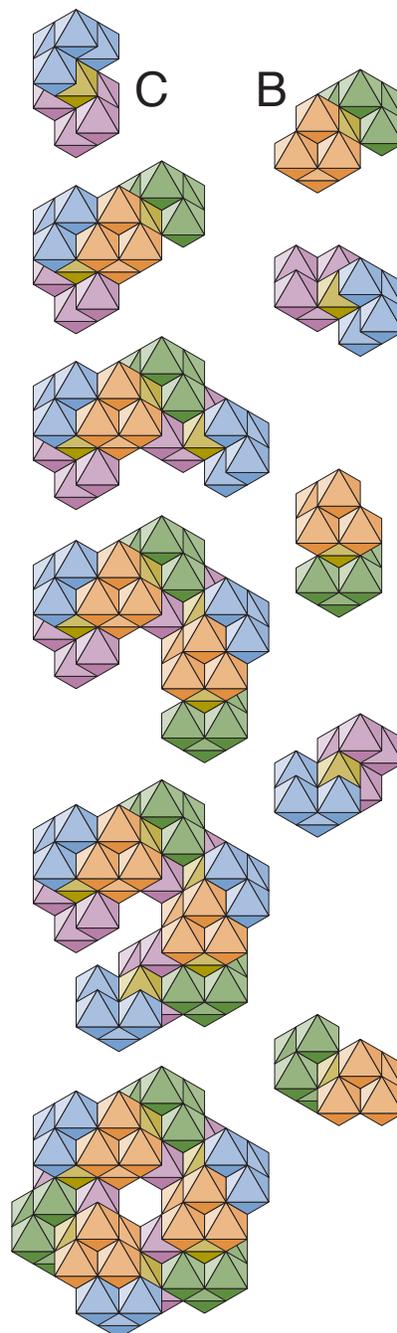
Three H_2O pairings are depicted. Each permits independent filling of the open He-octa void of each of the O-atoms.

Type A at the top is shown in two views which are rotated 180° about an axis parallel to the top of the page.

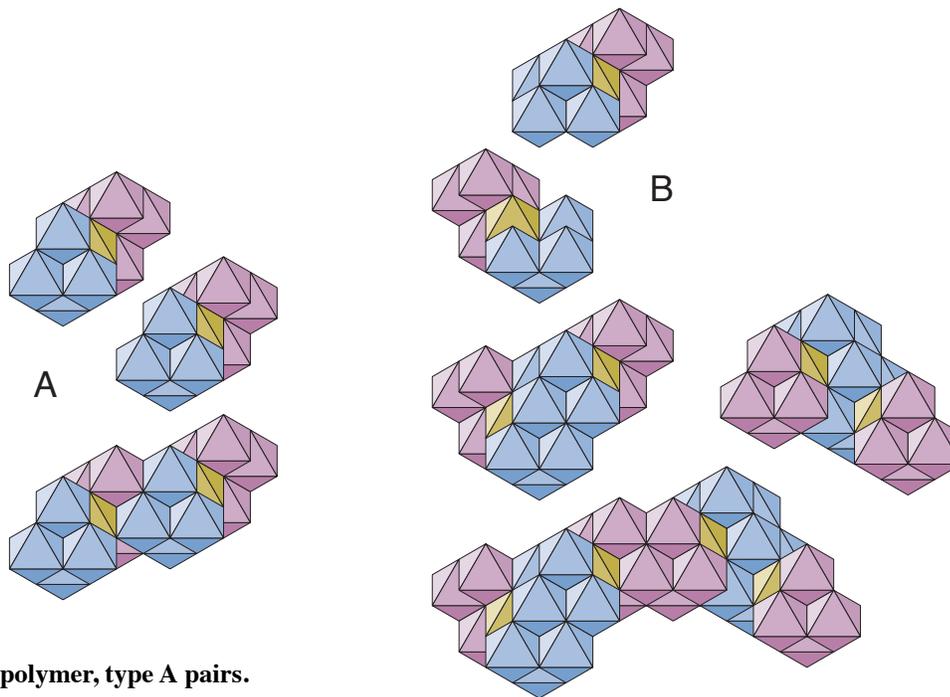
Type C mirrors type B. These are shown in three different orientations, B in the left column, C in the right.

Six H₂O-pair ring

Ring of six H₂O pairs.
Three Type B and three Type C H₂O-pairs can join to form a ring. The two types alternate and each pair of each type is rotated 120° to the other pairs of the same type.



H₂O polymer chains



H₂O polymer, type A pairs.

Type A pairs can form chains in which each of the pairs has the same orientation.

H₂O polymer, type B pairs.

Two type B pairs are joined to form the chain unit. The chain unit joins to an identical chain unit which is rotated 180° about the top of the page.

H₂O pairs can form chains wherein each of the O-atoms of one Type A pair can join to an O-atom of another Type A pair. Polymerization of water was discovered by Boris Deryagin¹.

Type B pairs form a monomer by pairing. The monomer then joins to another monomer which is rotated 180° to it. This pair of monomers chains by a simple translation in a direction parallel to an edge of the octahedron of which is composed.

1. Isaac Asimov, *Asimov's Guide to Science*, Basic Books, 1972 page 521, polywater.

CARBON

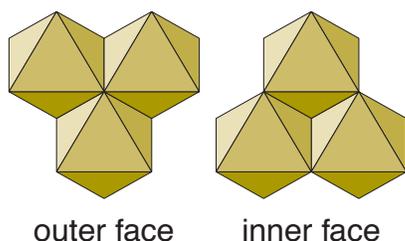
Diamond

Join directions are tetrahedral

The Bragg representation of the structure of diamond requires join directions which are perpendicular to the faces of a regular tetrahedron. It further requires that each center of such join directions be equivalent except for an inversion between adjoining units. The C-atom alone does not have such join possibilities.

Specific heat requires four atom cfu

The specific heat (C_v) of diamond is 0.124



Two views of a C-atom panel for the diamond cfu.

A tetrahedral assembly in which each of the four faces of the tetrahedron is provided by a C-atom provides the cfu for the diamond crystal. The figure shows two views of the C-atom. The inner face is turned toward the centroid of the tetrahedral assembly. The outer face is directed oppositely. The outer face is the inter cfu join face.

Assembly of the diamond cfu

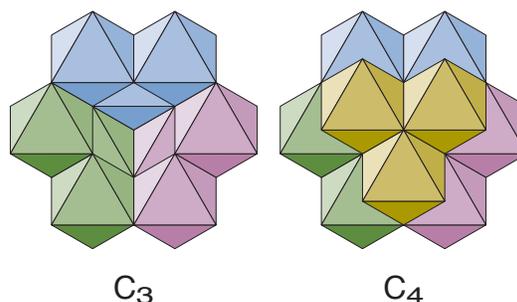
The figure to the right shows the assembly of the diamond cfu from opposite viewing directions. The C-atoms which form the cfu are grouped above the assembly.

cal/g¹. Using 12.0111 as the atomic weight of Carbon and four C-atoms as the cfu produces a value that conforms to the relationship established by DuLong and Petit for solids.

$$(4 \times AtWt \times C_v) = 5.957$$

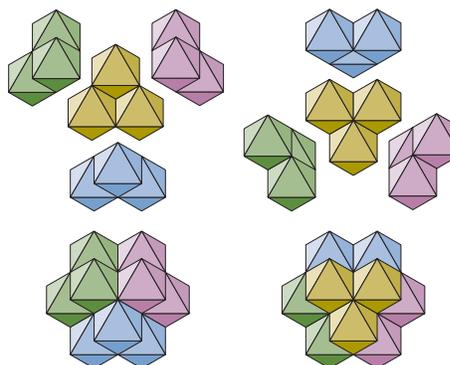
The diamond cfu

1. *Handbook of Chemistry and Physics*
48th ed., The Chemical Rubber Co.,
Cleveland 1967

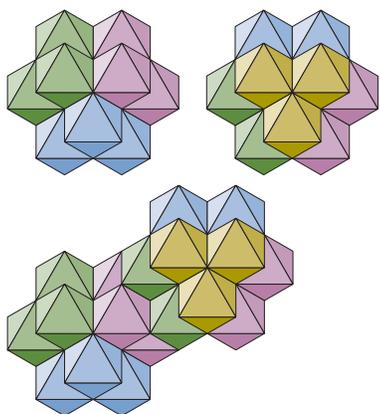


The diamond cfu.

The arrangement of the C-atoms is shown in the above figure. The view on the left shows three C-atoms joined so that each shares an edge with the other two C-atoms to form a structurally stable assembly. The view on the right shows the placement of the fourth C-atom of the assembly. Its outer face is towards the viewer.

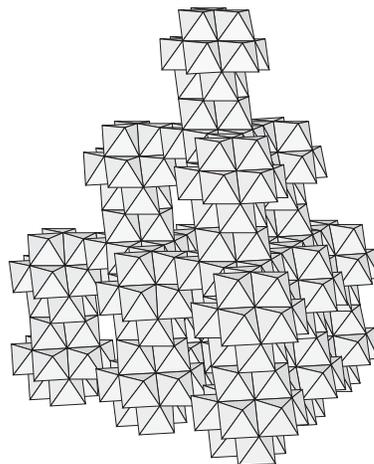
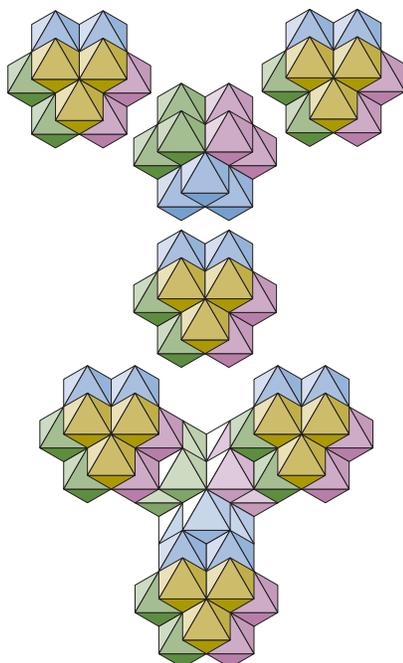


The join between diamond cfus



Diamond cfus joined

The join between the tetrahedra can be seen as a pairing of C-atoms so that the pair appears as a Mg-atom. For identical cfus to join in this manner, one must be inverted relative to the other. The above figure is a view of a diamond cfu which is inverted relative to the view of the previous cfu. The next figure shows the two cfus joined. The two orientations depicted in the above view of the joined pair are the only orientations in the diamond crystal. A cfu of one orientation is joined to as many as four cfus of the other orientation.



Diamond crystal

The arrangement of the cfus in the diamond crystal is shown in two views. The first view is an orthographic projection of the crystalline assembly. The gray colored cfus are identically oriented. The yellow cfus are inverted with respect to the gray. The next view is a perspective view which is nearly at right angles to the first view.

Graphite

Graphite crystal structure

The graphite crystal has cfus which lie in a plane. Each cfu is joined to three others and the angle between the joins is 120° . The joins of adjacent cfus are inverted. A lone C-atom as cfu cannot produce this crystal.

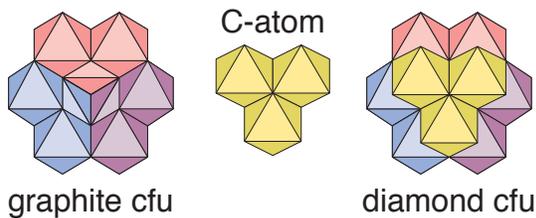
Specific heat requires three atom cfu

The specific heat (C_v) of graphite is 0.170 cal/g. The atomic weight of Carbon is 12.0111. Using three C-atoms for the cfu produces a value which conforms to the relationship established by DuLong and Petit.

$$3 \times AtWt \times C_v = 6.125$$

Comparison of diamond and graphite crystals

Using a three C-atom tetrahedral assembly as the CFU for graphite satisfies the DuLong and Petit relationship and permits the joins required of the cfu to produce the crystalline assembly. The graphite cfu is an open faced

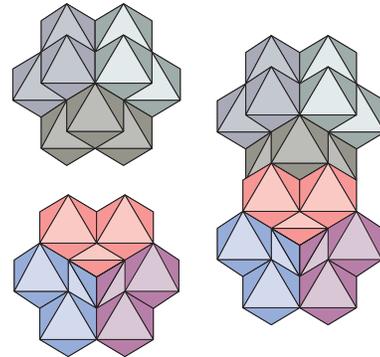


Graphite and diamond cfus.

tetrahedron in which each of the three C-atoms provides a face of the assembly. The graphite cfu differs from the diamond cfu by one C-atom. This relationship is seen in the above figure.

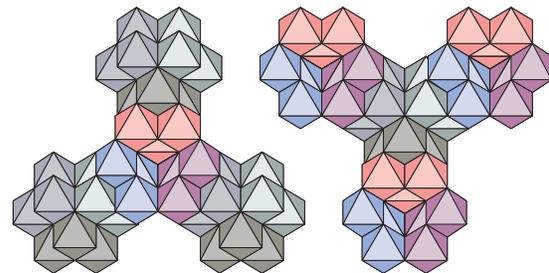
Joining graphite cfus

The join between the graphite cfus is the same as the join between diamond cfus. The



Joining graphite cfus

join is shown in the above figure. The joins between a given cfu and the three adjoining cfus can be seen in the next figure. The cfus are



Two graphite cfu hubs.

The two orientations of the graphite cfu which are required for their joining create two types of hubs within the planar crystalline assembly.

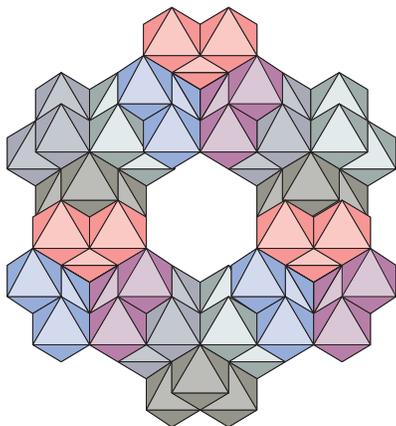
in one of two orientations and the joins are

between cfus which are not in the same orientation. Six cfus can form a ring which is hexagonal. Three of these rings can be joined so that they produce a fourth ring. From this assembly, the hexagonal ring structure attributed to graphite can be seen.

The thickness of the layer is two He-octa facial diameters. The open-faced tetrahedra are in the same plane.

Diamond cfus can form hexagonal layer

Consideration of the drawings will show that each of the graphite cfus can be replaced with a diamond cfu without disturbing the planar structure. The effect would be the same as add-



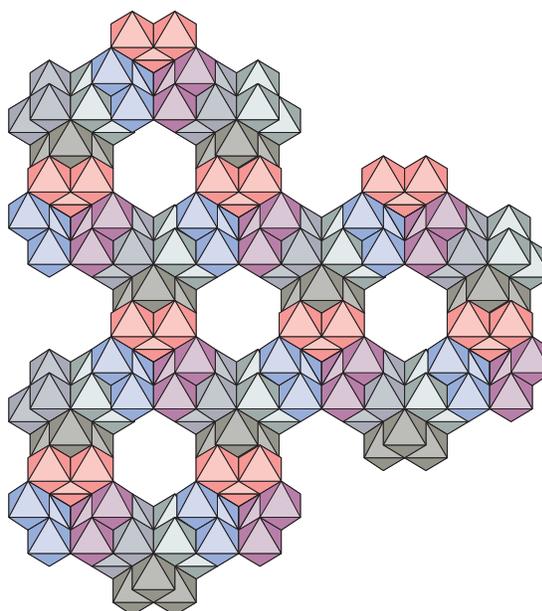
Ring of graphite cfus.

The cfus of graphite can form a ring in which alternate units are in the two orientations. There are six positions to which an additional cfu can be joined.

ing a C-atom to the open-face of each of the tetrahedral groups. The C-atoms would add a He-octa facial diameter to the width of the planar assembly on each of its sides.

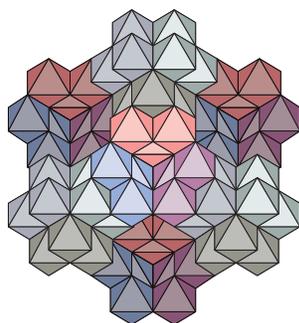
Layer to layer relationship in graphite

The octahedra in a crystalline structure have the same orientation. The octahedra in adjoining layers of graphite are in the same orientation. There are edge-to-edge joins between octahedra at the layer-to-layer join. The layers could be stacked in a regular way if the hubs were stacked so that their threefold axes were colinear.



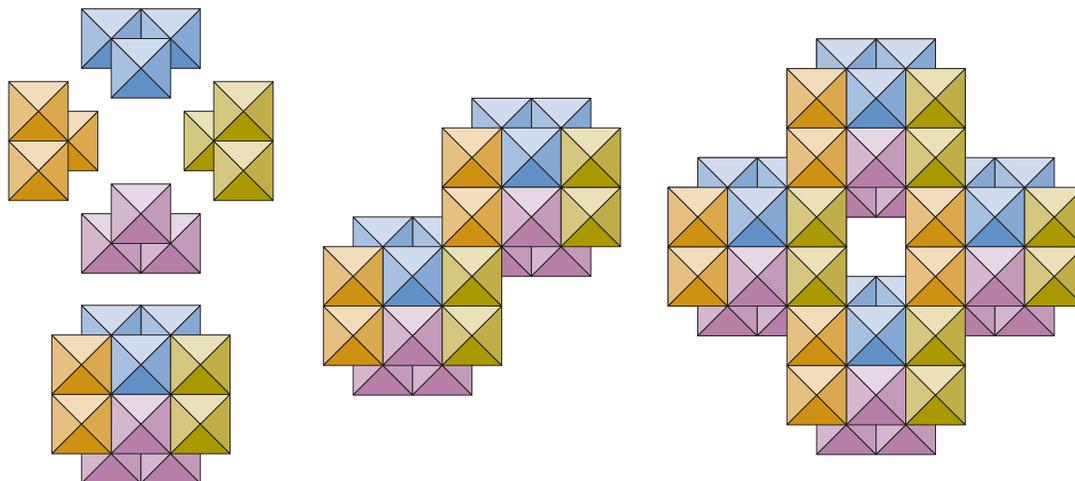
Three graphite cfu rings joined to form a fourth ring.

The crystalline assembly of graphite cfus produces a multiringed plane.



Graphite hub stack.

The two hubs of graphite are shown stacked so that their threefold axes are colinear.

C₄ ring**Ring of four C-atoms**

On the left, four C-atoms form a ring each of which is cleftly joined to each of two C-atoms and has He-octa edge contact with a third. Each C-atom of the ring has a cleft free for joining.

In the middle, a pair of C₄ rings join in a plane perpendicular to their axes of symmetry. This is a cleft join in which four atoms provide one face each. Two C-atoms from each of two C₄ rings are joined

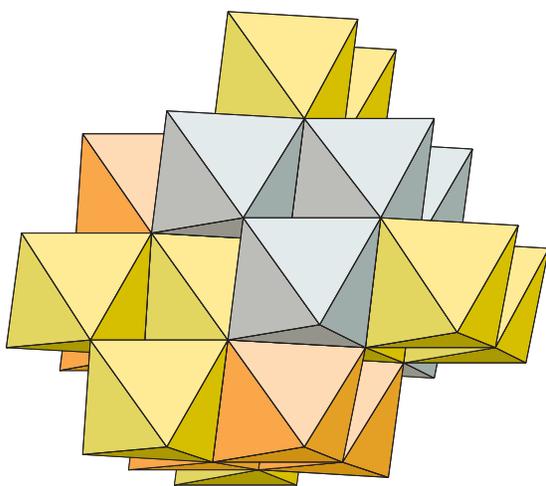
On the right, four rings join to form a larger ring which can be extended to form a crystalline layer.

Stack of two C₄ rings viewed in perspective.

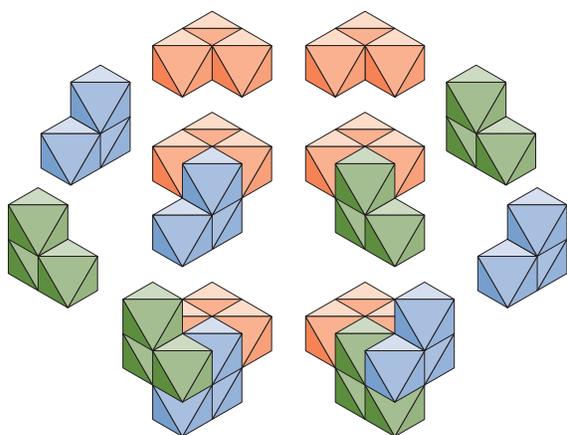
Two C₄ rings can be stacked parallel to the axis of symmetry. There are no cleft joins between the paired rings. Each C-atom is joined to the C-atom axially adjacent to it by a pair of He-octa edges. It also shares an edge with each of the C-atoms which are adjacent to this axial neighbor.

The eight C-atoms of the stack are in a cube-like array suggestive of cubane. For this stack to hold the NO₂ groups of octanitrocubane at the corners, each N-atom would have to have a cleft joined to the cleft formed by adjacent C-atoms of one of the rings. Four of the C-atoms have their third clefts blocked by the stacking.

The stack axis runs from lower left to upper right

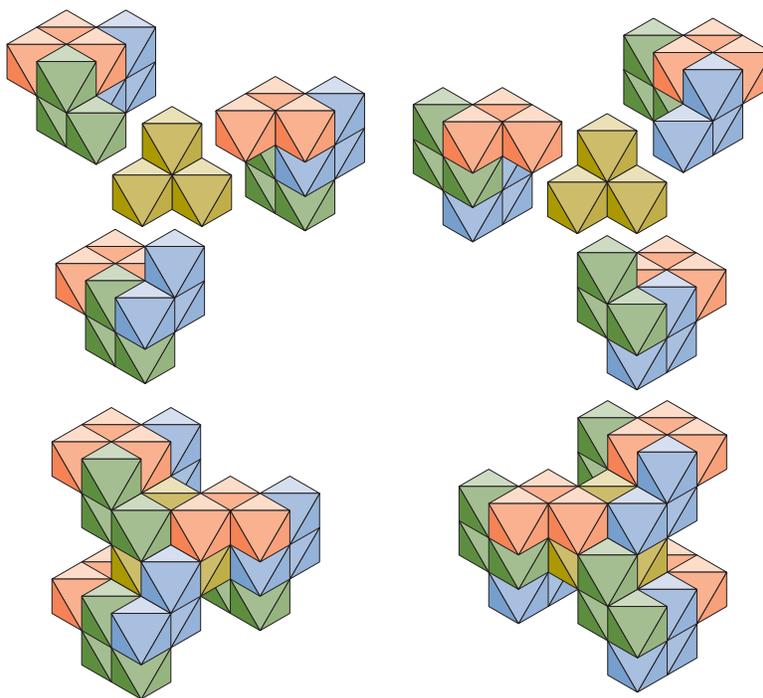


Carbon helices



One C-atom, 1/3 turn

The C-atom can form a helix with other C-atoms as shown in the next figure. The C-atoms are cleftly joined. Each C-atom is 1/3 turn different from its two adjoining C-atoms. The figure shows the atom by atom assembly of one turn of two helices. The helix on the left of the figure is growing clockwise toward the viewer. The helix on the right of the figure is growing counter-clockwise toward the viewer. The C-atoms of each helix have three orientations per turn. One of those orientations is common to a C-atom of each helical turn.



Linking three helices with a C-atom

Three of turns of the previously described helix can be linked by a C-atom to form an axially extensible unit. The figure shows three turns which are clockwise-toward helical turns. Identical units can be added in either of the axial directions so that a C-atom of each of the helical turns is cleftly joined to a C-atom of a helical turn of the added unit to continue the helix.

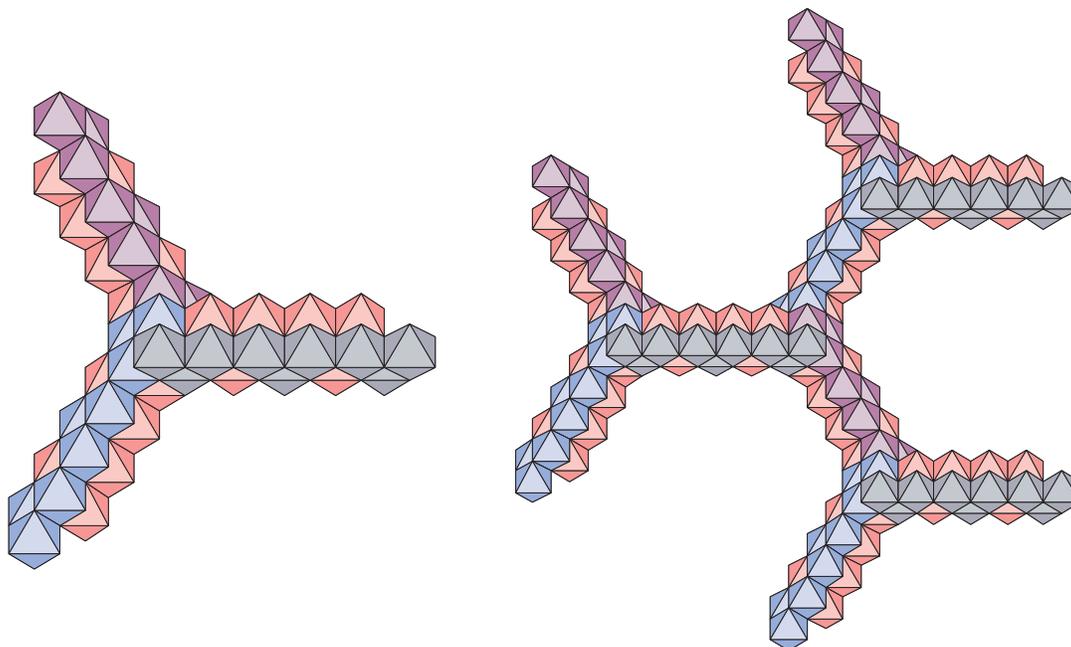
A similar assembly using helices of the opposite hand is shown in the next figure.

C-atom chain helix

C-atom chains with an odd number of atoms can form a threefold helix. The next figure shows a helix in which each of the units is a straight chain of five C-atoms. This is a counter-clockwise towards helix. Each chain is rotated $1/3$ turn relative to each of the two adjoining chains. Each chain is separated from the axially nearest identically oriented chains by a He-octa facial diameter.

Joining of helixes

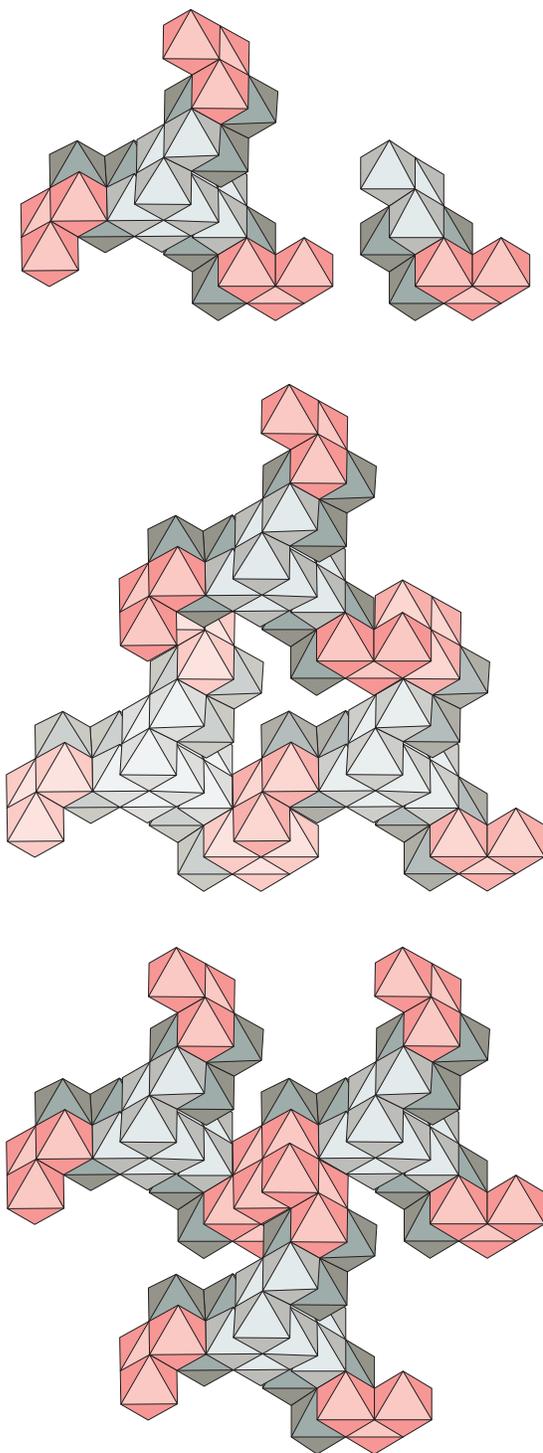
The five C-atom unit helixes can join with identical helixes to form a crystalline structure. The C-atoms furthest removed from the helix axis cleftly join with C-atoms of identical helixes to produce a helical join which is opposite in sense to the helixes of the joining units. It can be seen from this happenstance that the chains could form helixes of the opposite sense and form a similar crystalline structure.



Helix formed of chains of C-atoms

On the left is a single turn of carbon chain helix.

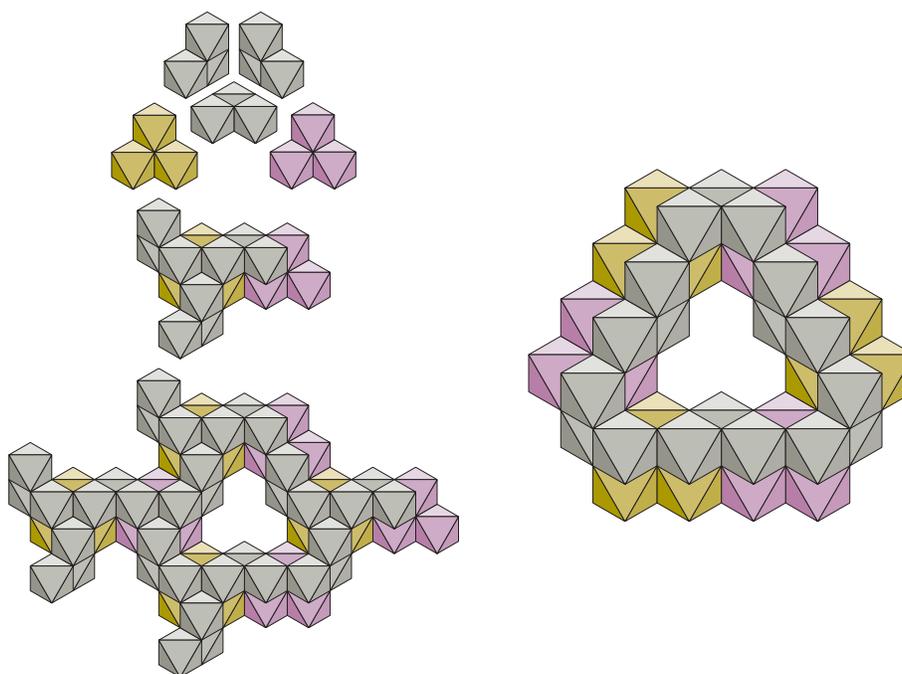
On the right, three carbon helixes are linked so as to form a helix of opposite sense.

CCC helix**CCC helix.**

The top figure on the left shows a group consisting of three C-atoms. The join between the center C-atom and either of the other two is left handed. Three identical groups form a helix in which the light gray C-atom of one group is cleftly joined to the light gray C-atom of each adjoining group.

The middle figure on the left shows a ring of CCC helices. Each helix joins to the other two helices by cleft joins between the red colored C-atoms.

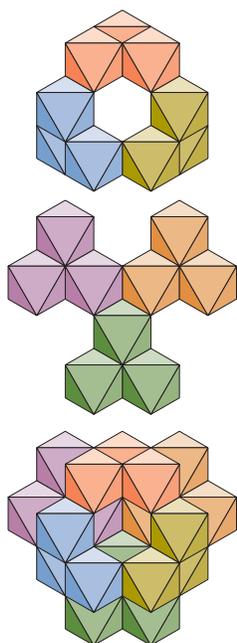
The bottom figure shows three CCC helices each of which contributes a red colored C-atom to form a helix.

CC₃C group**Ring of four CC₃C-groups**

At the top of the figure on the left are the five C-atoms which form the CC₃C group which is shown below them. Four of the groups combine to form the ring on the bottom left. The group acts here as the cfu for a planar crystal. Each of the groups contributes three of its C-atoms to the formation of C₁₂ ring shown on the right.

C₆ ring

Six C-atoms can join in a compact ring which has threefold symmetry. Each C-atom is cleftly joined to each of the neighboring C-atoms of the ring. Each also shares a He-octa edge with each of the C-atoms next to the nearest neighbors. These joins are shown by isolating these near neighbors which then appear as rings of three C-atoms each. The C-atoms are



C₆-ring

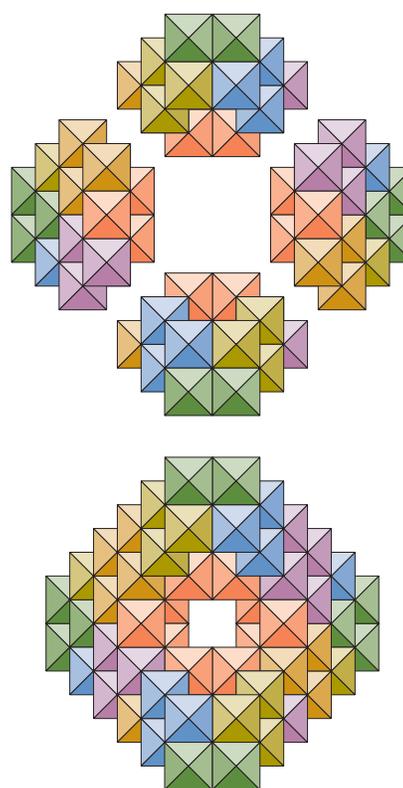
The two groups of three C-atoms each above at the top of the figure are combined in the C₆-ring at the bottom.

triplets of He-octas which are planar. Three C-atoms whose planes are parallel to the plane of the ring are shown here and the edgial joins between them are such that they share a common vertex at the center of symmetry. The plane of each of the C-atoms of the second group make an angle of $2 \times \text{atan} \sqrt{\frac{1}{2}}$ with the plane of the ring.

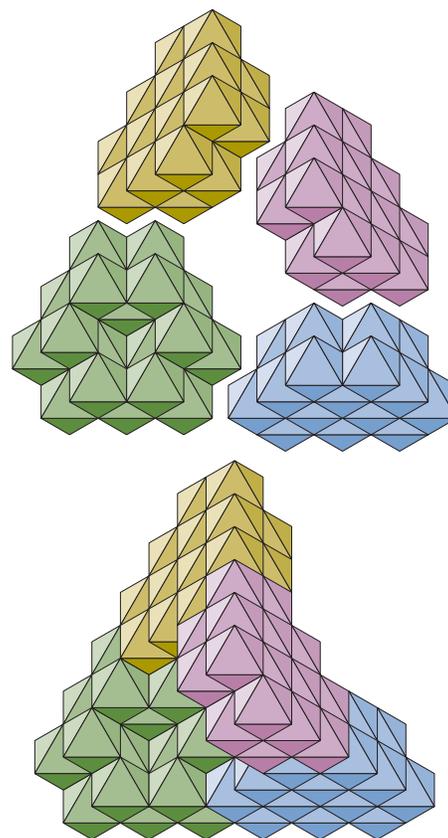
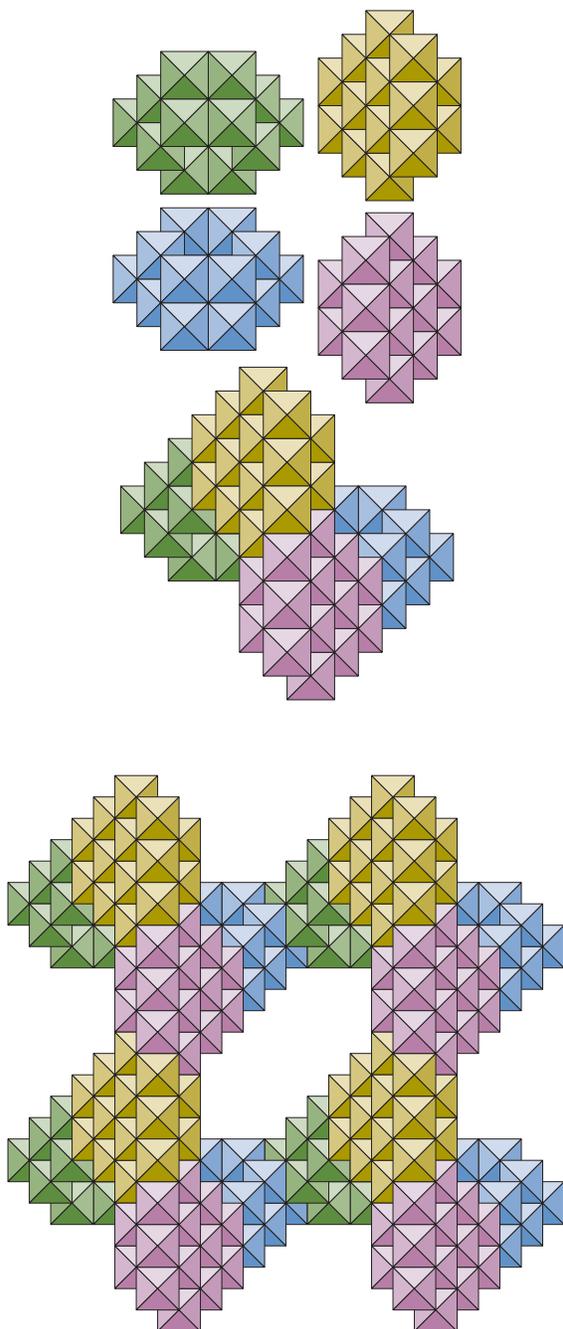
Ring of four C₆ rings

This group is equivalent to the four C-atom ring except that each C-atom is replaced with a ring of six C-atoms. Each ring adjoins two other rings and the connection is through a cleft join between a C-atom of each ring.

The following figure is a view normal to the plane of the ring.



Ring of four C₆-rings, view A

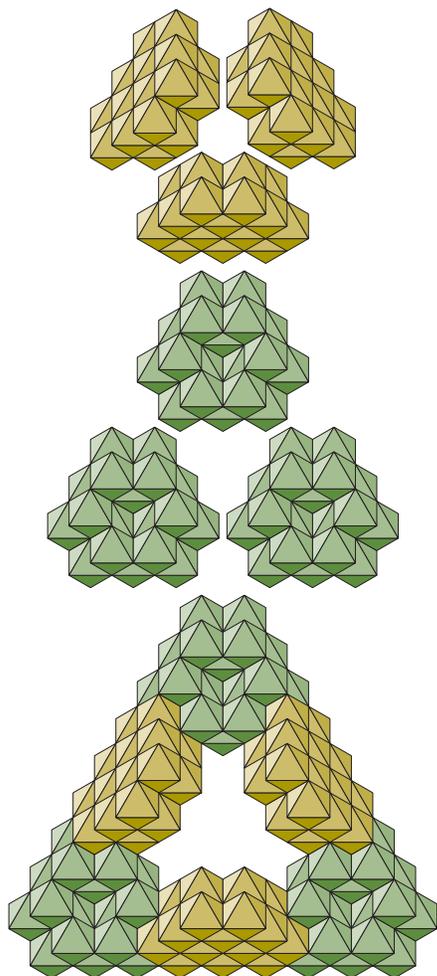


Ring of four $4C_6$ rings

The figure on the top right shows four C_6 rings which cleftly join to form the ring just below them. This ring is identical to the one shown in the previous figure but is viewed from another direction. Four of the $4C_6$ rings cleftly join to form the ring at the bottom left.

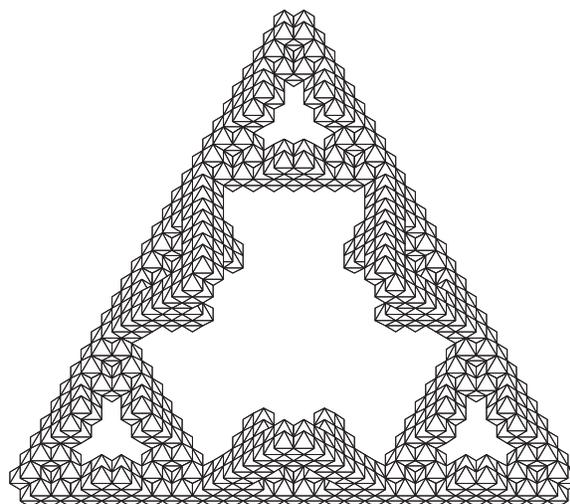
The figure directly above shows the assembly of the $4C_6$ ring from a third viewing direction.

Ring of six C_6 rings



Ring of six C_6 -rings

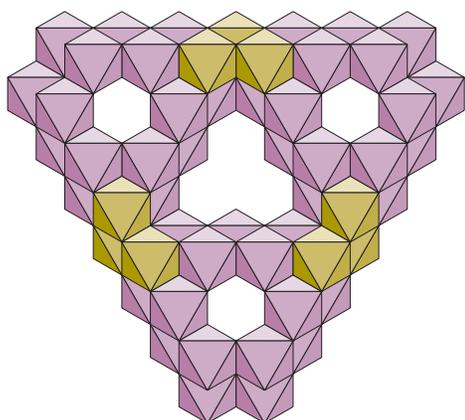
Two groups of three C_6 rings are shown at the top of the figure on the left. Together, they form the ring at the bottom of the left figure. The structure of this ring of rings is analogous in structure to the rings which make it—each of the C-atoms of the first is replaced with a ring of six C-atoms and the joins between the rings is the same as that between the C-atoms



Ring of six $6C_6$ -rings

A ring of six $6C_6$ rings is formed in the same way as the rings of which it is made.

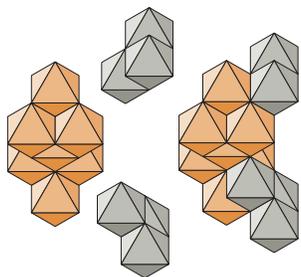
CC_6 group



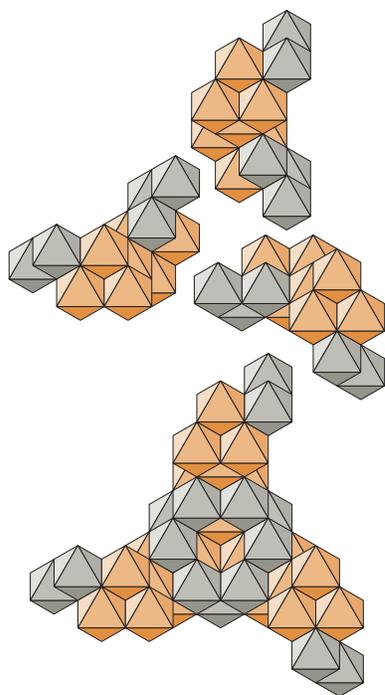
Ring of three C_6 -rings with C-atom links.

The addition of a C-atom to a C_6 ring permits the formation of a ring of three CC_6 groups.

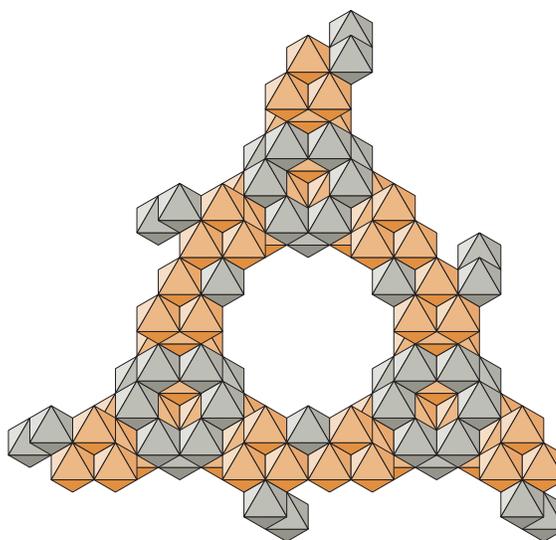
CN

**CN₂C unit**

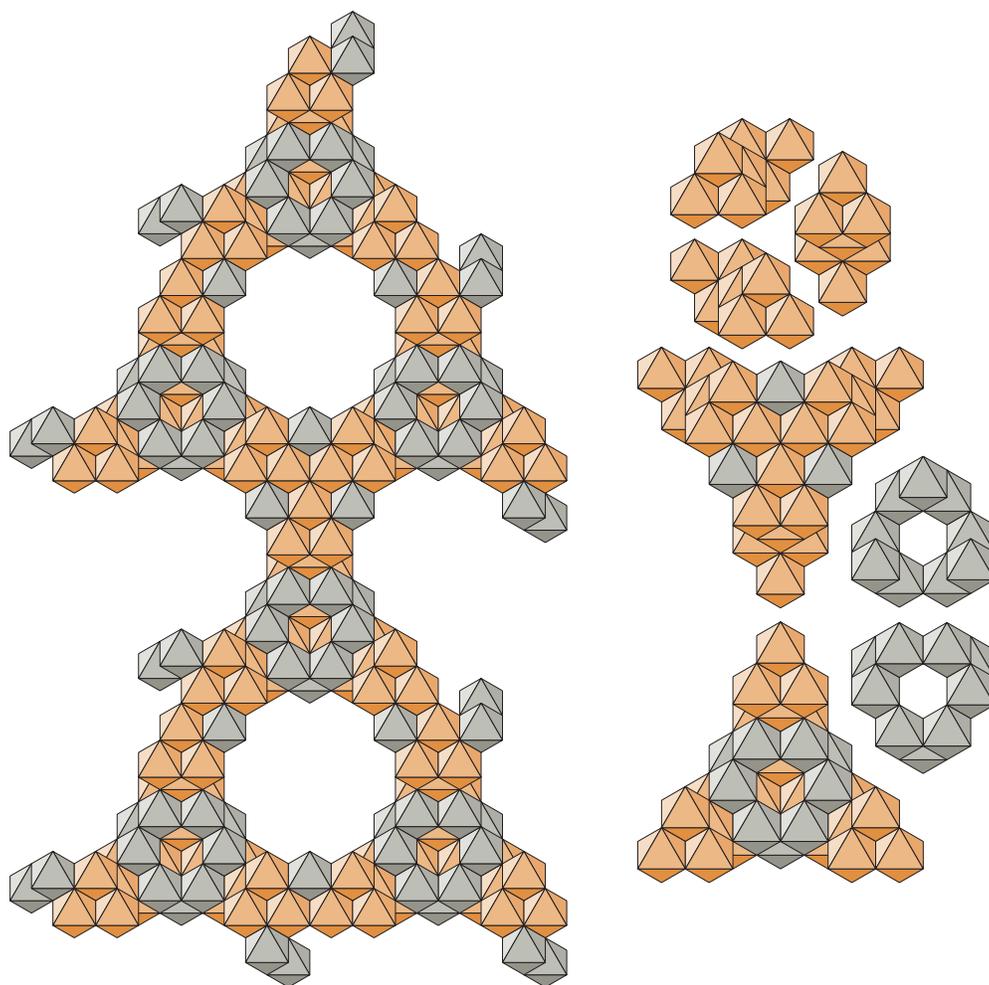
The plane-forming unit to the left is composed of a triplet-paired N₂ group to each N-atom of which a C-atom is cleft joined right-handedly.

**Three CN₂C ring.**

The three CN₂C units grouped at the top of the figure are identical except for a rotation of one-third of a revolution. A C-atom of one unit cleftly joins to an N-atom of a second unit. A third unit joins to each of the first two completing the ring which is at the bottom of the figure.

**Ring of three 3CN₂C rings**

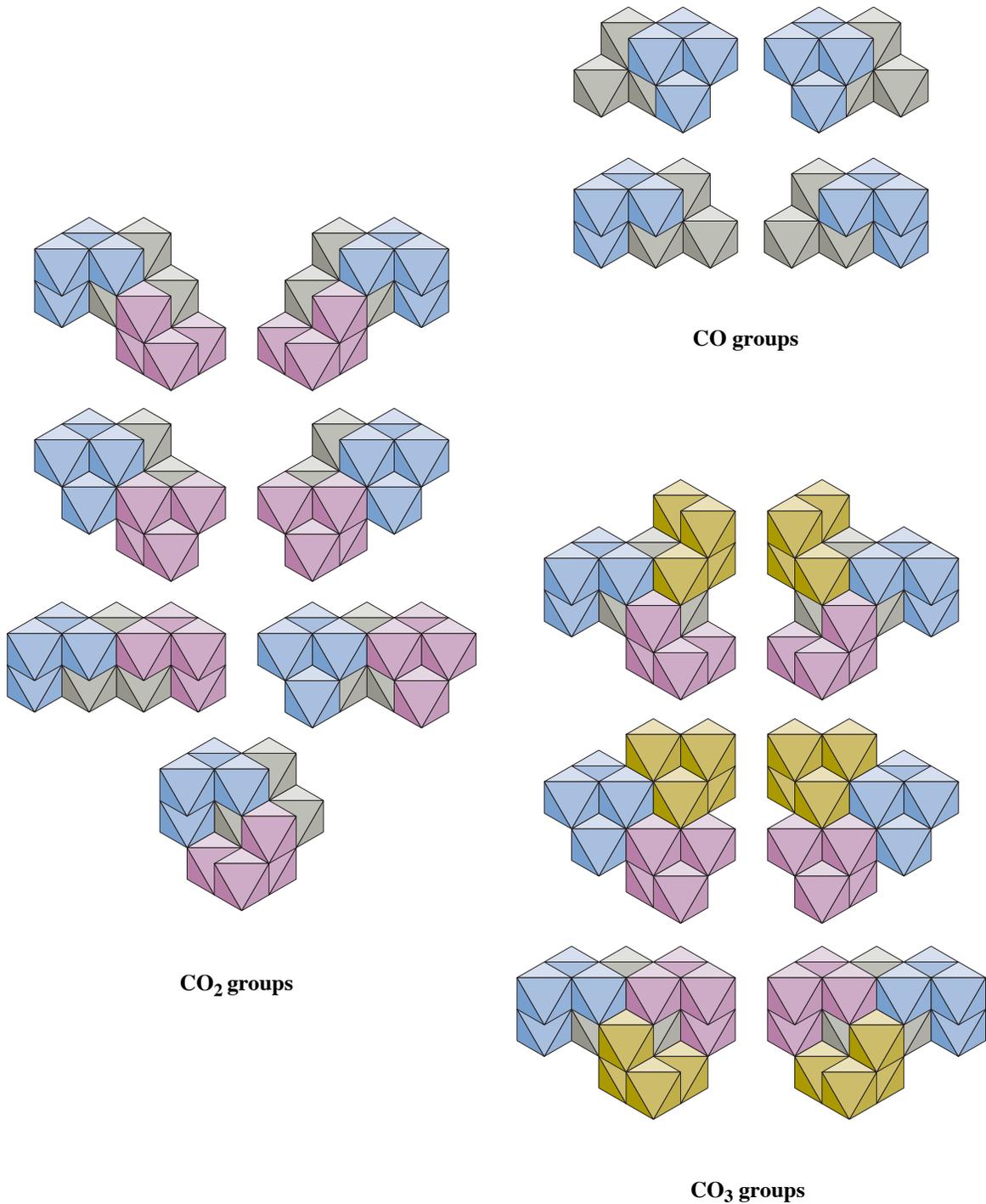
This ring of rings is held together by cleft joins between C-atoms and N-atoms.



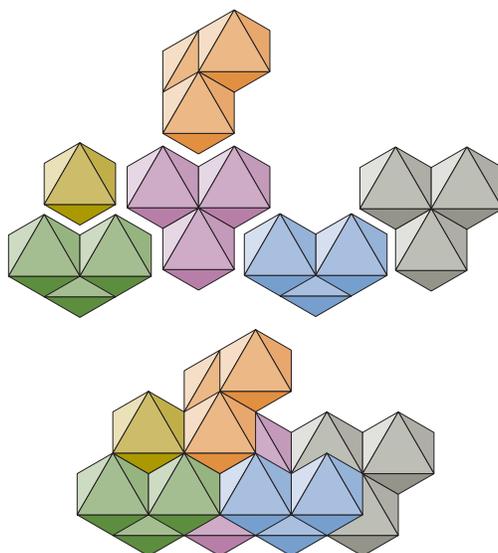
Pair of rings each composed of three 3CN₂C rings.

The figure on the left shows a pair of three 3CN₂C rings joined cleftly by two C-atom to N-atom joins. The figure on the right shows a ring of three CN₂ units which occurs throughout the assembly on the left.

CO, CO₂, and CO₃



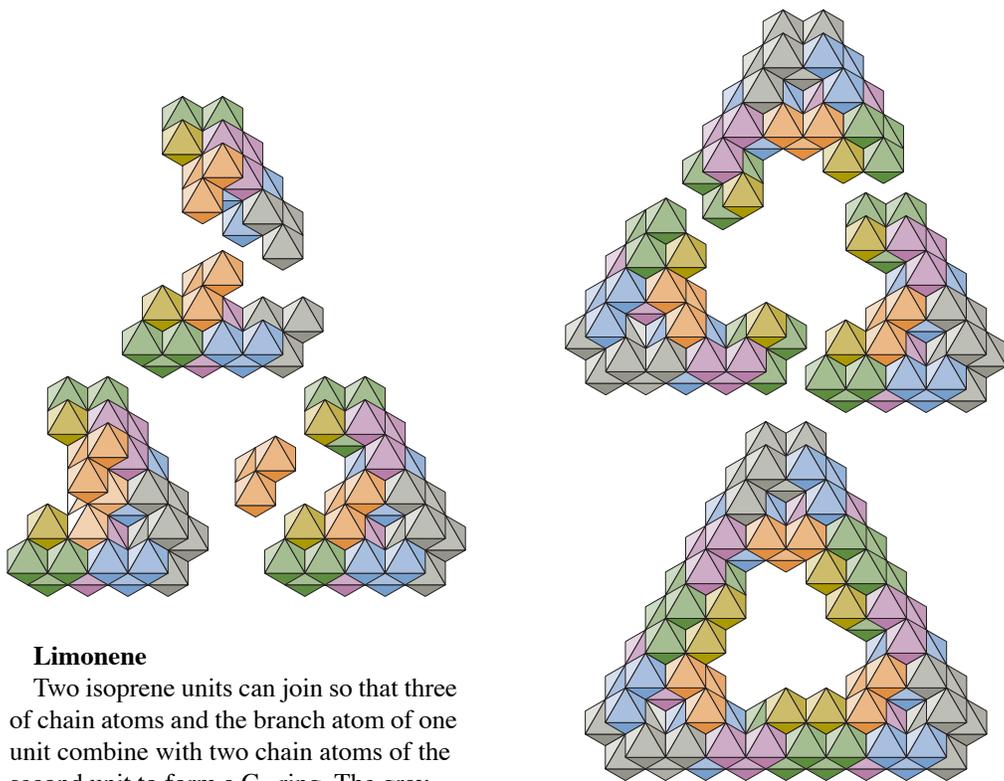
Isoprene



Isoprene

The isoprene unit consists of a chain of four C-atoms to which a C-atom is attached. The figure shows the atoms which combine to form the isoprene unit at the top and the assembled unit below. The chain is formed by the gray, blue, violet, and green C-atoms. The orange C-atom is the branch atom. The yellow octahedron is an H₃-group.

Limonene



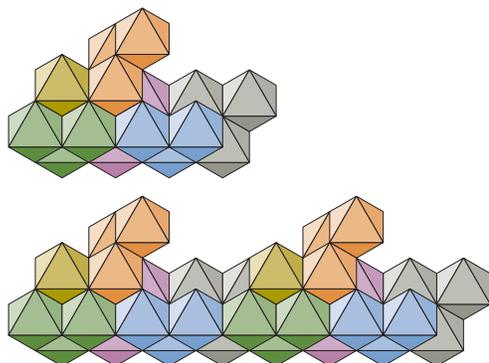
Limonene

Two isoprene units can join so that three of chain atoms and the branch atom of one unit combine with two chain atoms of the second unit to form a C_6 -ring. The gray, blue, violet, and orange C-atoms of the lower unit combine with the gray and blue C-atoms of the upper unit to form the ring. The two isoprene units are shown at the top. At the bottom left is the completed assembly. At the bottom right, the branch atom of the upper unit has been displaced so that the connection between the units can be shown.

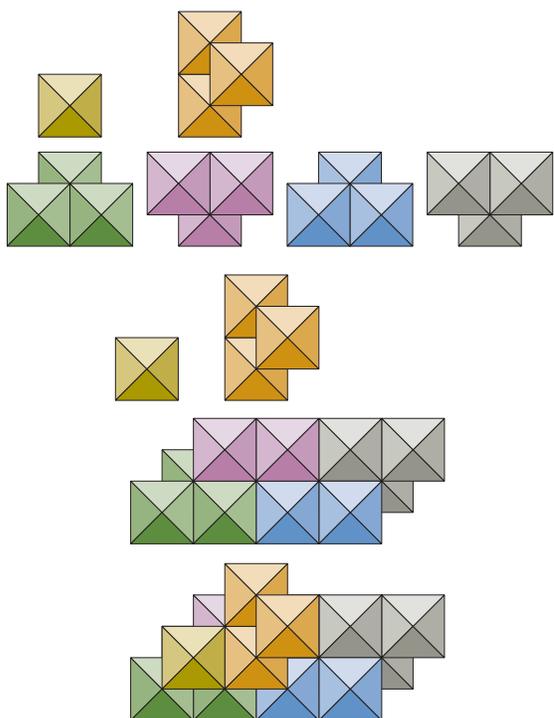
Limonene ring.

Three limonene units can form a threefold ring. The units which form the ring are shown at the top of the figure, the completed ring is at the bottom. The units are shown without the displaced orange C-atom.

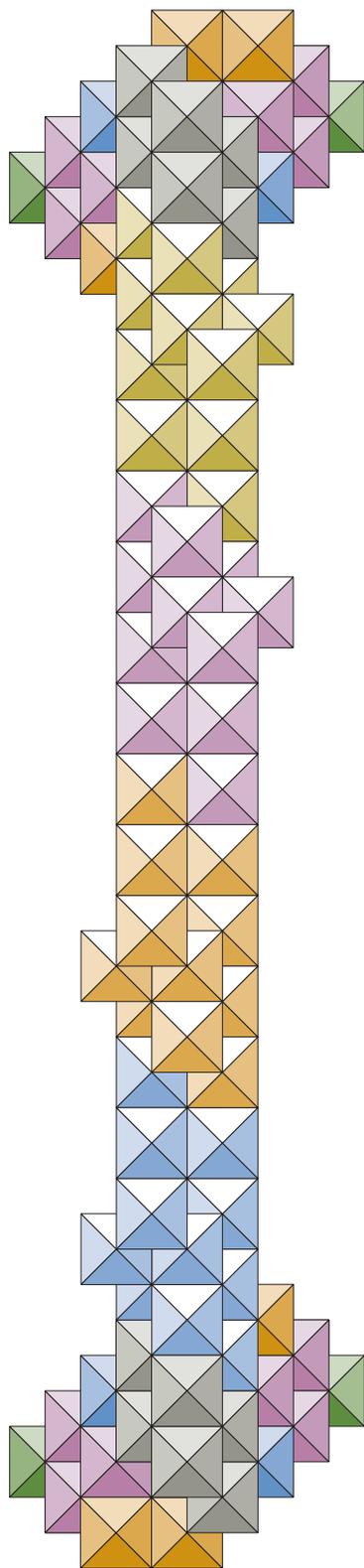
The three limonene units are rotated 120° relative to adjacent units. The join is effected with C-atom to C-atom cleft joins. The unit includes six isoprene units of five C-atoms each for thirty C-atoms. Cf. cholesterol.

β -Carotene**Isoprene chaining**

The chain portion of the isoprene unit is extended by the chain portion of a second isoprene unit in the next figure. A single unit is shown at the top and a pair of joined units is below it.

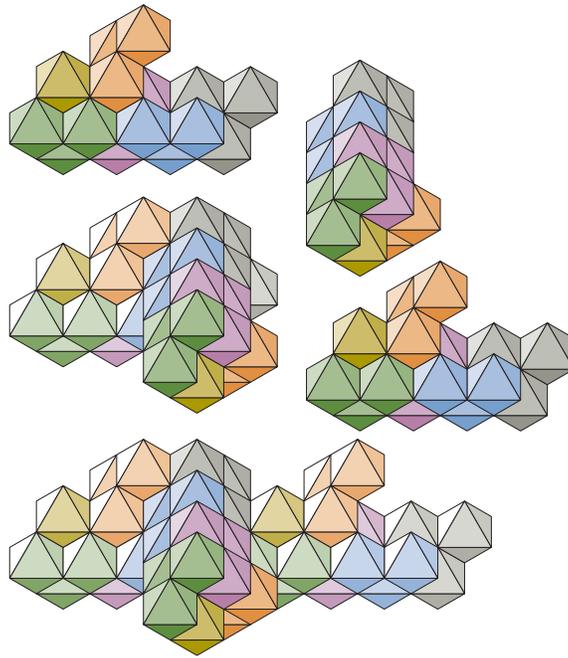
**Assembly of isoprene unit, vertexial view**

The isoprene unit is shown in a vertexial view normal to the chain in the next figure. The atoms which form the unit are at the top and the assembled unit is at the bottom. Between them, the chain is shown separately from the branch atom and the H_3 -group.



β -Carotene

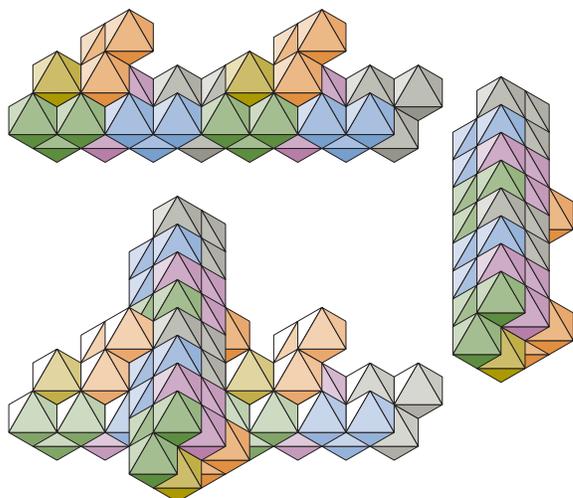
Two cyclicized units are connected by four isoprene units which consist of two pairs of units which are antiparallel components of a single chain. This is a β -carotene unit.



β -Carotene assembly detail

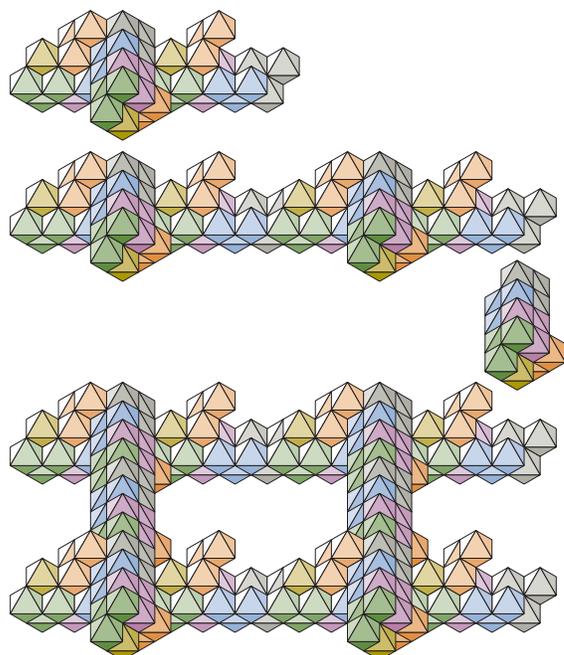
The cyclicized pair of units is shown in another orientation in the figure. The unit in the top left has a chain axis which is parallel to the top edge of the page. An identical unit on the right has an axis which makes an oblique angle with the viewing plane and is perpendicular to the chain axis of the first unit. In the second row of the left column, the two units are paired in the same manner as for the β -carotene assembly. A third isoprene is shown on the right which adds to the pair and extends the chain of the first isoprene unit.

Lattice of isoprene chains



Isoprene chaining—perpendicular junction

Two isoprene chains of two units each are depicted here. The axes of the two chains are perpendicular. The joined pair is shown at the bottom of the figure.

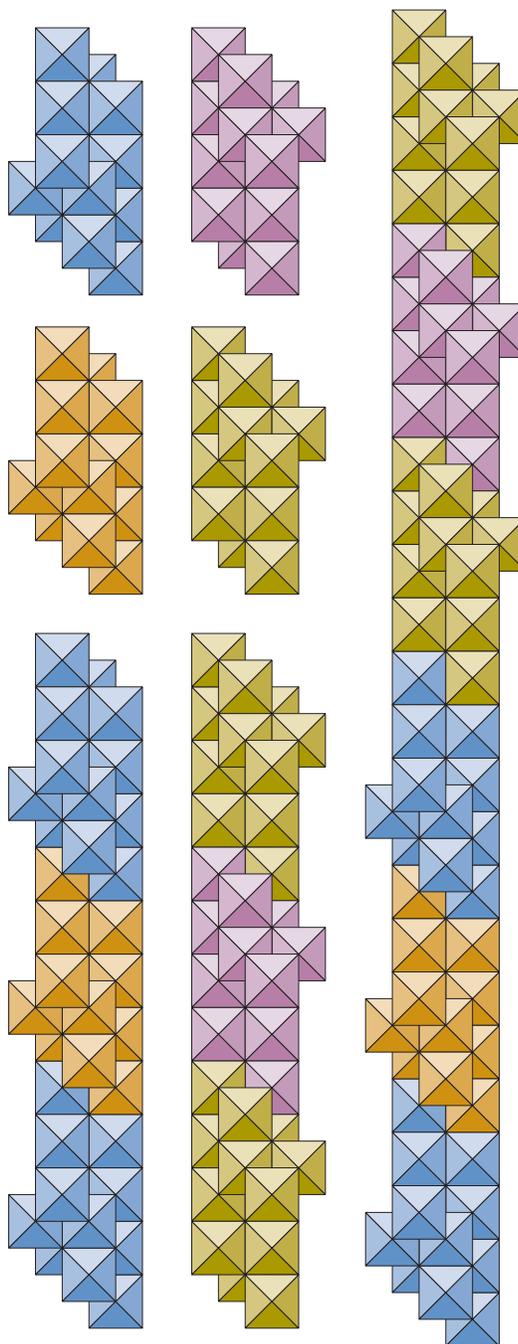


Square lattice of isoprene chains

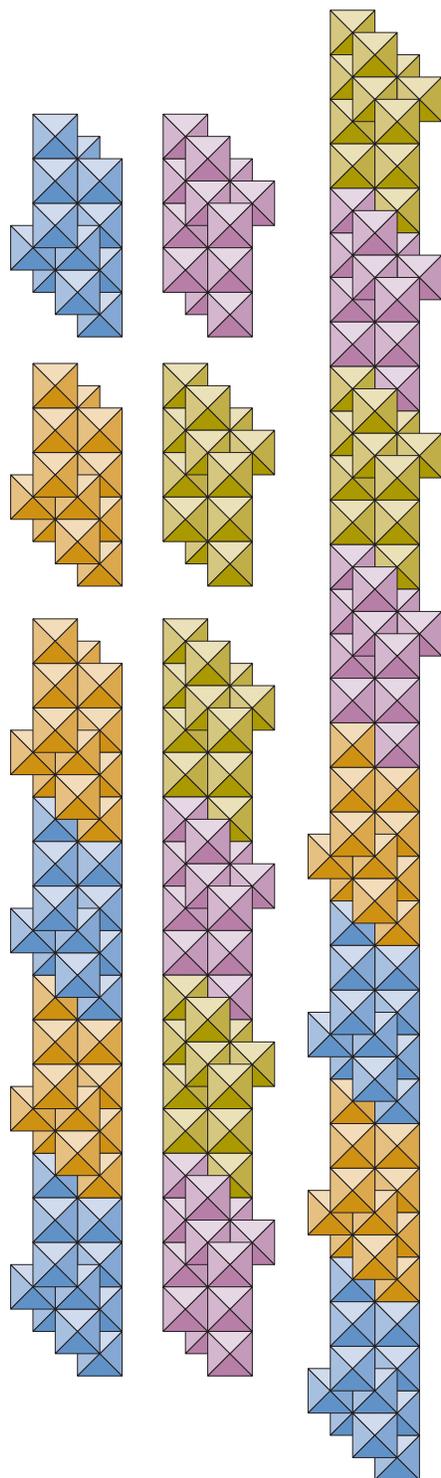
The perpendicular joining of isoprene chains permits the construction of a square lattice which can be extended in the plane. A one unit isoprene chain is joined to a perpendicular two unit isoprene chain at the top of the figure. In the second row, two identical units are joined so as to extend the two unit chain. Two of these chains are joined by a one unit extension between their perpendicular units.

Squalene

Squalene
The figure shows the assembly of two oppositely directed chains of three isoprene units each to form squalene. The isoprene units are colored according to their orientation.

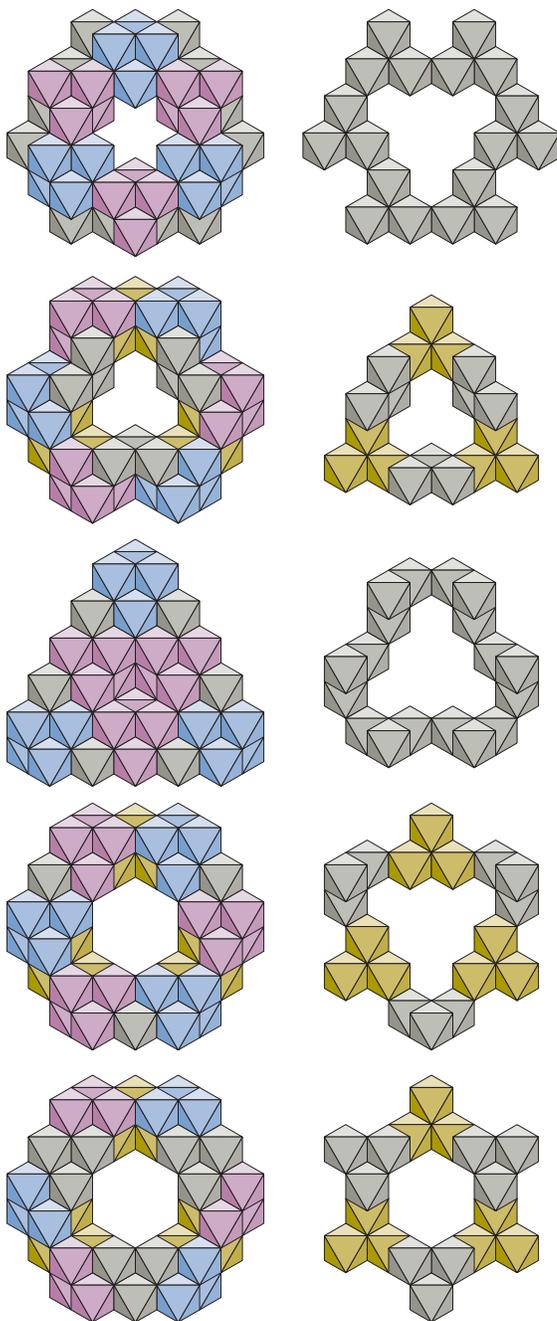


Phytoene



Phytoene
The figure shows the formation of phytoene from two chains of four isoprene units each.

Inositol



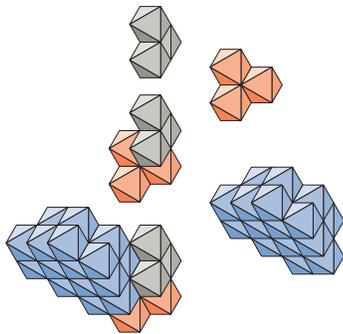
Inositol

There are five different rings of six CO groups each shown here. The complete rings are in the lefthand column. On the right, the arrangement of the C-atoms are shown. Each of the rings is two He-octa facial diameters thick. Each is six He-octa edgial diameters wide. Each is six and two-thirds He-octa facial altitudes deep.

PLASTIC

Styrene

The styrene monomer consists of a pair of C-atoms cleftly-joined and a C₆-group which is cleftly-joined to one of the C-atoms. The figure

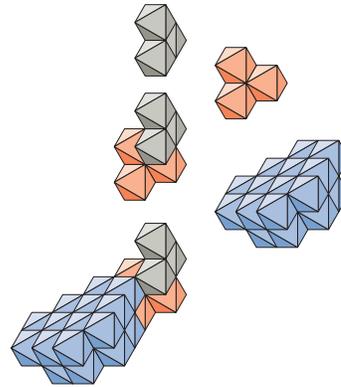


Styrene monomer, type I

The join between the C₆-group and the red C-atom is right-handed.

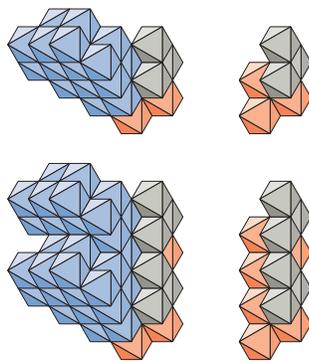
shows the assembly of a styrene monomer.

Another styrene monomer can be formed from the same atoms but with a different cleft-join between the C₆-group and the C-atom. In the first monomer, the join is right-handed; in the second assembly, the join is left-handed.

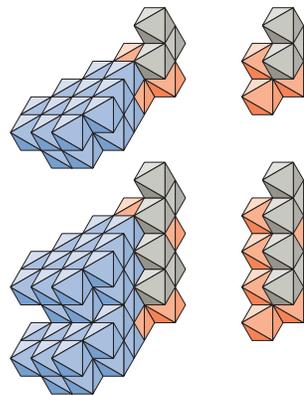


Styrene monomer, type II

The join between the C₆-group and the red C-atom is left-handed.



Styrene polymer

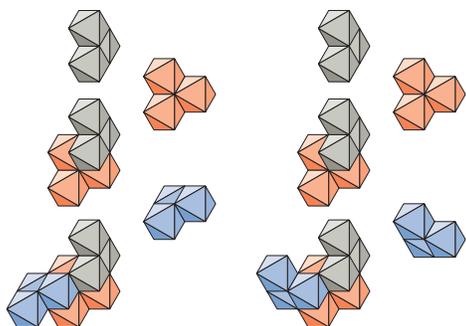


Styrene polymer type 2.

Propylene

Type 1 can only form a chain with its backbone atoms, but type 2 can form a chain in two directions.

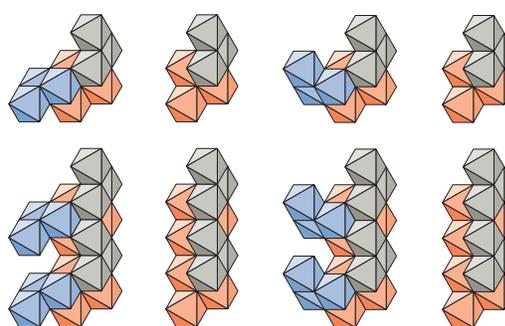
Propylene monomers



Type 1

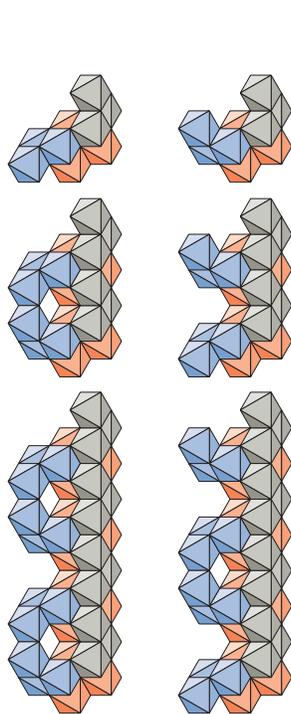
Type 2

Propylene polymers

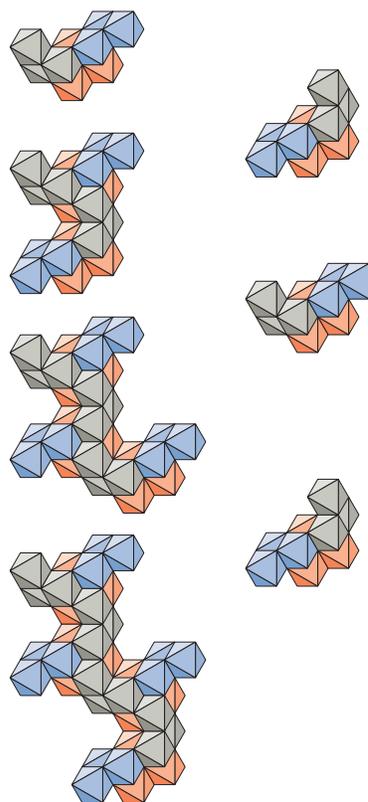


Type 1

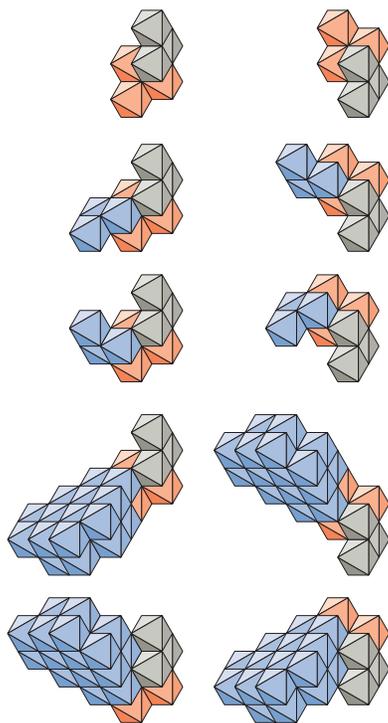
Type 2



Propylene polymer, syndotactic



Propylene polymer, type 1, mixed hand

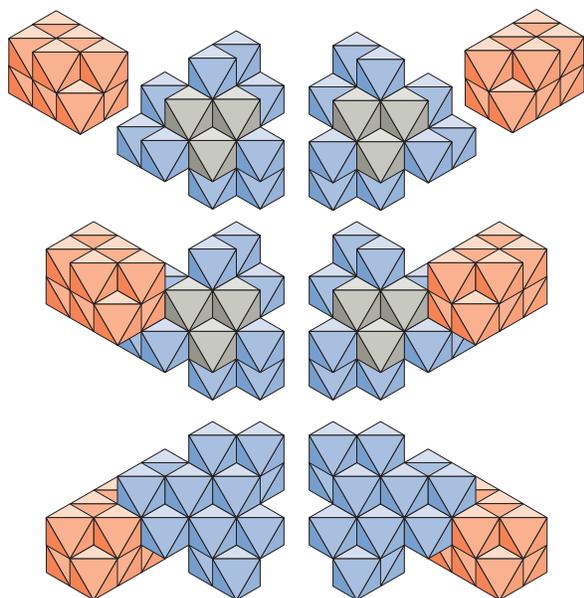
**Handedness of monomers**

The monomers of styrene and propylene in the column on the left have main chain C-atoms joined left-handedly. Those in the right column have main chain C-atoms joined right-handedly.

CARBONATE

Ca-atom joined to a CO₃ group

Three O-atoms can join to a C-atom in two ways which are mirror images. A Ca-atom can cleftly join to any of the three O-atoms of the CO₃ group. The figure shows the two types of



Ca-atom joining to a CO₃ group

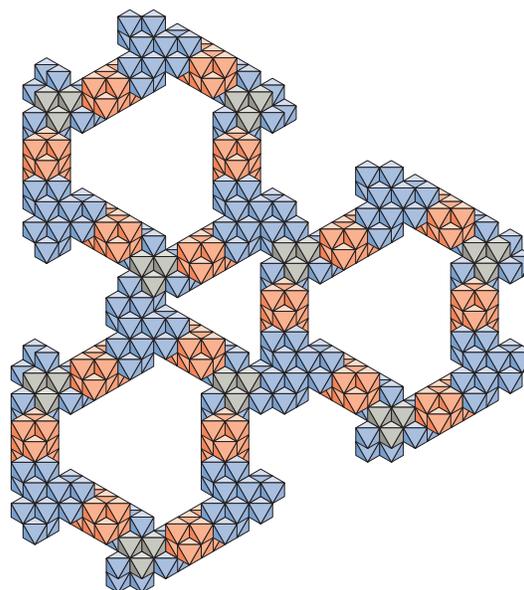
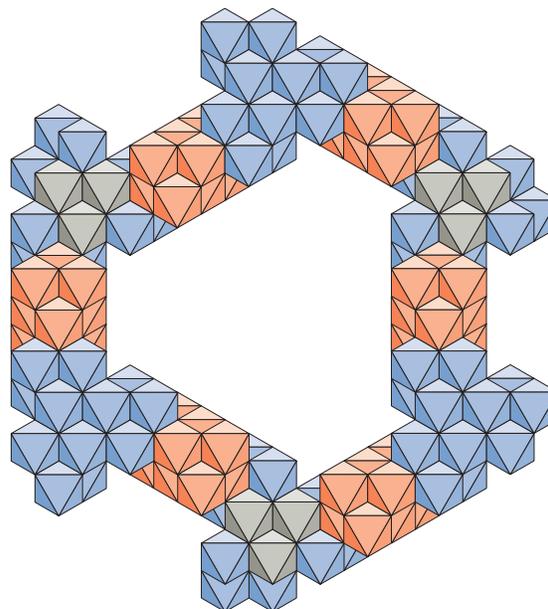
CaCO₃ groups in the middle of the top row with C-atoms to either side. The middle row shows the CaCO₃ groups and the bottom row show the same groups inverted.

Forming a ring of CaCO₃ molecules

Six CaCO₃ groups of the hand shown in the left column of the previous figure can form a ring in which adjoining groups are inverted. Alternate groups are rotated 120° relative to one another.

Planar assembly of 6CaCO₃ rings

The ring of six CaCO₃ groups can join with



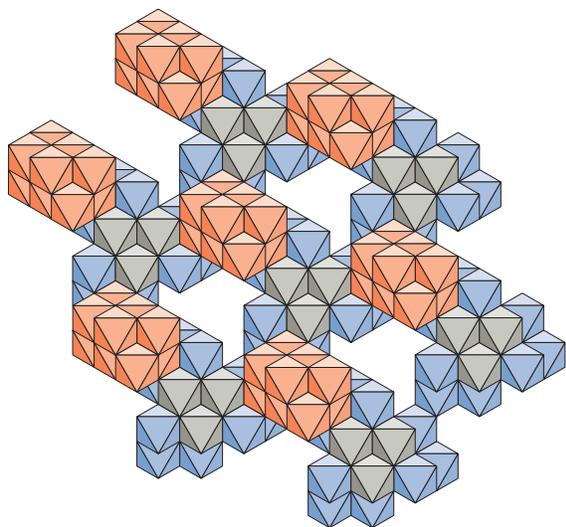
Ring of six CaCO₃ groups

Three 6CaCO₃ rings joined as a ring.

identical rings to form a planar crystal. A ring of three 6CaCO₃ rings is shown in the figure. The join between two rings is a cleft join between an O-atom of each ring.

CaCO₃ assembly with Ca-atom cleftly joined to O-atom

In the previous assembly, the CO₃ groups are in the same plane. The plane is parallel to a pair of faces of the He-octahedra of which its atoms are formed. Another planar assembly which uses the same CaCO₃ groups results in a



Planar assembly of CaCO₃ groups.

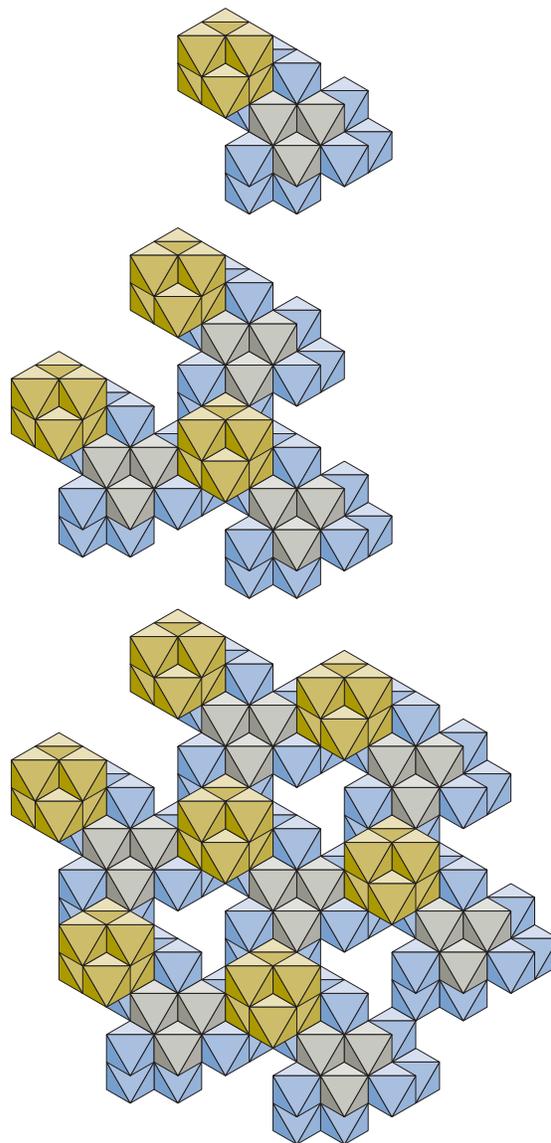
planar assembly in which the CO₃ groups are not parallel to the plane of the assembly. Each of the groups in the assembly is oriented the same as any other.

Planar assembly of MgCO₃ groups

A Mg-atom can join with an O-atom of a CO₃ group so that one of its He-octas occupies a void of the O-atom. The MgCO₃ group can join with identical groups to form a planar assembly in which each of the CO₃ groups lies on the same plane which parallel to a pair of octahedral faces. Each of the groups is oriented in the same manner as any of the other groups.

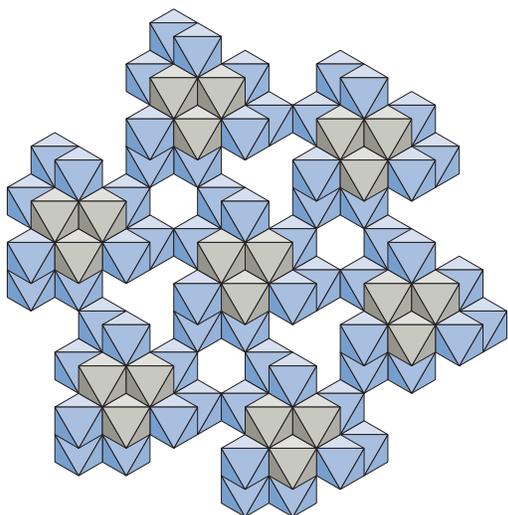
Spacing of the CO₃ groups

The spacing of the O-atoms and their orien-

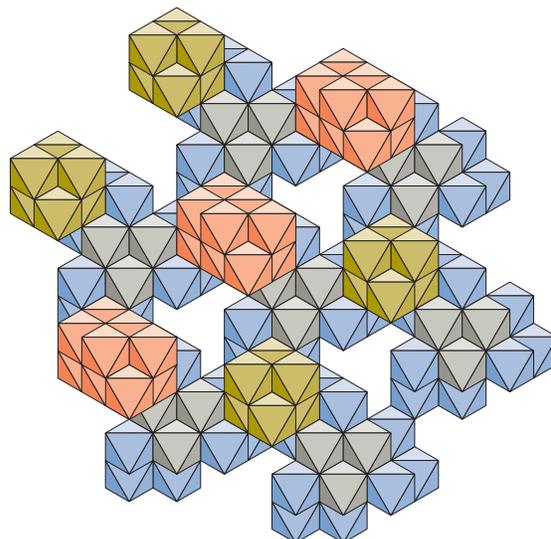


Planar assembly of MgCO₃ groups.

tation is the same for several planar assemblies. This is shown in the figure wherein just

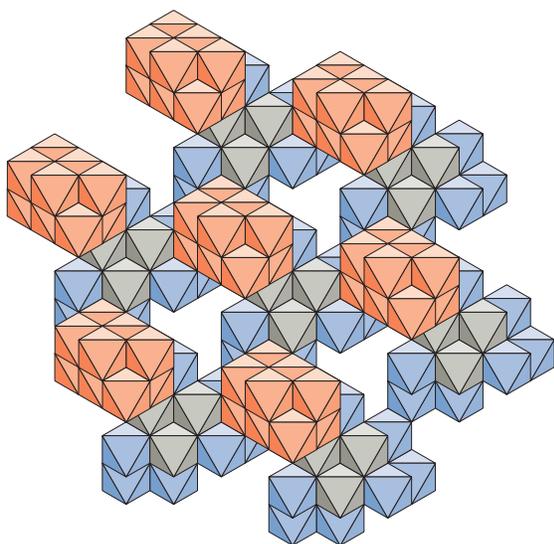


the CO₃ groups are depicted without the Mg-atoms. This spacing is common to the next three assemblies in which the Mg vacancies are occupied by Ca-atoms, both Mg-atoms and Ca-atoms, and Fe-atoms



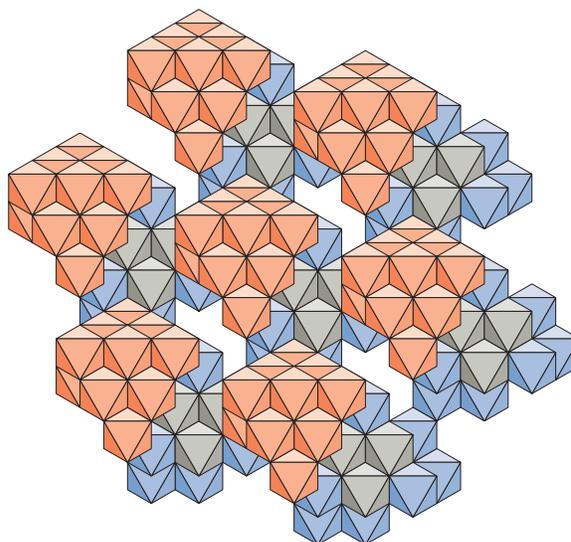
MgCO₃ and CaCO₃ assembly

Ca-atoms are colored red; Mg-atoms are colored yellow



CaCO₃ assembly

Ca-atoms are colored red



FeCO₃ assembly

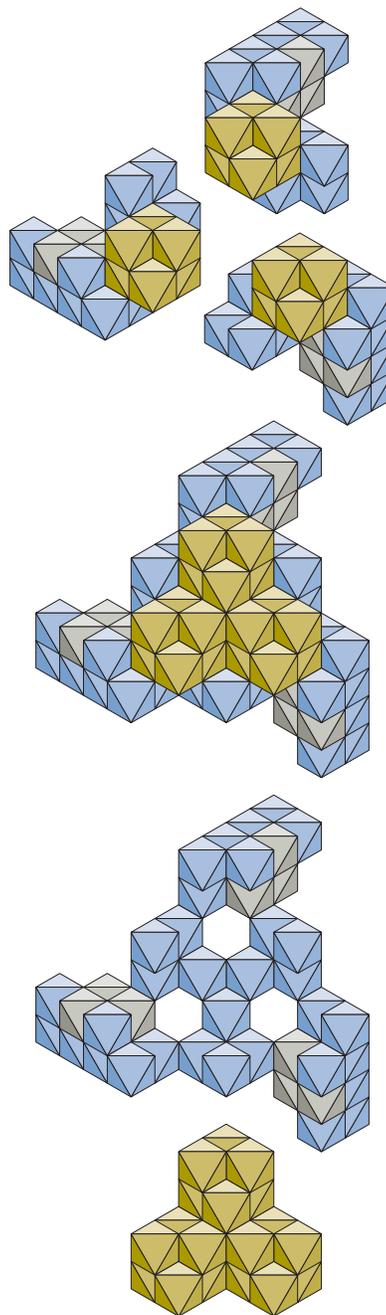
The Fe-atoms are colored red.

Rhombohedral crystals of ROCO_2 groups

None of the previous assemblies has joins which produce rhombohedral crystals. The next groups are characterized by rhombohedral joins. None of them contains a CO_3 group. The formula is more precisely stated as ROCO_2 which is what the chemical analyses reveal to be true for minerals. The CO_2 group is a linear group in which a C-atom joins two O-atoms to form a short chain. The O-atoms are identically oriented. In MgOCO_2 , the chain is joined to a CaO group to form the crystal unit. The units are in one of three orientations which differ by a rotation of 120° . The chain axis is parallel to a pair of edges of the He-octa. In the crystal, the chain-axis of one unit is colinear with that of the other units in a given join direction. The Mg-atom is joined to an O-atom of the colinear unit.

In the above figure, the three MgOCO_2 groups are depicted at the top in the orientations which they have in the crystal. The view is along the threefold axis. The three assembled units are depicted just below the individual units. Each Mg-atom shares an edge with each of the other Mg-atoms. The remaining void of the O-atom of the MgO group is filled by a He-octa of a Mg-atom of an adjoining crystal unit.

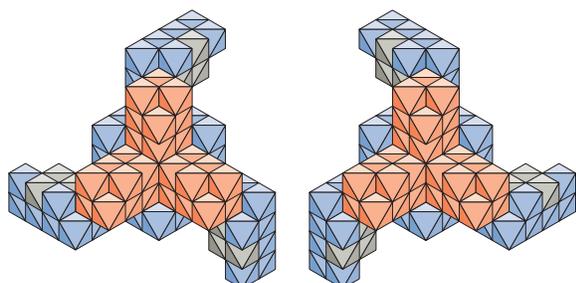
Just below the depiction of the three chain assembly, the arrangement of the three OCO chains and the O-atoms of the MgO are shown as they are in the assembly. Below this, the three Mg-atoms are shown as they appear in the assembly.



Rhombohedral crystal of MgOCO_2 .

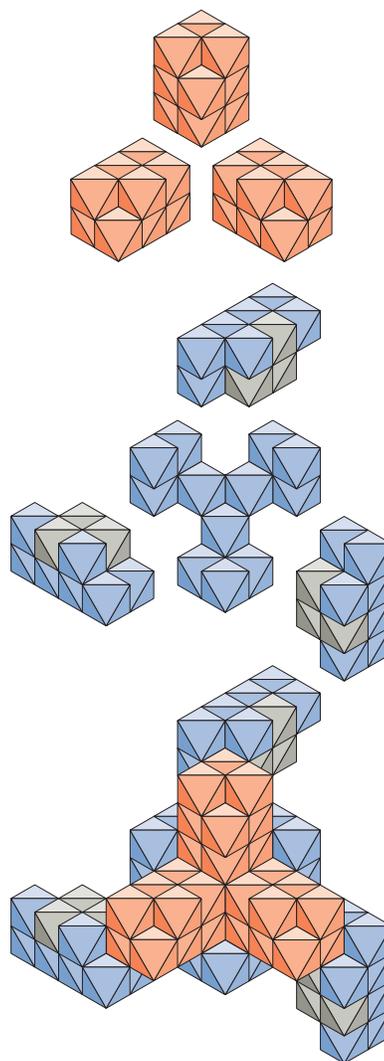
Rhombohedral crystal of CaOCO_2

The crystal unit for CaOCO_2 is formed in the same way as the MgOCO_2 crystal unit. In the figure, the three Ca-atoms are shown in the orientation each has in the crystal. Below these atoms is the arrangement of the CO_2 chains and the O-atoms of the CaO groups. At the bottom of the figure is the assembly of the three crystalline units.

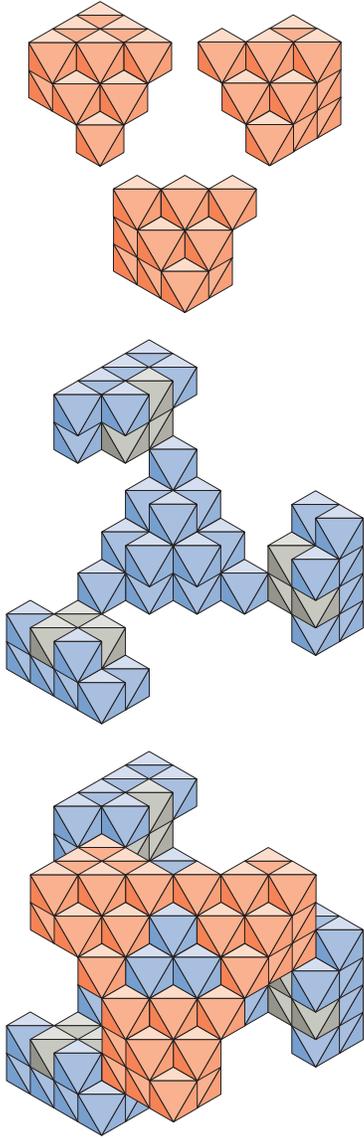


Rhombohedral crystals have handedness.

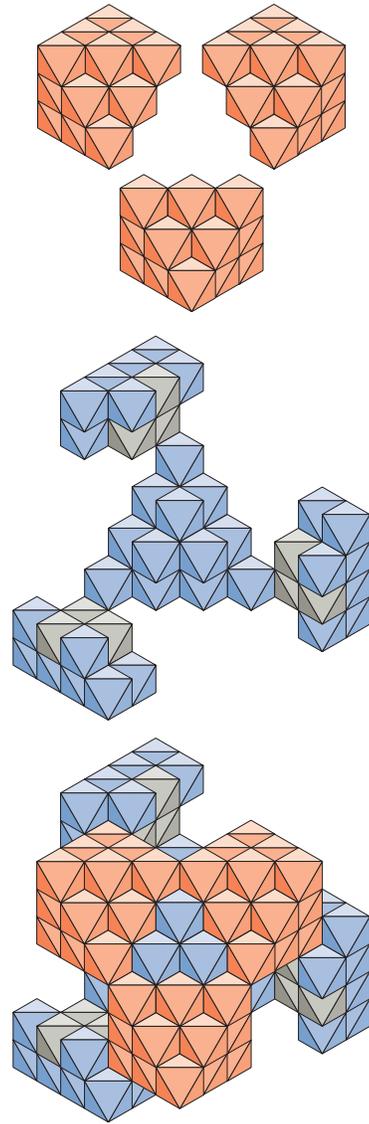
The O-atom of the CO_2 group can join at the same position of the Ca-atom in one of two ways. If the CaOCO_2 units are identical, then they can form a rhombohedral crystal. The two crystal units which result from each of the two rhombohedral joins are shown in the figure. The units are mirror-images on one another. While only the CaOCO_2 crystal units are depicted, the handedness is possible in each of the rhombohedral crystal formers.



Rhombohedral crystal of CaOCO_2 .



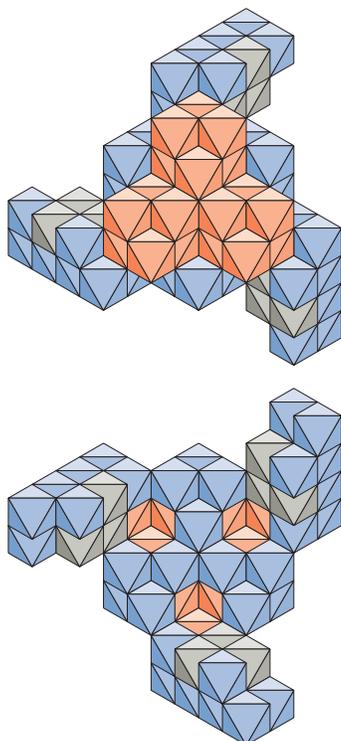
Rhombohedral crystal of FeOCO₂.



Rhombohedral crystal of ZnOCO₂.

Three fold axial view of crystal units.

The crystal units are terminated on one end by a Mg-atom and at the other by an O-atom. The Mg-atom of the crystal unit is towards one end of the threefold axis and the O-atom is towards the opposite end of the threefold axis. this is seen in the next figure where the threefold assembly of crystal units is viewed parallel to the threefold axis from either end.



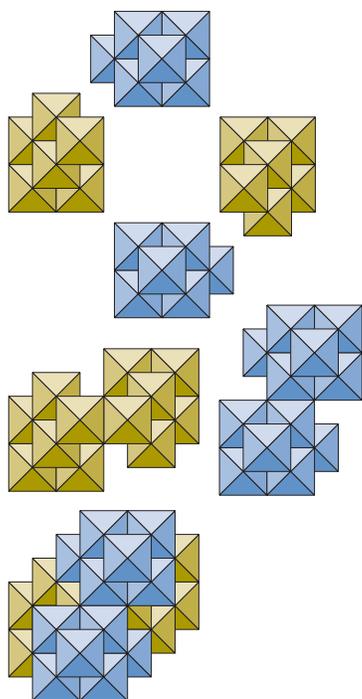
Assembly of MgCO₃ crystalline units viewed from either end of the threefold axis.

SULPHUR

Rings

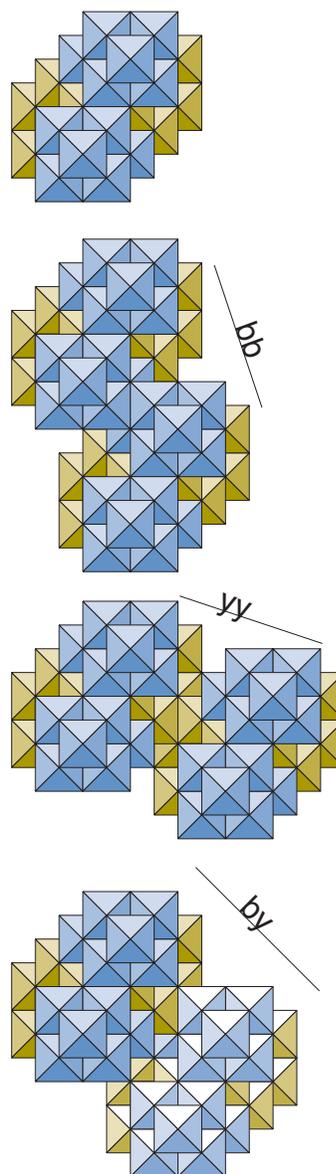
S₄ ring

Four S-atoms can cleftly join to form a ring with a vertexial axis. Each S-atom which is colored yellow has its S-octa towards the viewer. The two yellow atoms differ by a rotation of one half revolution about the viewing direction. The blue atoms are inverted relative to the yellow atoms and rotated one half revolution about the viewing direction.



Of the four clefts of the S-atom, two are used for the joins and one is blocked by the joining. The remaining NeSi-cleft of each atom is available for joining. Joining two units yellow cleft to yellow cleft is a translation parallel to the viewing plane. The blue to blue join is also a translation parallel to the viewing plane. Blue

to yellow joins make an angle with the viewing



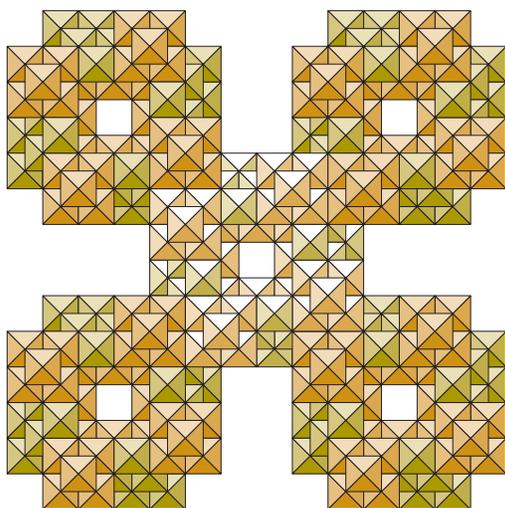
3	1	by-joins are 45,2 or 43,2.
2		yy-joins are 56,1,56,3.
6	5	bb-joins are 56,3,51,1

plane. The figure shows a single ring at the top. Below it are ring pairs which are cleftly joined in the three possible NeSi-cleft joins.

S₈ ring

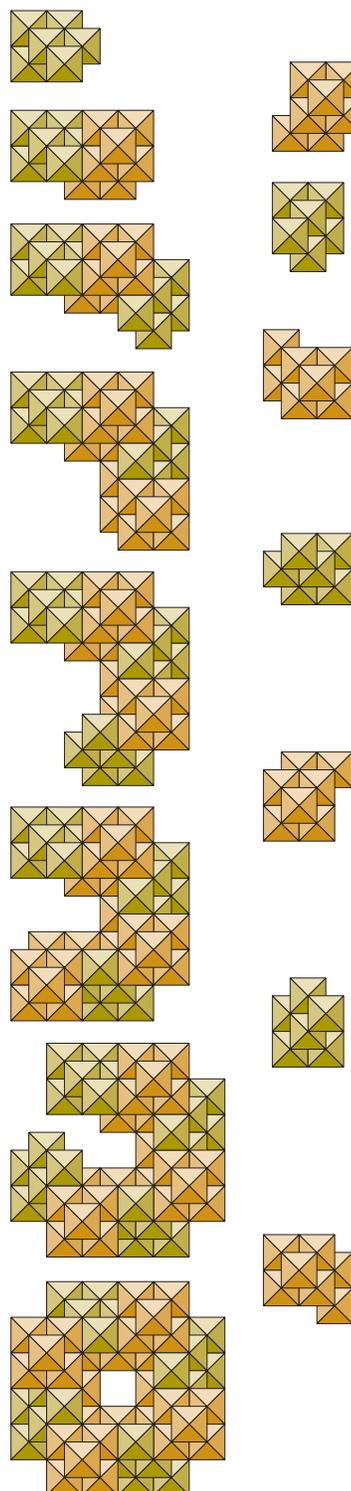
An S₈ ring is described¹ as the arrangement of S-atoms in a face-centered orthorhombic crystal. The assembly of the ring is shown in the figure to the right.

Two rings could join so that two S-atoms of each ring supply a face of a regular tetrahedron. The central ring in the figure shown here is so joined with each of the four rings surrounding it.



Joining of S₈ rings.

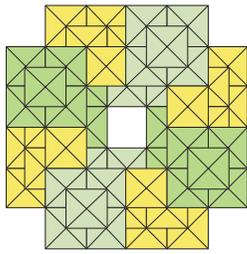
The central ring is joined to each of the four surrounding rings to form a structural assembly. The planar assembly is extensible.



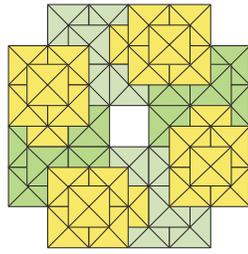
S₈ ring assembly

The S-atoms on the right add to the growing ring assembly on the left.

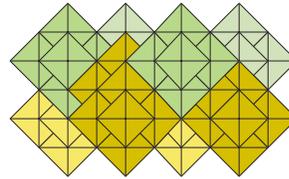
1. Brian Mason & L. G. Berry, *Elements of Mineralogy*, W. H. Freeman and Co., San Francisco 1968, p. 216 <Figure 8-8><(d) An S₈ ring (each sulfur atom has two closest neighbors); 16 such rings are contained in the face-centered orthorhombic unit cell.>



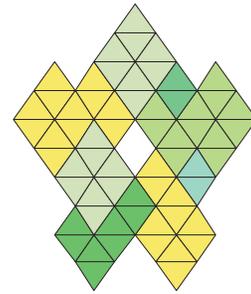
S₈ ring, parallel to axis of symmetry



S₈ ring, inverted, parallel to axis

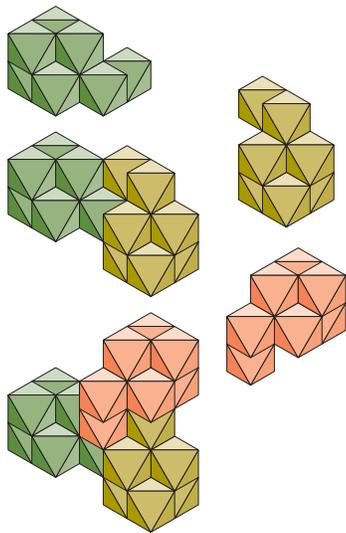


S₈ ring, normal to axis of symmetry

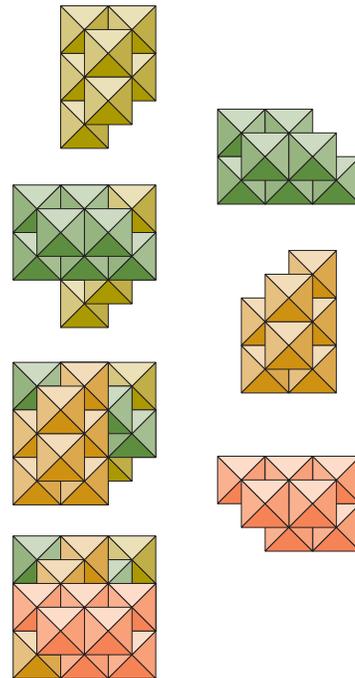


S₈ ring, a- or b-axial

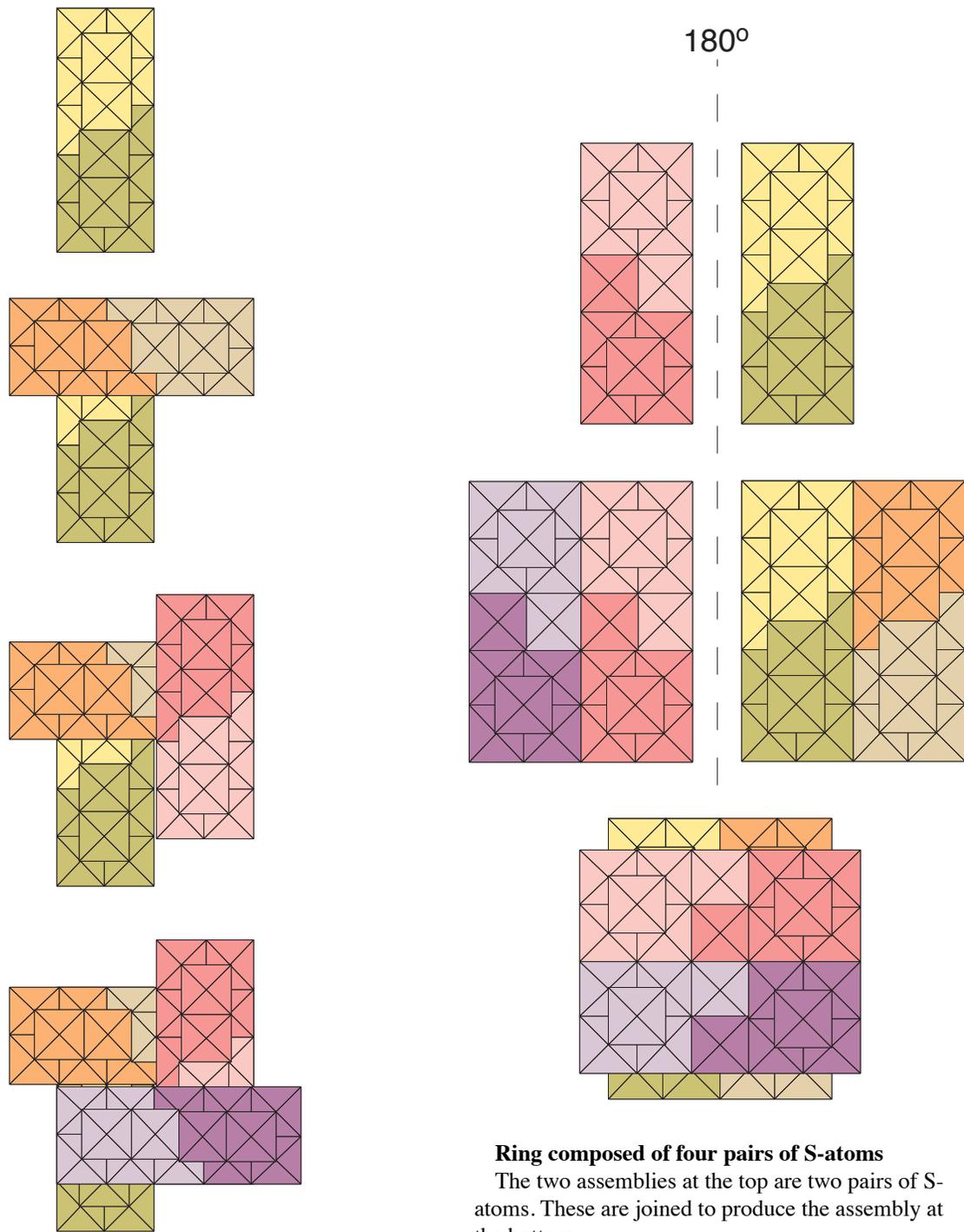
Helices



Threefold helix of S-atoms, single turn



Fourfold helix of S-atoms, single turn



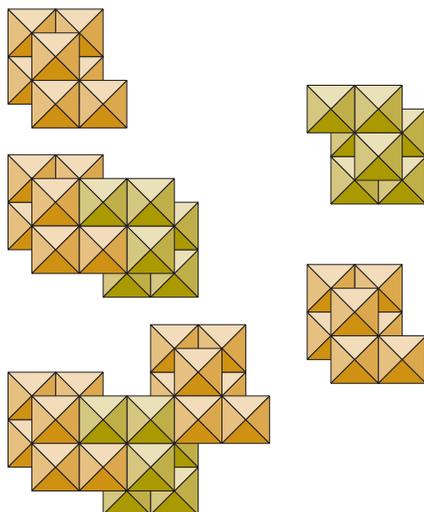
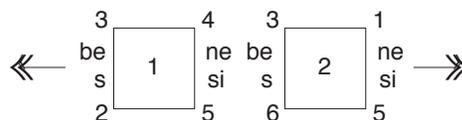
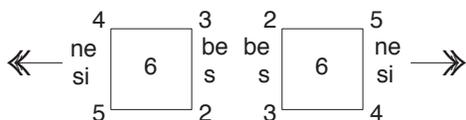
Helix composed of four pairs of S-atoms

Ring composed of four pairs of S-atoms

The two assemblies at the top are two pairs of S-atoms. These are joined to produce the assembly at the bottom.

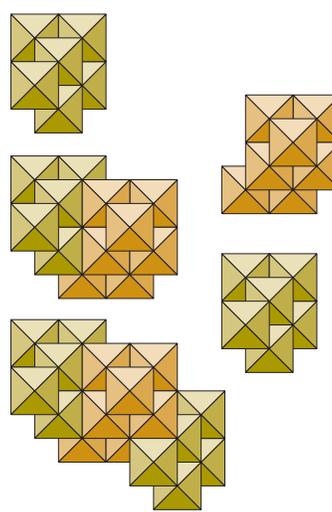
S-atom chains

A pair of S-atoms cleftly joined can join cleftly with identical pairs in identical orientations to produce chains.



S-chain I

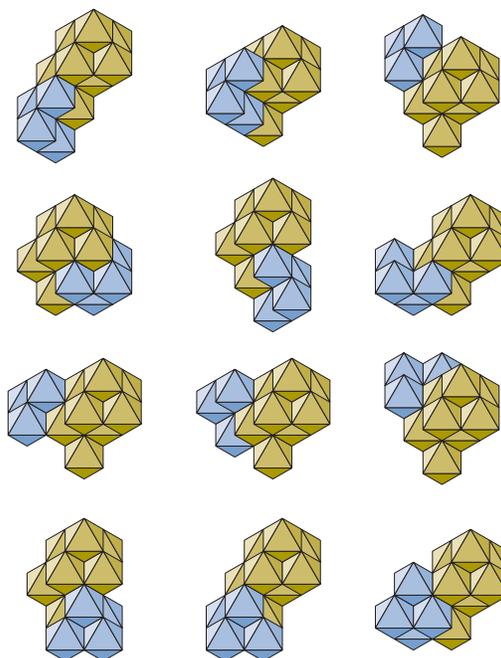
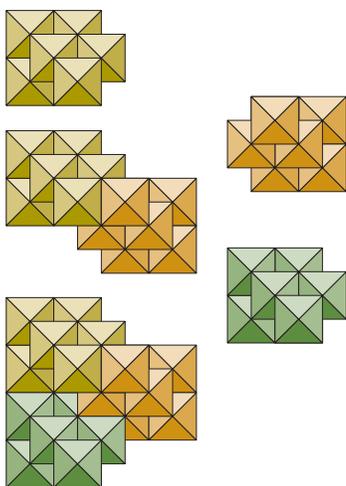
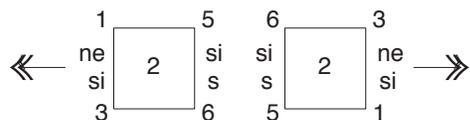
The second atom cleftly joins the first atom be-slbe-s. The third atom, which has the same orientation as the first, adds to the pair by joining cleftly to the second atom ne-silne-si.



S-chain II

The second atom cleftly joins to the first atom be-slne-si. The third atom, which is identically oriented to the first, joins to the second atom be-slne-si.

SO groups

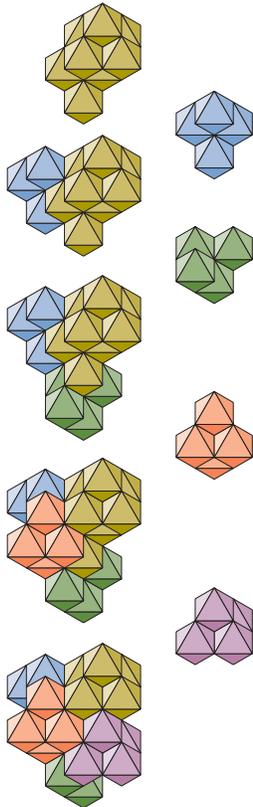


S-chain III

The second atom cleftly joins to the first atom si-slsi-s. The third atom, with the same orientation as the first, cleftly joins the second atom ne-silne-si.

Cleftly joined SO groups.

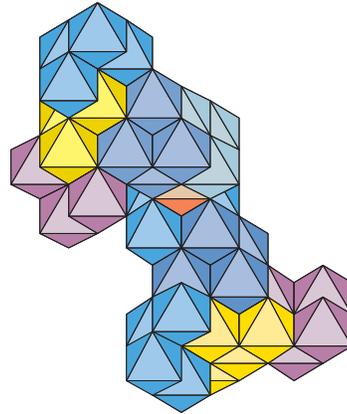
The twelve groups shown are the possible combinations in which an S-atom and an O-atom are cleftly joined. The S-atom has the same orientation in each of the depicted groups.

SO₄ group**SO₄ group**

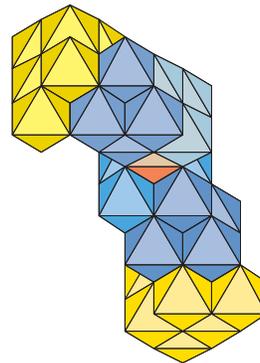
The assembly of an SO₄ group is shown in the left column. The O-atoms are shown on the right. The second O-atom is not cleftly-joined to the S-atom, while the other three O-atoms are so joined.

2H₂SO₄ group

This group consists of two SO₂ groups joined by a pair of H₂O groups whose H₂-groups are triplet-paired.

**2H₂SO₄ group.**

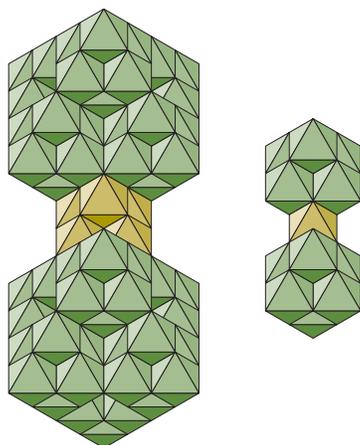
This figure shows how an O-atom cleftly joined to the S-atom is cleftly joined to the O-atom of an H₂O-group.

**2H₂OSO group**

ALUMINUM

Alumina Al_2O_3

The arrangement of the alumina group proceeds with the notion that the triplets of the two Al-atoms are paired. The paired triplets result in the equivalent of a Si-octa shared by the Si-atom and the Mg-atom.

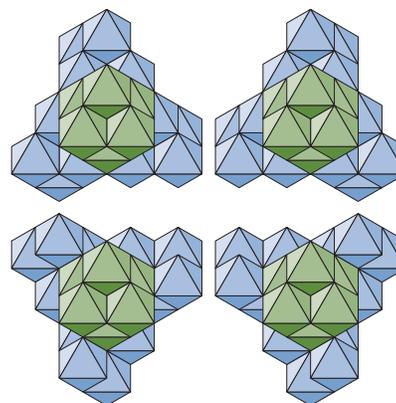


Al_2 group.

A pair of Al-atoms which are triplet-joined is shown in epn detail on the left and in He-octa detail on the right. The paired triplets are colored yellow.

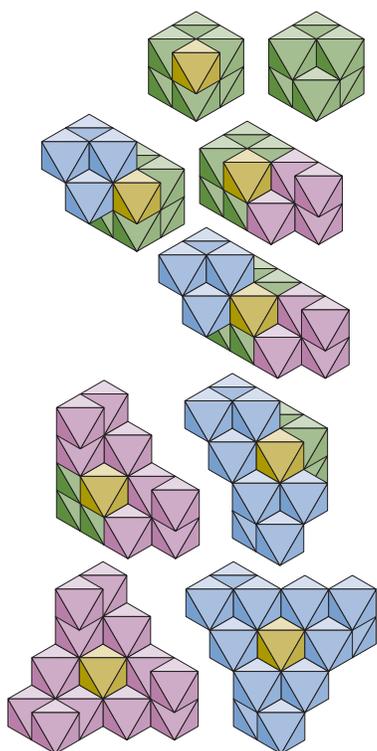
The Al_2 group provides a cleft for each of three adjoining O-atoms. Three O-atoms in the same orientation, except for a rotation about the axis defined by the paired Al-atoms, are joined to the same Al-atom so that a he-octa location of each O-atom is filled by a he-octa of the Al-atom. The O-atom has a Ne-location and a Mg-location. Either location can be filled by one of three he-octas of each Al-atom. Each joining permits two orientations of the O-atom. These four joins result in just two forms. In each form, either the 2-vertexial direction of the O-atom or the 4-vertexial direction of the O-atom is parallel to the 6- or 5- or 2-vertexial direction of the Al-atom and has either a clock-

wise or counterclockwise sense because of its radial displacement from the Al-Al axis. The two forms of the alumina groups are differentiated as either clockwise or counterclockwise based on the arrangement of the O-atoms.



Al_2O_3 groups

The O-atoms join to the Al_2 group in two different ways. Each way is shown in two views which differ by a rotation about an axis which is parallel to the bottom of the page. The views in the left column are of the same group. Those in the right are of the other group. The groups mirror one another.

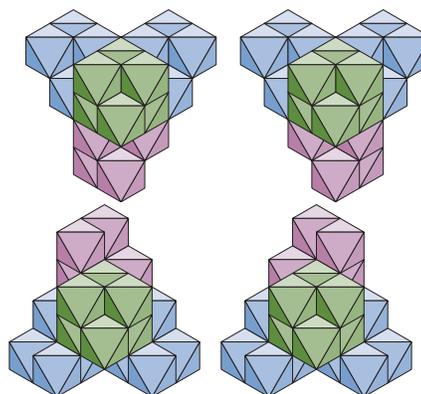


O-atom attachments on Al-atoms of Al₂ group.

If two O-atoms are joined to one of the paired Al-atoms, a third cannot be attached to the other Al-atom. If an O-atom is cleftly joined to each Al-atom then there is no place to attach a third O-atom.

At the top the Al₂ group is shown separated into a Si-portion on the left and a Mg-portion on the right. In the second row, the Si-portion is shown with one O-atom in each of two orientations. The one on the left is making a cleft join with the Si-portion and the one on the right is not. In the third row, the Si-portion has each of the two O-atoms mounted in the same orientation and the same position as the row above. It is seen that there is no place to mount a third O-atom. In the fourth row, there are two Si-portions each with two O-atoms mounted. The blue colored O-atoms are cleftly-joined to the Si-portion. In the bottom row, each Si-portion has three O-atoms mounted. In each SiO₃ group, each O-atom differs from its neighbors by a rotation of one-third turn about an axis parallel to the viewing direction.

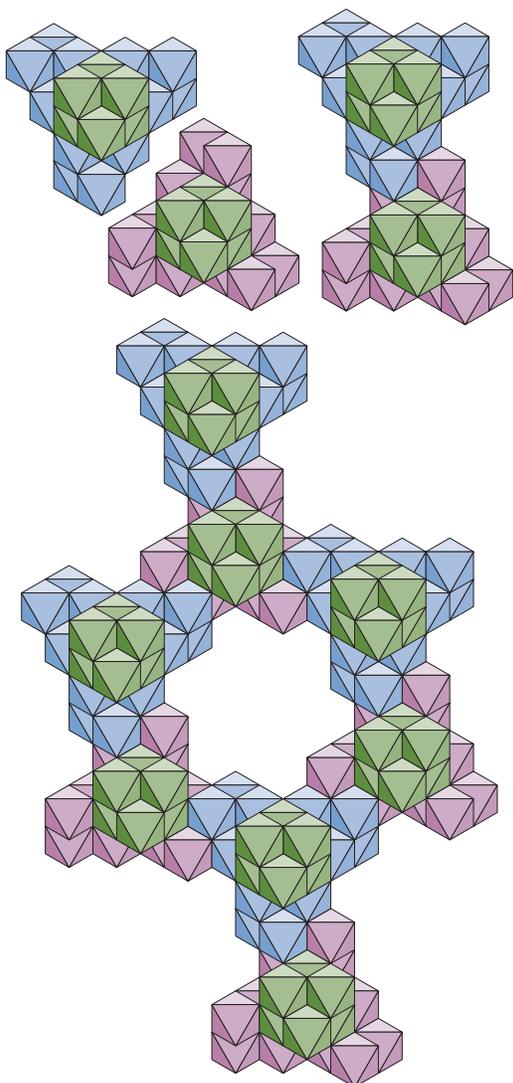
Another form of alumina group occurs when the O-atoms are of mixed rotational orientation, either two clockwise and one counterclockwise or two counterclockwise and one clockwise.



Al₂O₃ group with mixed O-atoms.

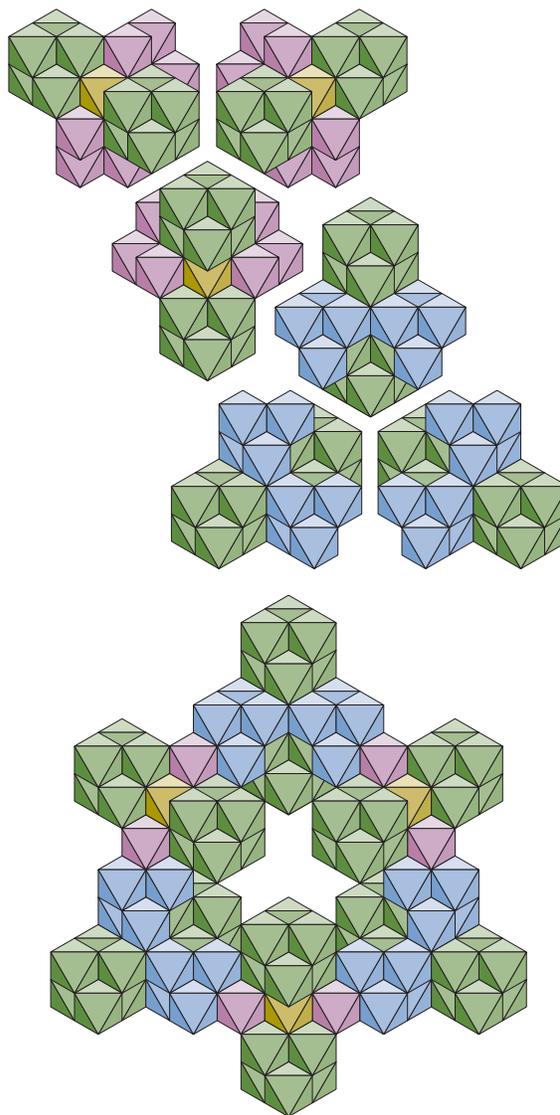
Ring of six alumina groups

A ring can be formed using six alumina groups, three with clockwise O-atoms and three with counterclockwise O-atoms. Adjoining alumina are of opposite hand and inverted relative to one another. In its top lefthand corner, the figure shows a counterclockwise alumina with blue colored O-atoms and an inverted clockwise alumina with violet colored O-atoms. To the right of these individual alumina the two are shown joined O-atom to O-atom. Four identical pairs are used to form the ring in the lower part of the figure. The pair is the cfu for the planar crystal of which the ring is a part.



Ring of six mixed-O-atom Alumina groups

Alumina which has adjacent O-atoms in the same orientation, mixed clockwise and counterclockwise, can form a ring of six peculiar to the type. It is a double threefold ring in which



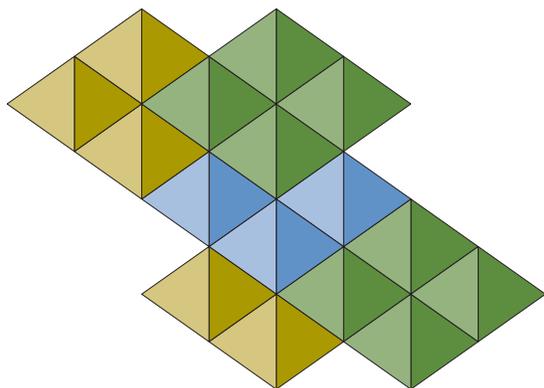
Ring of six mixed-O-atom Alumina groups

the Al-Al axis of the alternate alumina groups differ by a rotation of $1/3$ turn about the normal to the plane of the ring. Adjacent alumina differ by a rotation of $2 \cdot \tan^{-1} \sqrt{2}$ about an axis perpendicular to the Al-Al axis and in the

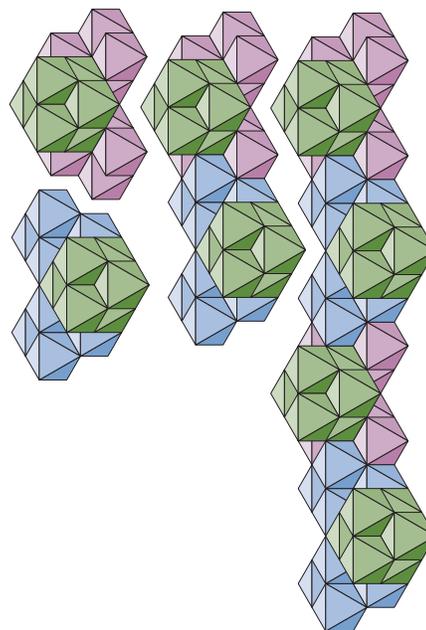
plane defined by the Al-Al axis and the ring normal as well as a rotation about the ring normal of $1/6$ turn. The arrangement is shown in the figure except that the third O-atom of each alumina group, which has no role in the formation of the ring, is not shown. The third O-atom can be of either hand. Three of these atoms will be on either side of the plane of the ring.

Chain of mixed-O-atom Alumina groups

The O-atoms of each of the Al_2O_3 groups which participate in the chain have the same orientation. Adjoining groups are rotated one half turn about the chain axis. Adjoining groups are linked by cleftly joined O-atoms. The third O-atom of each group can be in either of the allowed orientations. The chain forming unit is a pair of adjacent alumina groups. The chain units then join with a translation in a direction which is parallel to an edge of the regular octahedron of which the atoms are composed.



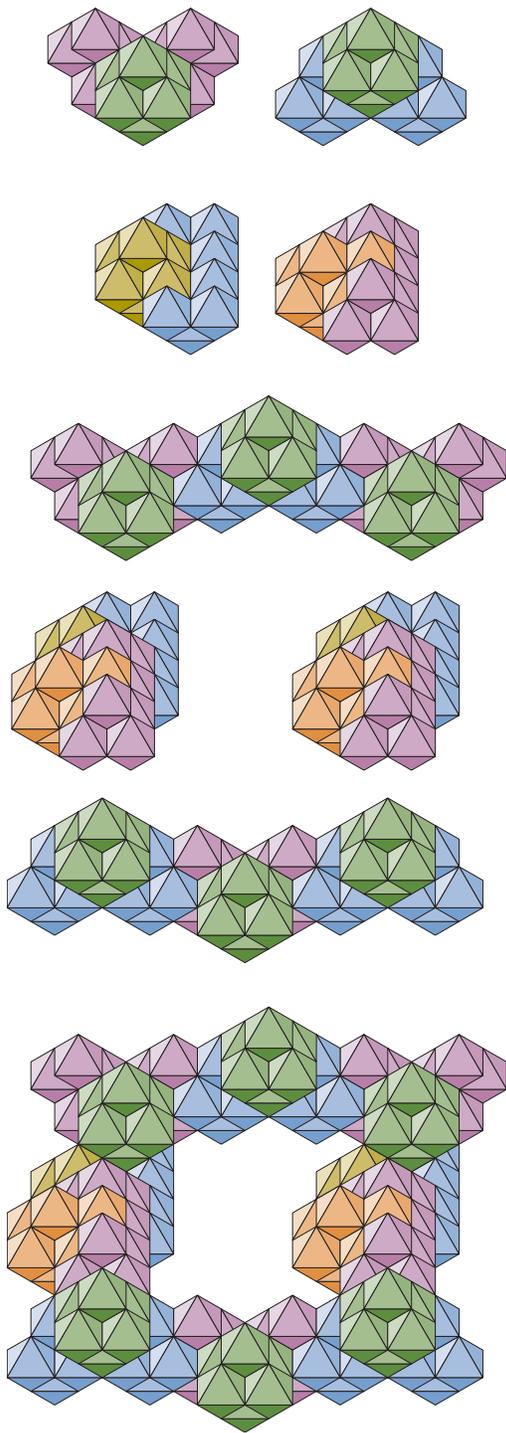
Chain of mixed-O-atom Alumina groups, axial



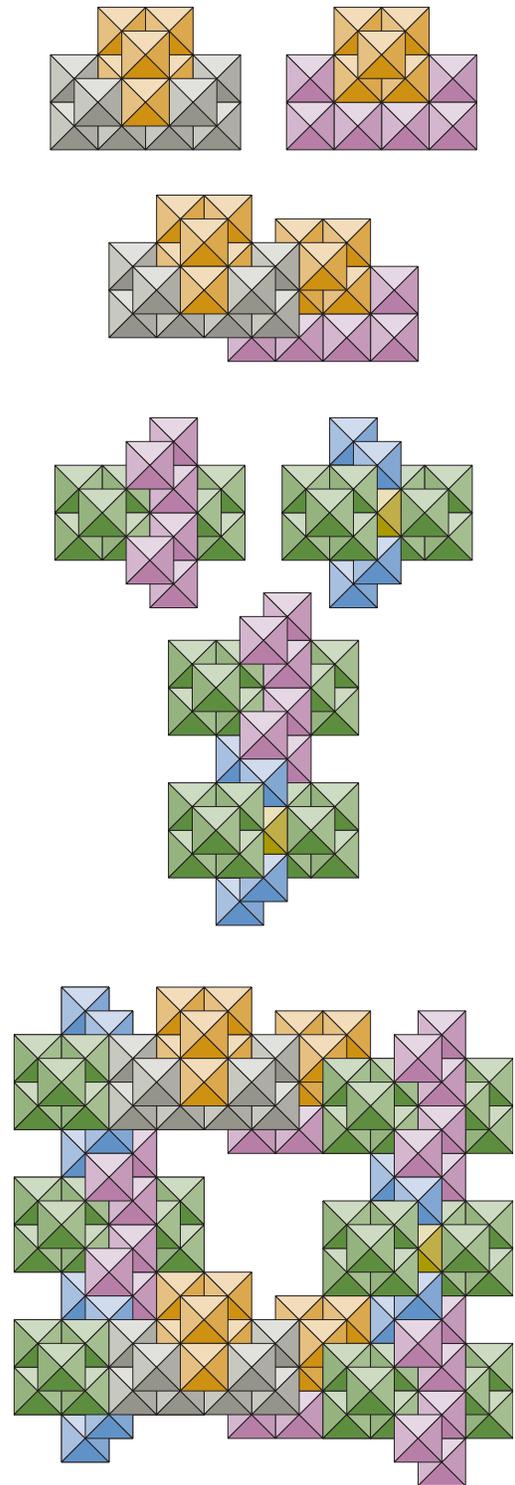
Chain of mixed-O-atom Alumina groups, oblique

Mixed-O-atom-alumina chains linked by SiO_2 groups

These chains occur in the minerals sillimanite, andalusite, mullite, kyanite, and staurolite. Each of the silica groups is attached to an alumina group of the chain. Only the silica groups which join the chains are shown. The silica groups attached to the other alumina groups would extend to the right and to the left. The silica groups are absent an O-atom, and the alumina groups which are not joined with a silica group are also absent an O-atom.



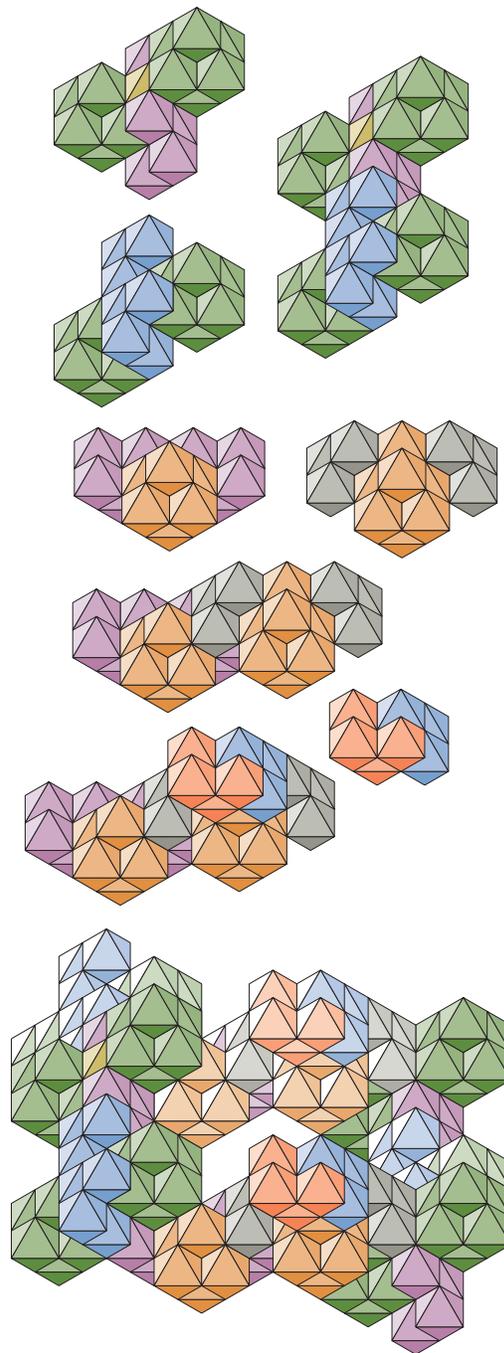
Pair of linked Al_2O_3 SiO_2 chains, oblique



Pair of linked Al_2O_3 SiO_2 chains, radial

Pair of linked Al_2O_3 SiO_2 chains showing O-O linkage between silica groups

A pair of O-atoms has been joined to each of the Si-atom clefts which are on this side of the plane established by the axes of the two chains. This shows the O-O linkage between the silica groups linking an identical pair of chains in an adjoining plane.

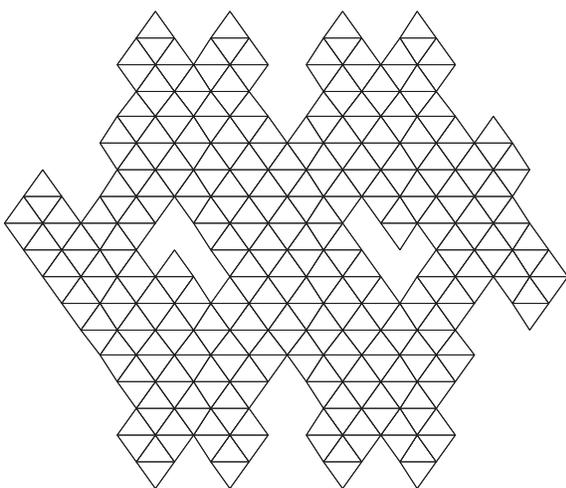


**Al₂O₃ chains linked by SiO₂ groups,
type 2**

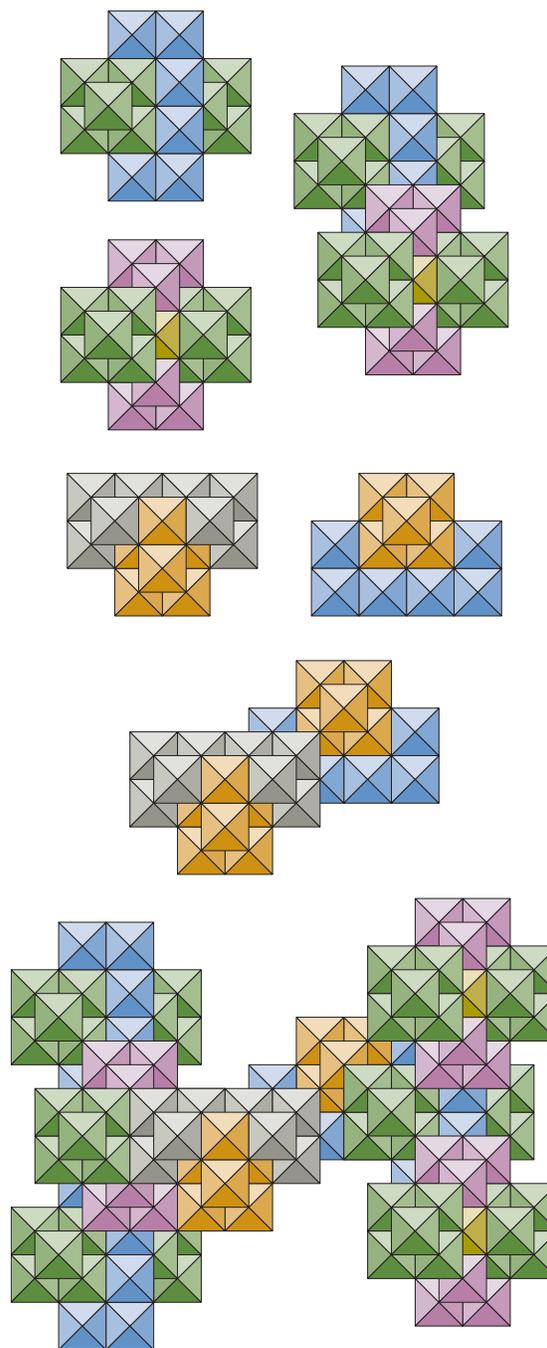
The O-atoms of the Al₂O₃ groups are mixed like the previous chain but of different orientation. Only the silica groups which link the chains are shown. O-atoms are missing from the alumina groups for which the silica groups are absent and from each of the two silica groups as well.

The second pair of linked chains has been added to the above pair to form a two plane stack. This indicates the crystalline growth that is possible with the assembly. Any pair of adjoining groups, each of which consists of an alumina group adjoined to a silica group, is a suitable cfu. There is but one alumina group-silica group grouping, but there are two orientations for the group which differ by a rotation of 1/2 turn about the alumina-chain axis. The join between the pair can be alumina-alumina intrachain, or silica-silica interchain, or silica-silica interplane.

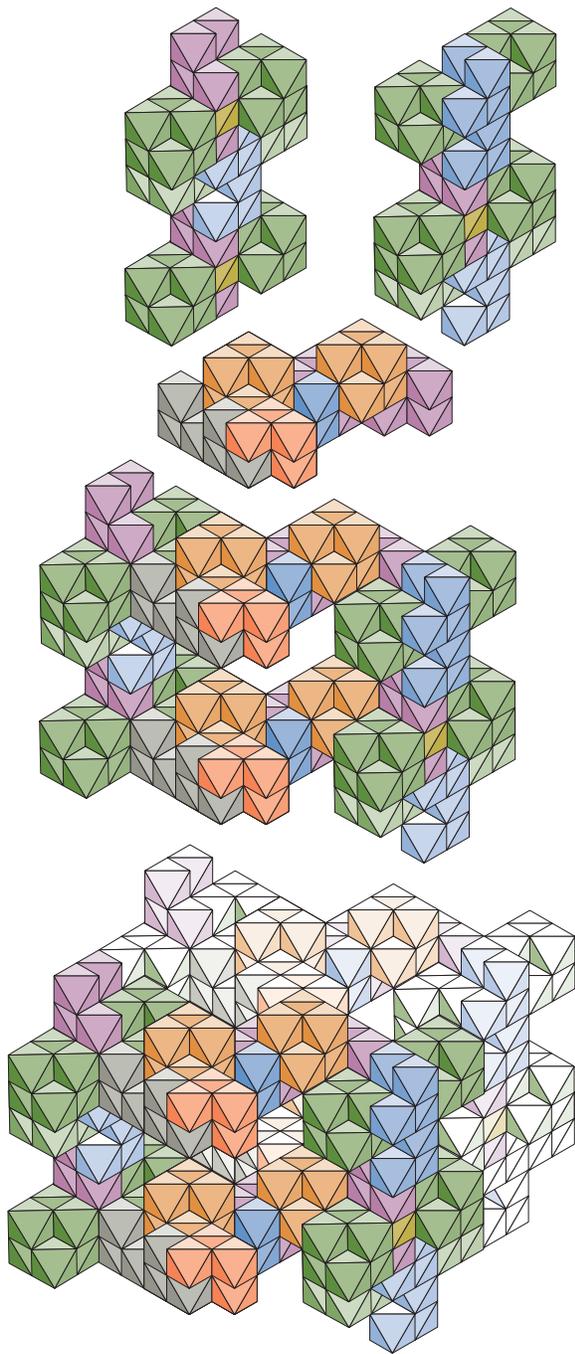
The next figure shows the separation between the planes.



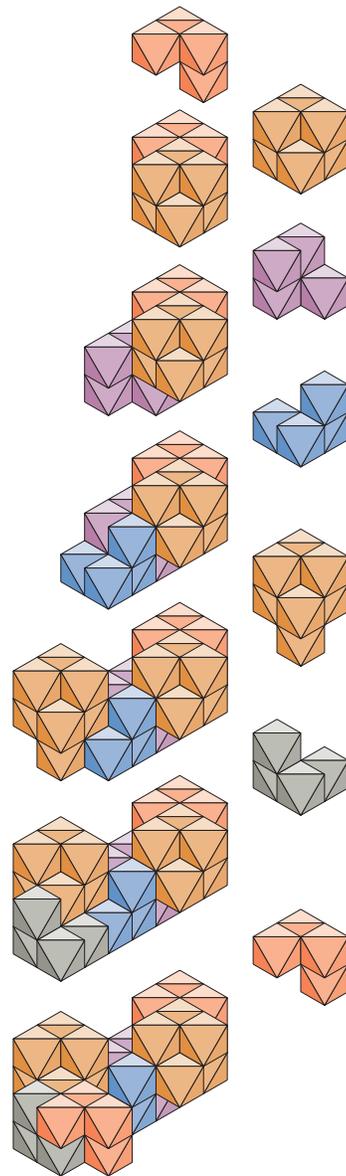
Two pairs of linked Al₂O₃ SiO₂ chains



Pair of linked Al₂O₃ SiO₂ chains, oblique



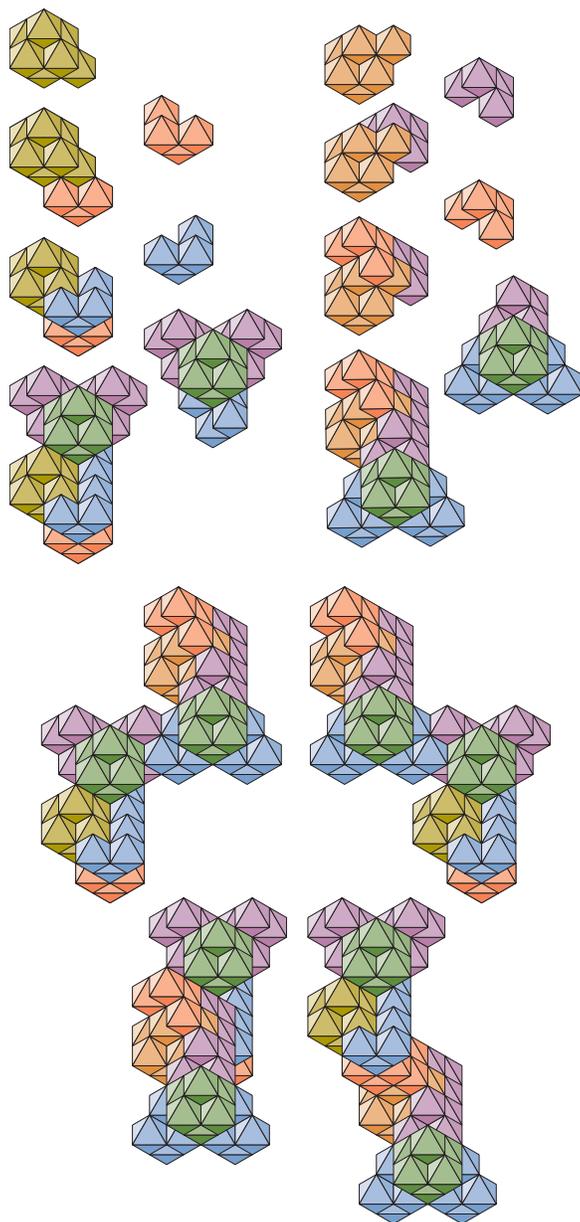
Two pairs of linked Al_2O_3 SiO_2 chains



Bridge to bridge connection.

The figure shows the connection between Si-atoms of adjacent pairs of silica joined alumina chains. The growing assembly is shown in the left-hand column, the adding units are on the right. The assembly progresses from the red colored O-atom at top to the red colored O-atom at the bottom, which marks the beginning of an identical join.

This join permits a crystalline formation in which each alumina chain is parallel to the other alumina chains of the crystal. Each silica bridge is parallel to the other silica bridges.

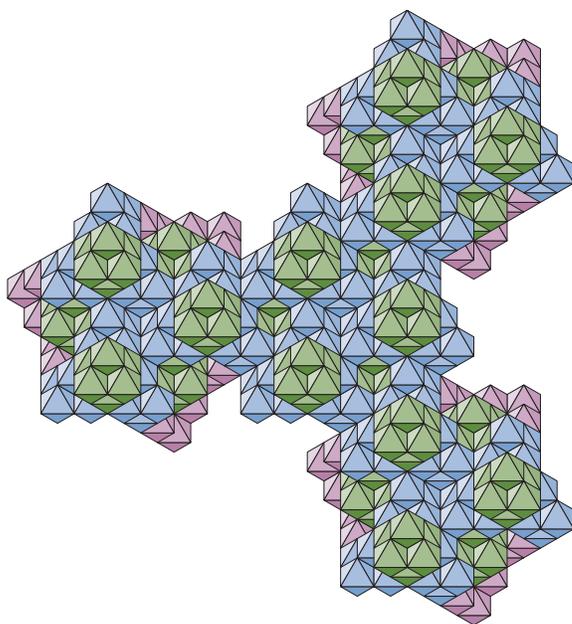
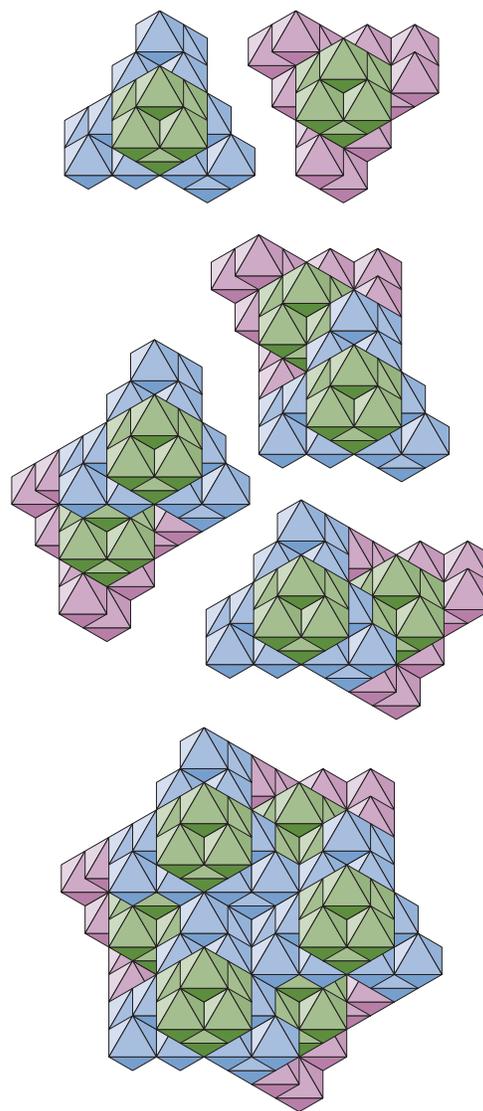


Silica and alumina groups of kyanite-like crystals

At the top, the assembly of two $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ groups is shown, one on the left and one on the right. Each begins with a Si-atom to which is added first one O-atom then another and then an alumina group. The two assemblies are then joined in four different ways in the lower part of the figure.

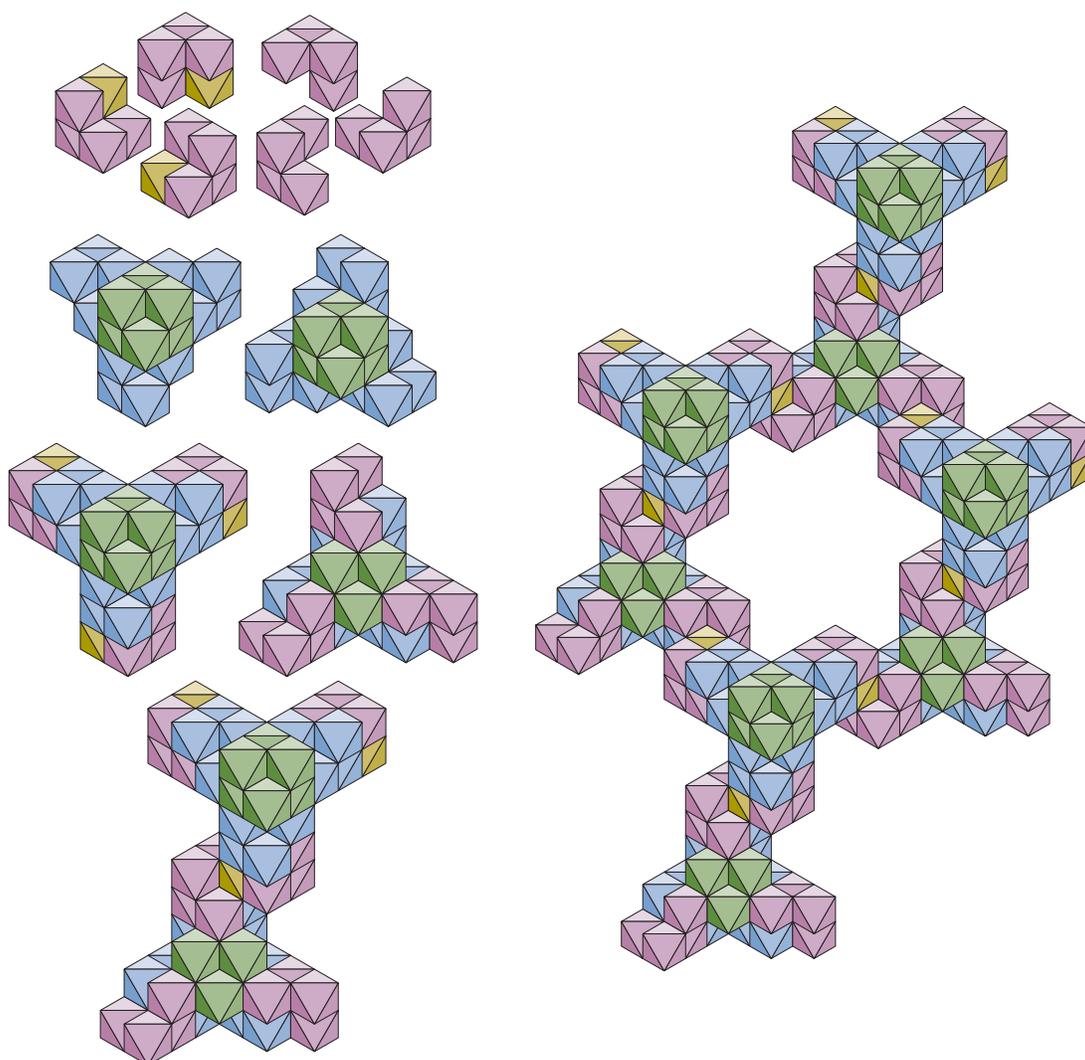
Compact ring of six alumina groups

This ring is composed of adjoining pairs of alumina in which one is counterclockwise and the other is counterclockwise and inverted. The attachment between adjoining groups is such that an O-atom-location is filled by a he-octa of an Al-atom. Adjoining groups have two such bonds. The Mg-positions of the Al-atoms lie in three planar groups. The middle group of six, one for each alumina group, participate in the joins. The upper and lower planar groups have just three each. Two O-atoms of each alumina group are used in the ring joins which leaves the third for planar joins between rings which are identical to those which form the ring. The rings stack with a facial move of two units or $6 \times \sqrt{2/3} \times s$ where s is the edge length of the He-octa. The stacking merges the upper and lower Mg-portion-layers so that the Mg-positions of the merged layer are identical to those of the middle layer of the ring. The intraplanar move is $6 \times s$. There are six join directions one-sixth turn apart. The ring joined in the described way is a cfu.



Assembly of four compact rings.

Compact rings can form a planar crystal in which a He-octa of an Al-atom of one ring fills the void of an O-atom of an adjoining ring. An Al-atom of the central ring is connected to an O-atom of each of the outer rings. Three additional rings can be joined to the central ring by an Al-atom.



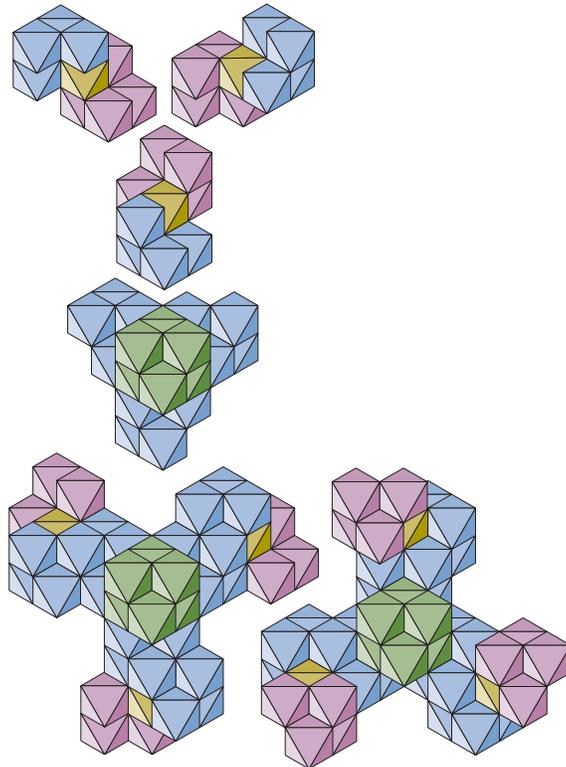
Gibbsite ($\text{Al}_2\text{O}_3 + 3\text{H}_2\text{O}$)

The molecular formula for gibbsite is $\text{Al}(\text{OH})_3$. This requires $\text{Al}_2\text{O}_3 + 3\text{H}_2\text{O}$.

At the top of the figure on the left there are six violet colored O-atoms in two groups of three. To each of the atoms of the left group a yellow He-octa has been added which represents a pair of H_2 groups. When joined, two O-atoms share the yellow He-octa and represent a pair of H_2O groups.

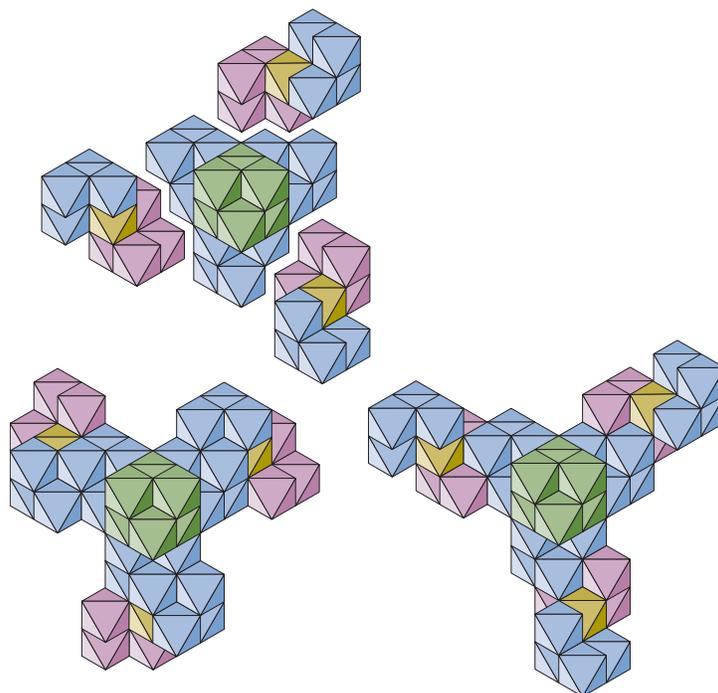
Below the atoms which are to represent the H_2O groups are two alumina groups whose O-atoms are opposite in sense and inverted with respect to one another. Each of these is shown joined with the violet O-atoms to form the groups immediately below them. The two groups are then paired to produce the group at the bottom.

The figure on the right is formed from four groups which are identical to the group at the bottom of the figure on the left. The join is between violet colored O-atoms and the yellow colored He-octa which represents the paired H_2 groups.



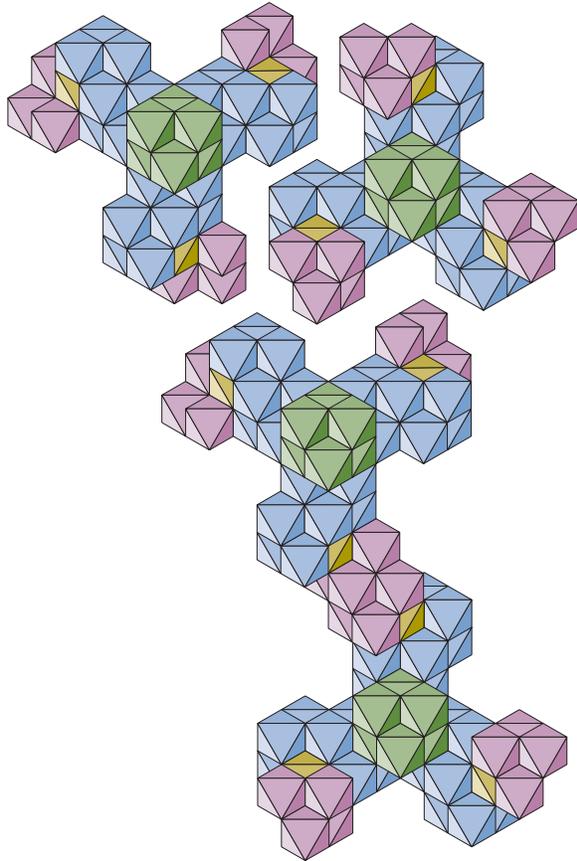
Alumina with counterclockwise O-atoms joined to Ne-paired H₂O

The H₂O groups are joined so that the H₂ pair is held in common by the two O-atoms as if it were the Ne-octa of each. Each pair is joined to a counterclockwise O-atom of an alumina group.

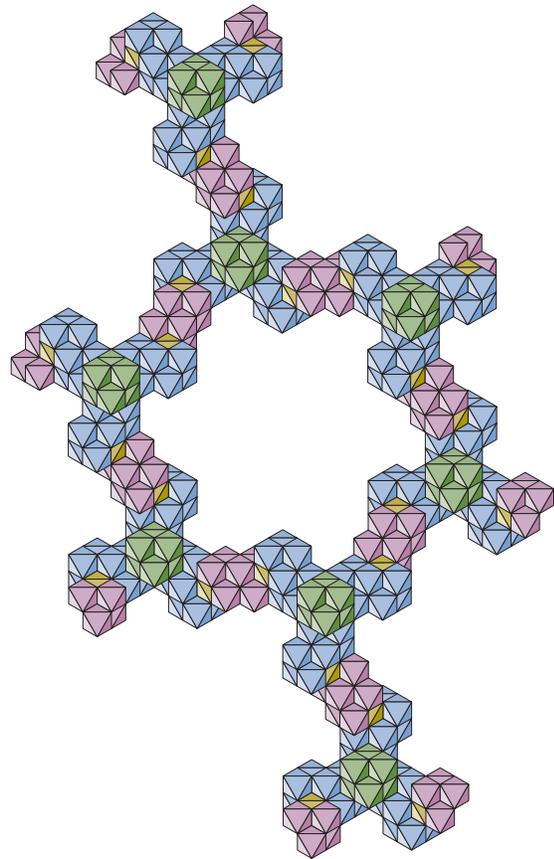


Alumina joined to OH₂H₂O groups in two ways

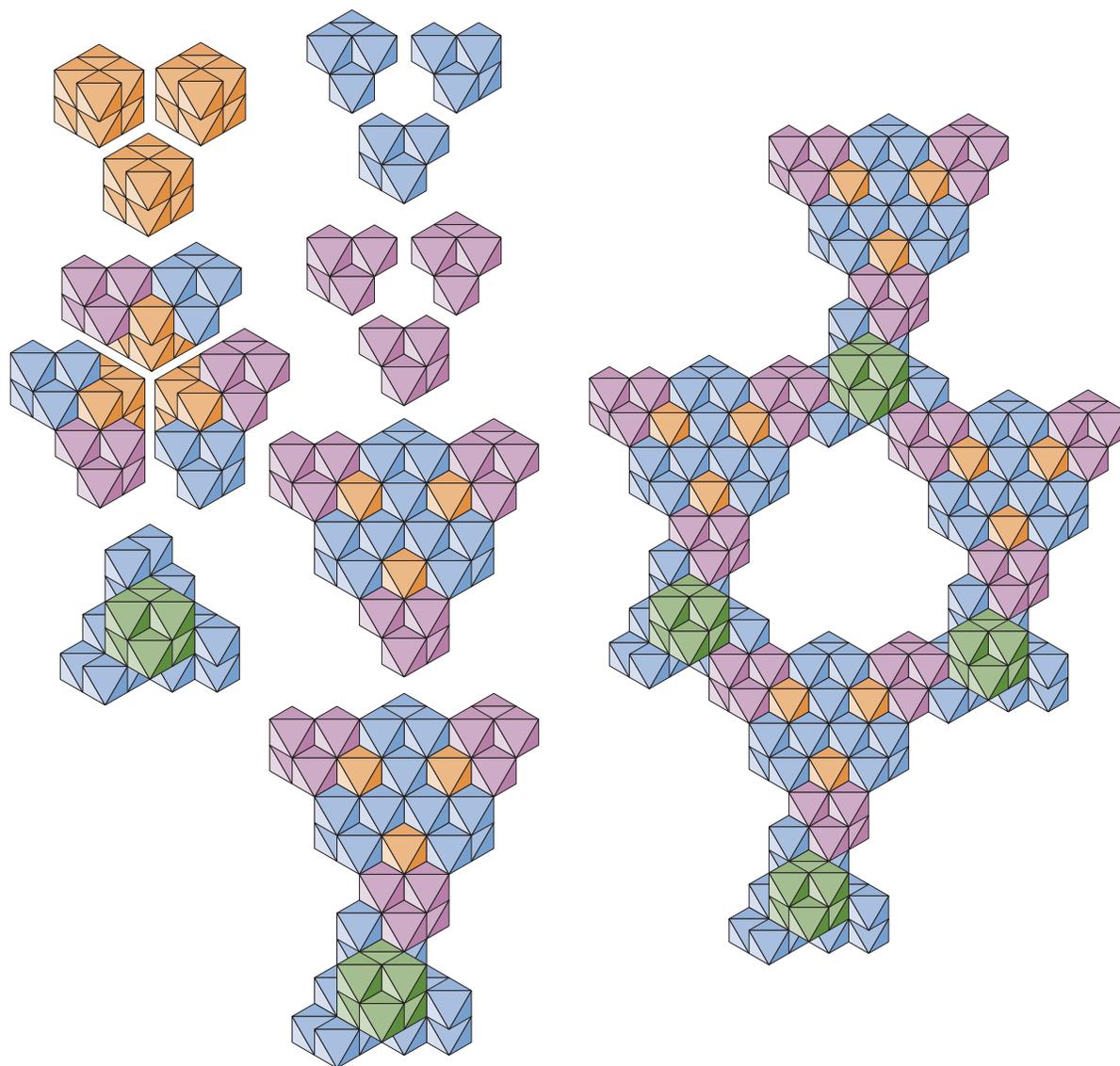
The figure shows two assemblies which result from different joinings of the same subunits. The subunits are grouped at the top of the figure. The central subunit is an alumina group whose O-atoms are oriented in a counter-clockwise sense. Each of the three subunits around it are identical OH₂H₂O groups in which the paired H₂ groups occupy the Ne-void of each of two O-atoms. In the assembly on the bottom left, the blue colored O-atom of each of the OH₂H₂O groups is joined to an O-atom of the alumina group; in the assembly on the bottom right, the violet colored O-atom of each of the OH₂H₂O groups is joined to an O-atom of the alumina group.



$\text{Al}_{23}\text{O}_{39}\text{OH}_2\text{H}_2\text{O}_{6\text{mg}}$ group



Ring of $3(\text{Al}_{23}\text{O}_{39}\text{OH}_2\text{H}_2\text{O}_{6\text{nc}} + \text{Al}_{23}\text{O}_{39}\text{OH}_2\text{H}_2\text{O}_{6\text{mg}})$

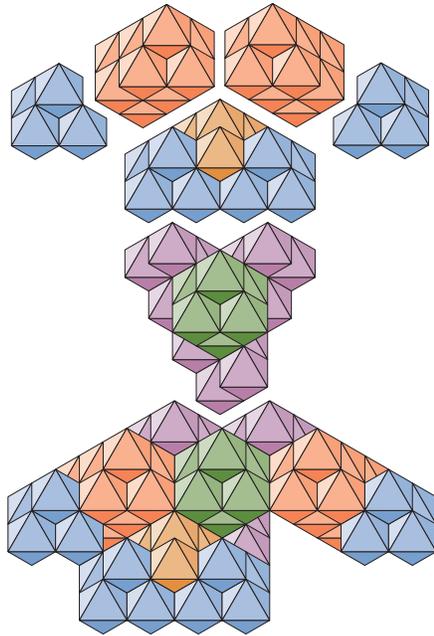


Alumina group joined to ring of three silica groups.

The atoms which make up the silica ring are shown at the top of the left figure. The formation of the three silica groups from these atoms is shown in the middle of the left column. The silica ring is just to its right. At the bottom of the left column is the alumina group. The complete assembly is at the bottom of the righthand column.

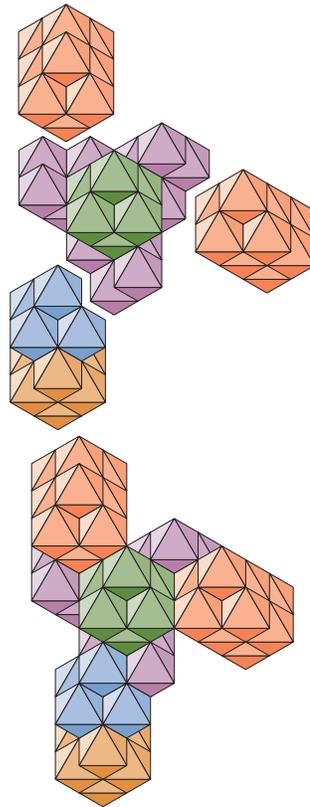
Planar crystal formed by four $\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ assemblies.

Four of the $\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ assemblies form the ring shown in the figure on the right. A violet colored O-atom of the silica group of one assembly is joined to an O-atom of the alumina group of another assembly.



$\text{Al}_2(\text{OCa})_2\text{OSi}$ or Serend

The red colored units at the top are Ca--atoms. They form two CaO groups with the O-atoms beside them. Just below the Ca-atoms is a silica group and below that an alumina group. The combined assembly is at the bottom. The alumina group has atoms of mixed sense.



Serend group

The figure shows another arrangement of the Ca-atoms and a SiO group joined to an alumina group in which the O-atoms have the same sense. This arrangement allows several possible joinings of the O-atoms required to complete the CaO groups and the SiO₂ group.

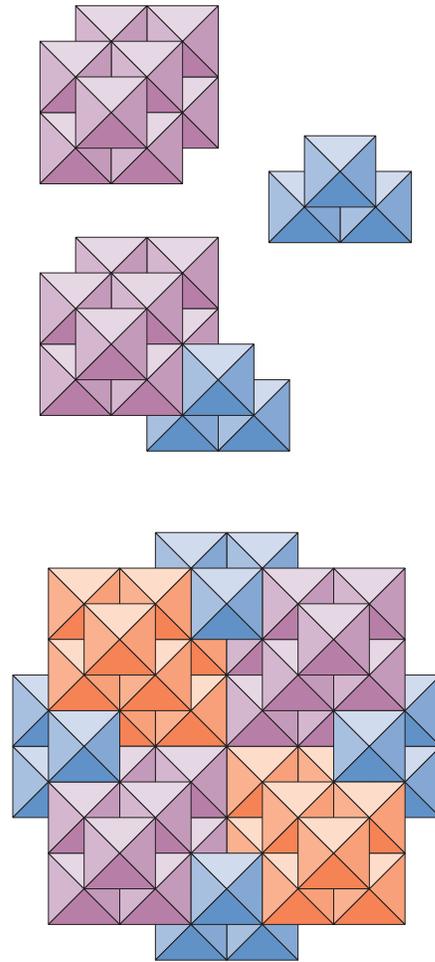
CALCIUM

CaO group

CaO group

The Ca-atom has two clefts. Each cleft provides a location for a cleft-to-cleft join. The figure shows a cleft-to-cleft join between a Ca-atom and an O-atom to form a CaO group. Calcium occurs in the chemical analyses of minerals as CaO and is called *lime* or *calcia*.

Both clefts are used in the formation of a ring of four CaO groups. Each cleft of each Ca-atom is joined to a cleft of an O-atom in the ring. The ring has a fourfold axis which is parallel to a vertexial diameter of the octahedron.

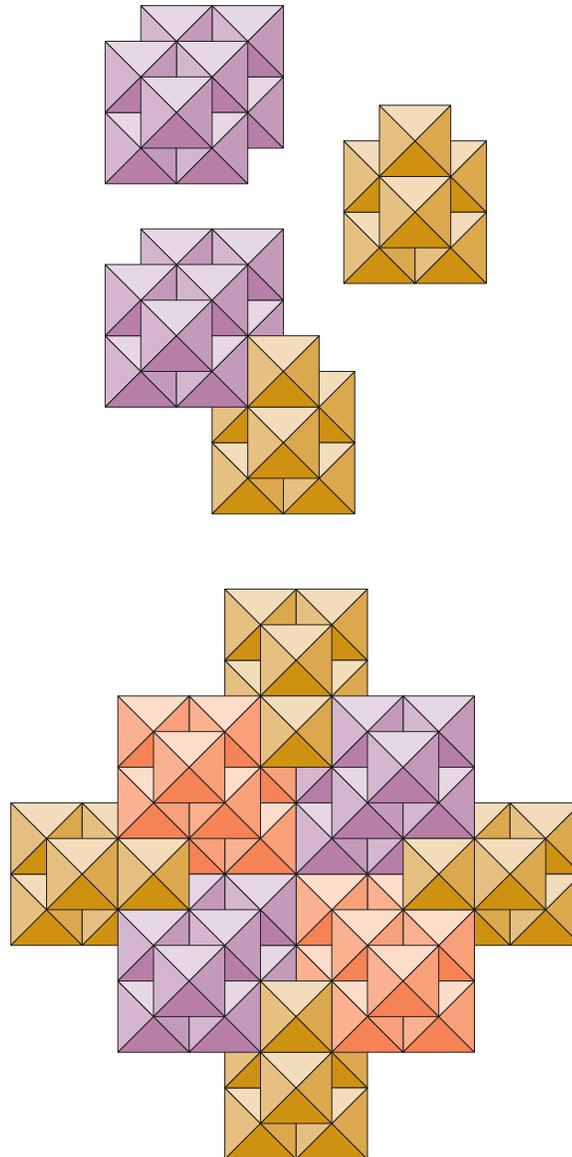


Ring of four CaO groups

CaSi group**CaSi**

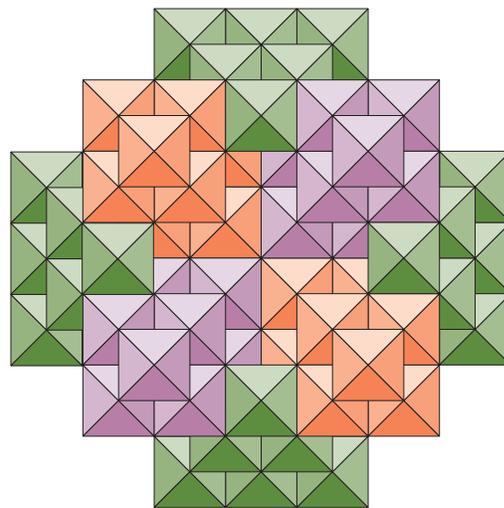
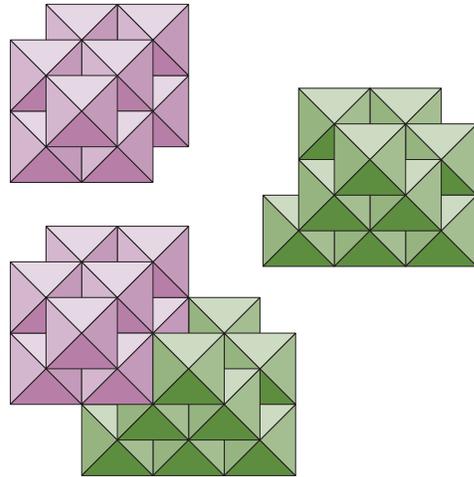
A Ca-atom and a Si-atom can join cleftly as shown in the figure.

Four CaSi group can form a four-fold ring which is similar to the CaO ring.



CaFe group

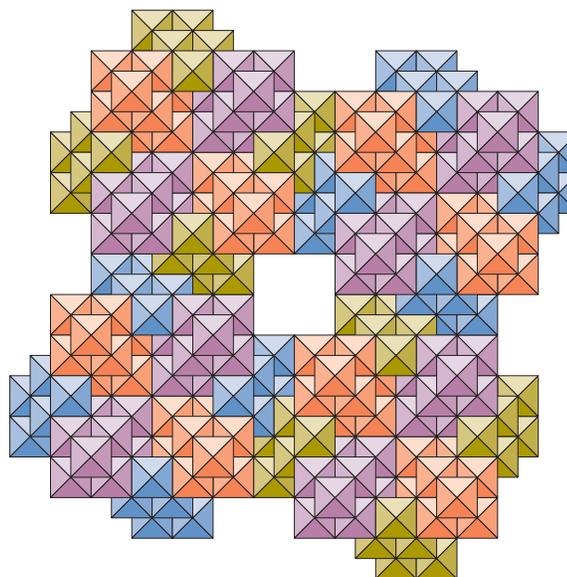
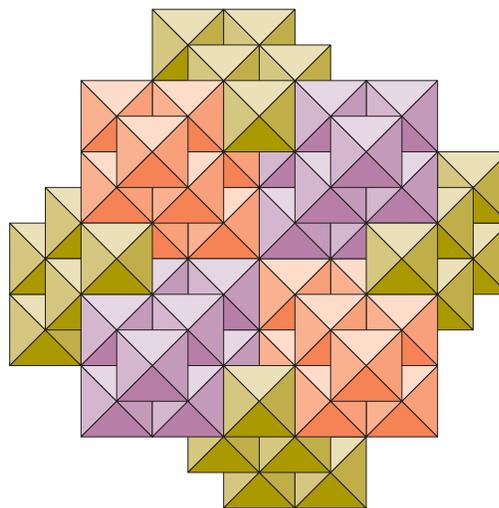
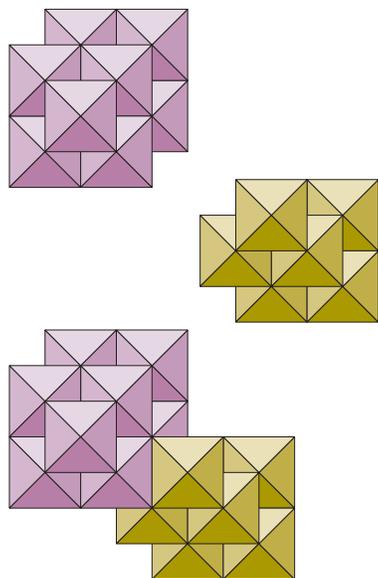
CaFe group
A Ca-atom can join with an Fe-atom in a way that permits the formation of a fourfold ring.



CaS group, type A

CaS group, type A

There are two ways in which a Ca-atom and a S-atom can join so as to produce groups which can form a fourfold CaS ring. The first CaS group joins a cleft of the Ca-atom to the Si-S cleft of the S-atom. These groups join so that the open cleft of the Ca-atom of one group joins with the B-S cleft of the S-atom of another group.



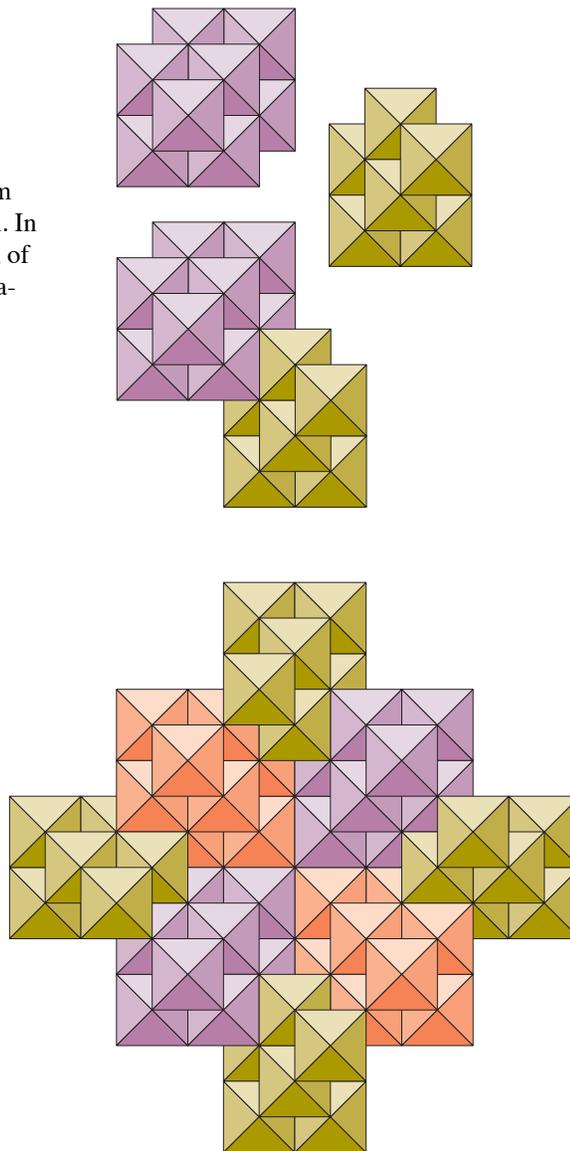
A ring of four 4CaS-rings¹

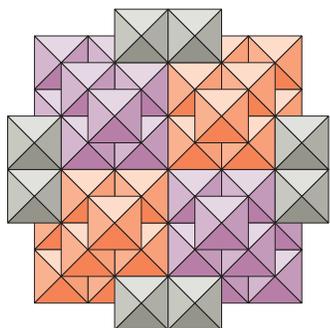
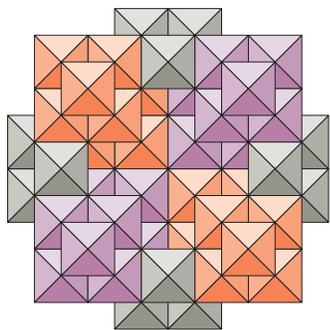
Four 4CaS rings can form a ring in which a S-atom of one 4CaS ring is cleftly joined to an S-atom of an adjoining ring. The join is between the Si-Ne clefts of S-atoms. The 4CaS ring is the CFU for a planar crystal.

1. S. S. Bhatnagar and K. N. Mathur, *Physical Principles and Applications of Magnetochemistry*, Macmillan, 1935

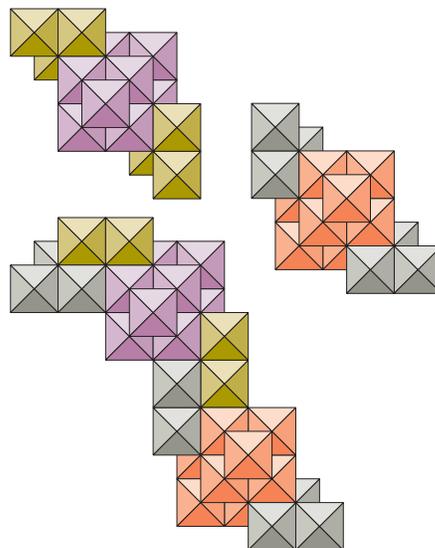
CaS group, type B**CaS group, type B**

Another type of CaS group has the Ca-atom cleftly joined to the Ne-Si cleft of the S-atom. In a fourfold ring, the Mg-Si cleft of the S-atom of one group is joined to the open cleft of the Ca-atom of another group.



CaC group**Ring of four CaC groups**

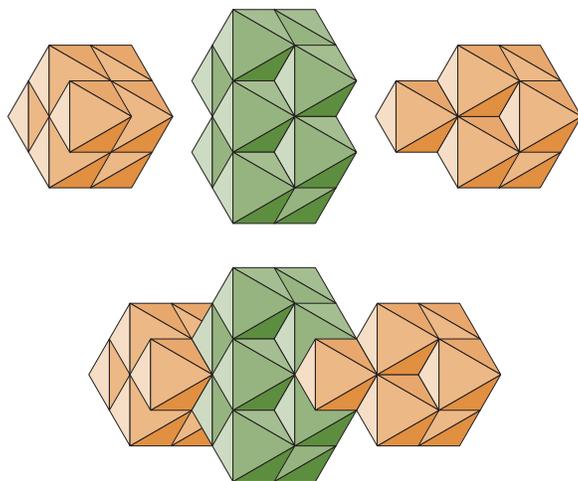
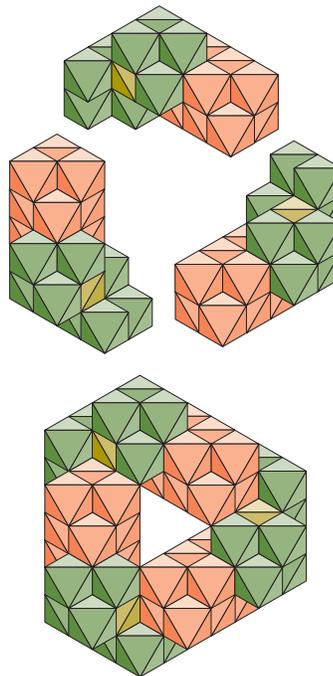
Four CaC groups can form the fourfold ring shown in the figure. The ring is shown from the two axial directions.

CaC₂ group**Chain of CaC₂ groups**

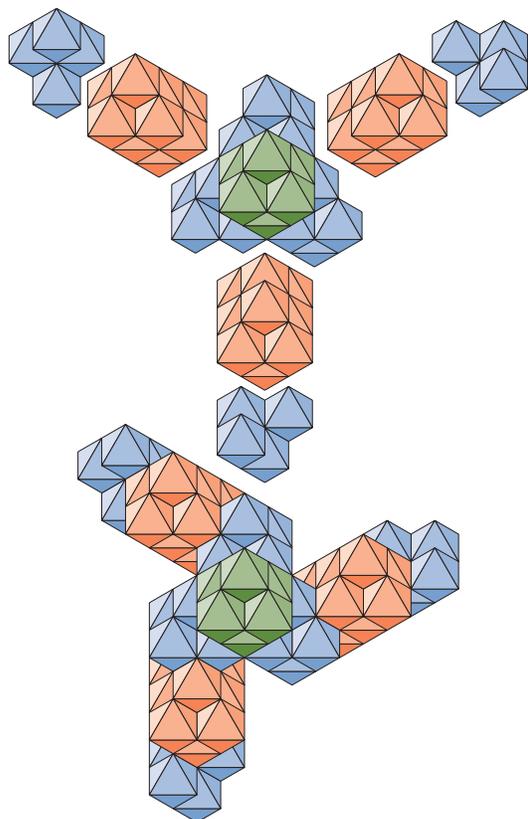
A Ca-atom with a C-atom joined at each cleft can form a chain in which the C-atom of one CaC₂ group is cleftly joined to the C-atom of another CaC₂ group

CaF₂ group**Calcium fluoride group CaF₂**

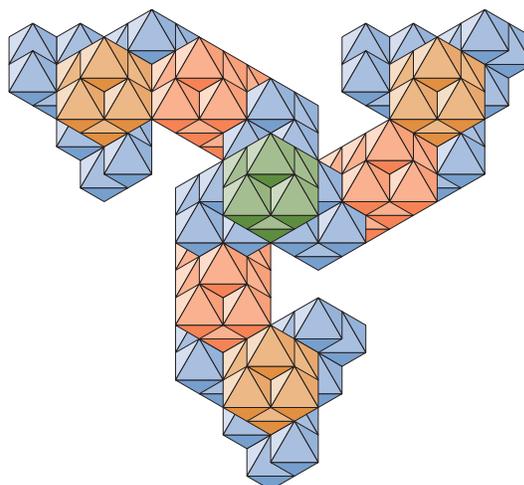
An F-atom of the triplet joined F₂ group is cleftly joined with the Ca-atom. Three of the groups can join so that the F-atom of one CaF₂ group is cleftly joined to the Ca-atom of another CaF₂ group.

CaSi₂ group**Calcium silicide CaSi₂ group**

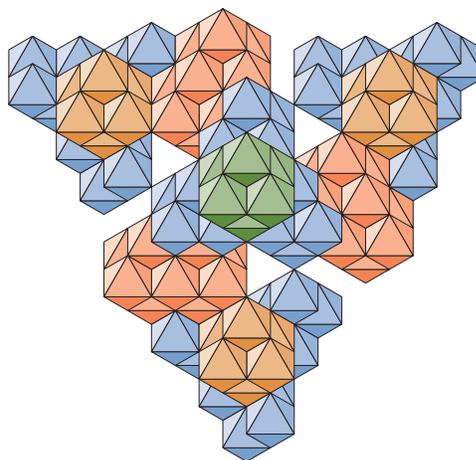
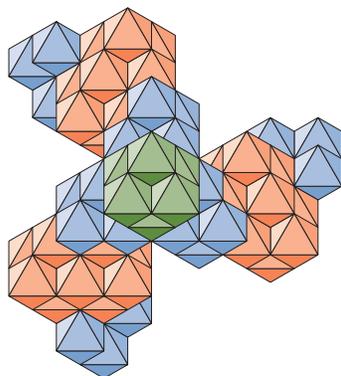
Each Si-atom is cleftly joined to the Ca-atom. The group shown has the Si-atoms oriented so as to provide for a symmetrical group.

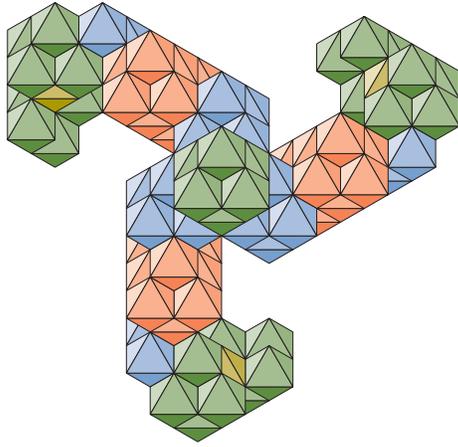
Tri-calcium aluminate group**Tri-calcium aluminate group**

The hub is a triplet joined pair of Al-atoms with a symmetric array of O-atoms each of which is cleft joined with a Ca-atom which is cleft joined with an O-atom.

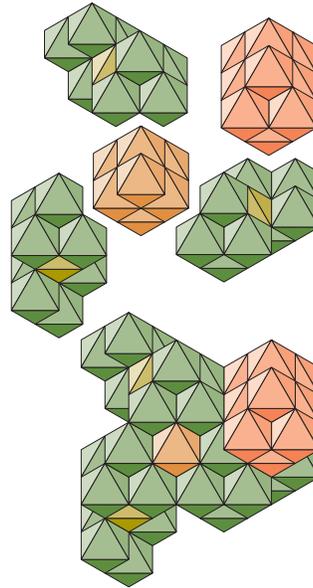
Grossularite group**Grossularite group**

This is the tri-calcium aluminate group to each peripheral O-atom of which the Si-atom of a SiO_2 group is cleftly joined. The group above is built on the group in the upper left; the group below is built on the group in the lower left.



Tri-calcium aluminate hexahydrate**Tri-calcium aluminate (type 1) hexahydrate**

An O-atom of the $\text{OH}_2\text{H}_2\text{O}$ group is cleftly joined to each of the peripheral O-atoms of the tri-calcium aluminate (type 1) group.

Ca-fluosilicate CaSi_3F_2 **Ca-fluosilicate CaSi_3F_2**

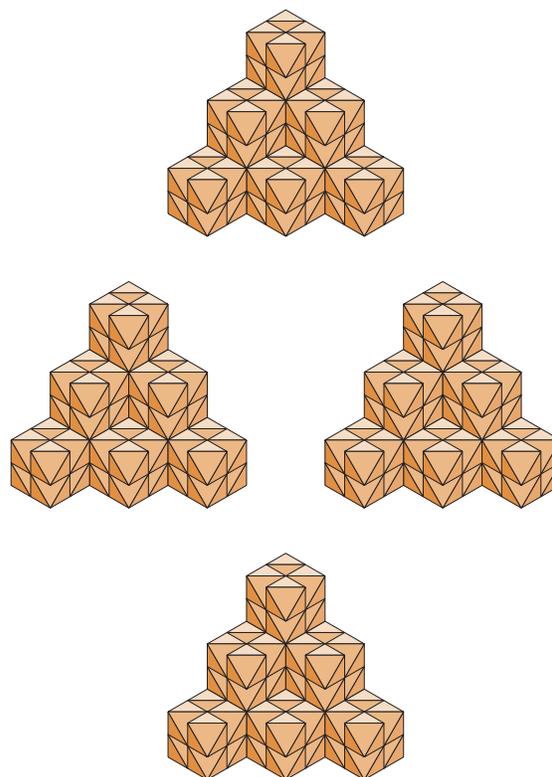
A F-atom of each F_2 group is cleftly joined to the Si-atom which acts as a hub for this threefoldly symmetrical group.

SILICON

Si-atom pattern is octahedral

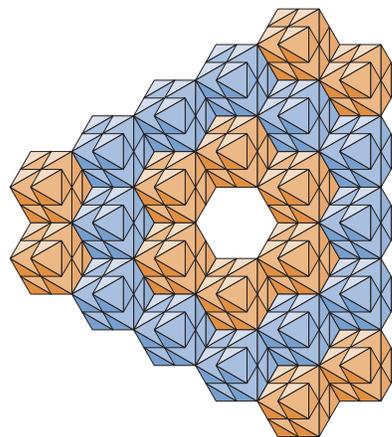
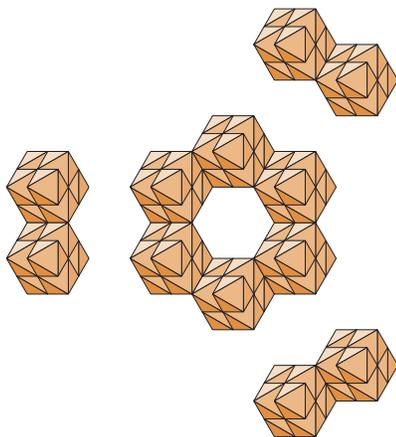
The pattern of an image produced by Si-atoms upon a (111) surface of a Si-crystal¹ is producible using the octahedral Si-atom. The figure on the left at the bottom of the page shows a grouping of Si-atoms arranged to produce the pattern. The spacing between the Si-atoms of the ring and the two-atom groups between each pair of rings is just fillable with other Si-atoms as the figure to its right shows. The Si-atoms which have been added to the unit as spacers have a different color than the Si-atoms of the previous unit. Spacer atoms have also been included for establishing the spacing between identical units. Four units with spacers and four units without spacers are shown in the figure on the next ²page.

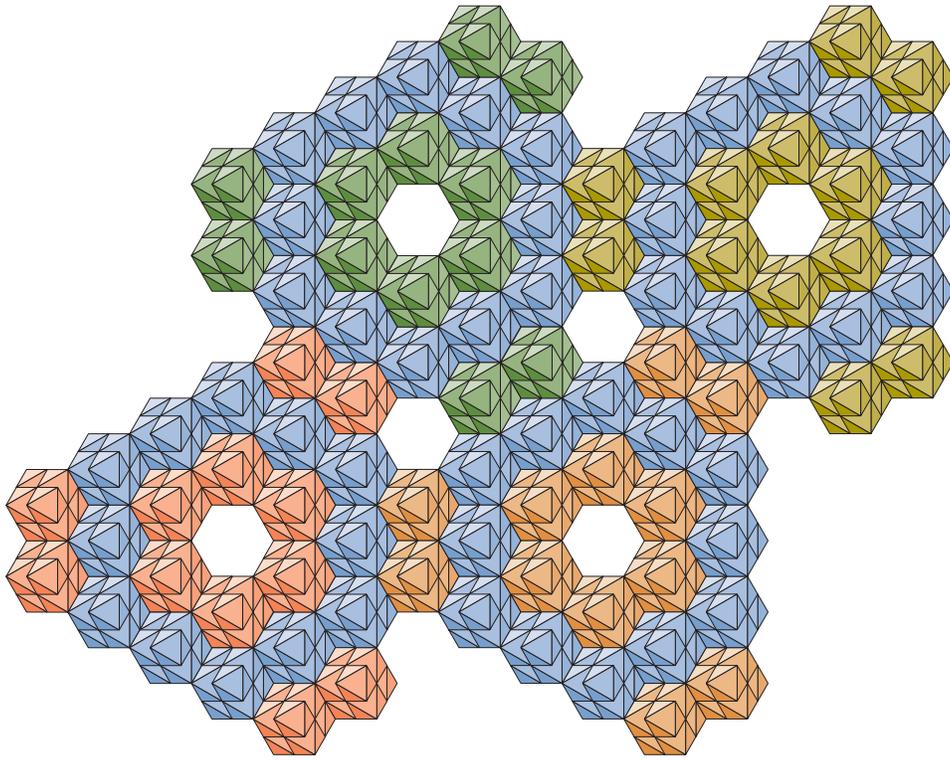
Another pattern³ consisting of smaller bright spots isolated from one other are like the Si-octas of the Si-atoms is depicted here. The Si-octas are nearest to the viewer.



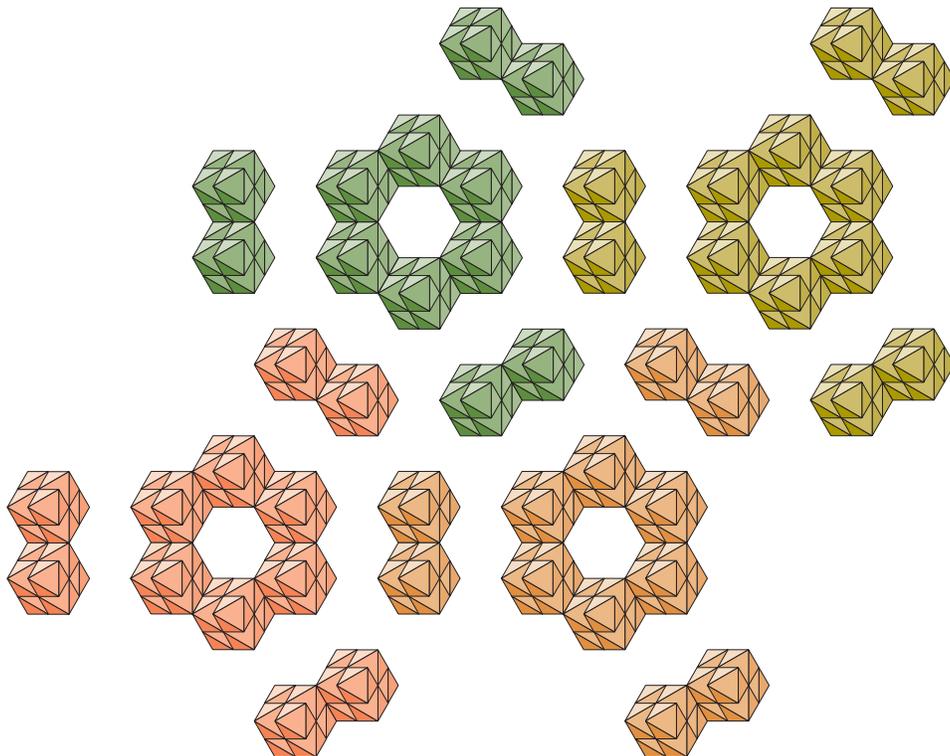
1. R. Martel, Ph. Avouris, I. -W. Lyo, Molecularly adsorbed oxygen species on Si (111)-(7x7): STM -induced dissociative attachment studies, *Science* v. 272, 19 April 1996, p. 387, Fig. 5(c). The figure is encaptioned "Empty-state STM images of a Si (111)-(7x7) surface..."

2. Hans Christian von Baeyer, *Taming of the Atom*, Random House, 1992. The same pattern is depicted here in a photograph between pages 102 and 103 which is encaptioned <Silicon atoms form a hexagonal pattern on a surface. Courtesy of IBM Research.>
3. Baeyer, *ibidem*. A photo encaptioned <A more irregular silicon surface. Courtesy of Burleigh Instruments.>





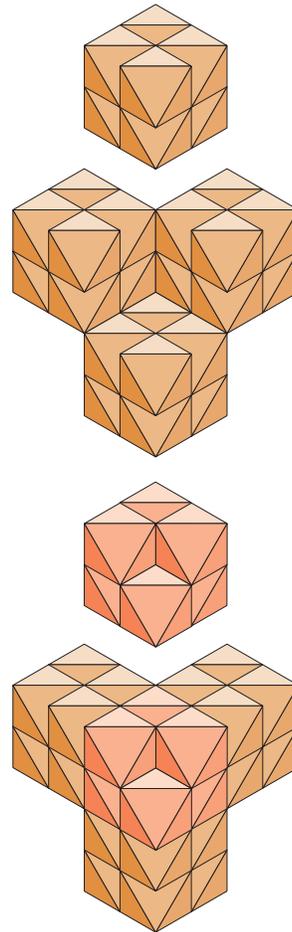
Arrangement of Si-atoms upon a Si-crystal (111) surface as shown by STM images.



Si CFU for diamond-like cubic crystal

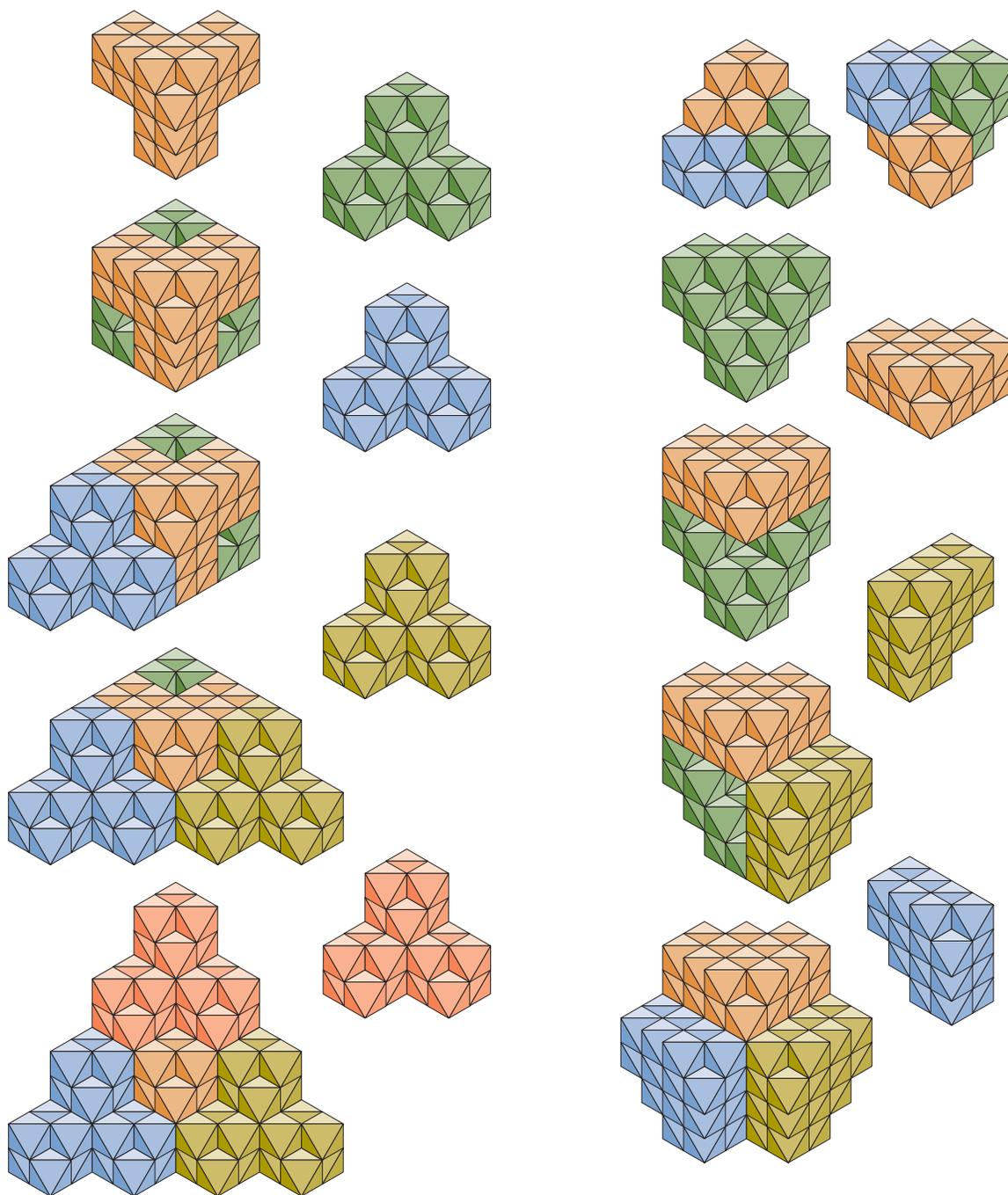
The crystalline structure of diamond is built of tetrahedral assemblies of four C-atoms. Four Si-atoms can join to form a regular tetrahedral assembly. These can join to form a diamond-like crystal. In the figure the assembly of a tetrahedron using four Si-atoms is shown.

An identical tetrahedron which is inverted relative to the first tetrahedron can join facially to it.



Tetrahedral assembly of Si-atoms.

At the top, is a Si-atom with its Si-octa uppermost. Below it is a group of three identically oriented Si-atoms. Below this is a Si-atom which is inverted relative to the previous Si-atoms which completes the tetrahedral assembly shown at the bottom.



Si-atoms in diamond-like cubic crystal.

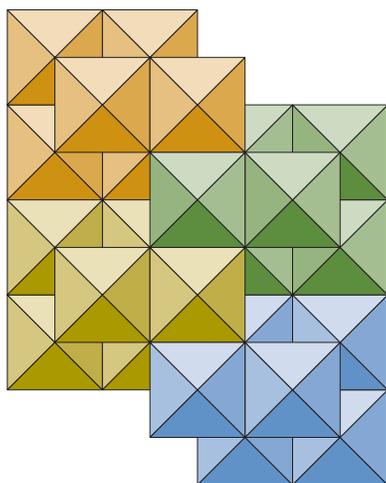
The top unit is a tetrahedral assembly of Si-atoms. In the right hand column are four identical assemblies which are inverted relative to the top unit to which they join. The units in the left column show the facial joining of the inverted units to the top unit.

Tetrahedron formed of four panels of Si-atoms.

The top row shows two views of a panel formed by three Si-atoms. The view on the right is of the inverted panel. The panels in the right column are added to form the assemblies on the left.

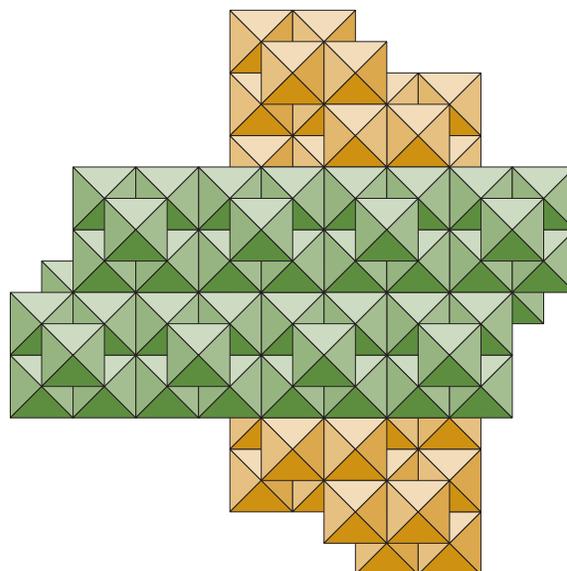
Si chain

Si-atoms can be cleftly joined in a chain which is parallel to an edge of the regular octahedron. Alternate Si-atoms have the same orientation. Adjoining Si-atoms are rotated one half turn about the 16-vertexial diameter. Two of the three clefts of each Si-atom are used for the chain.



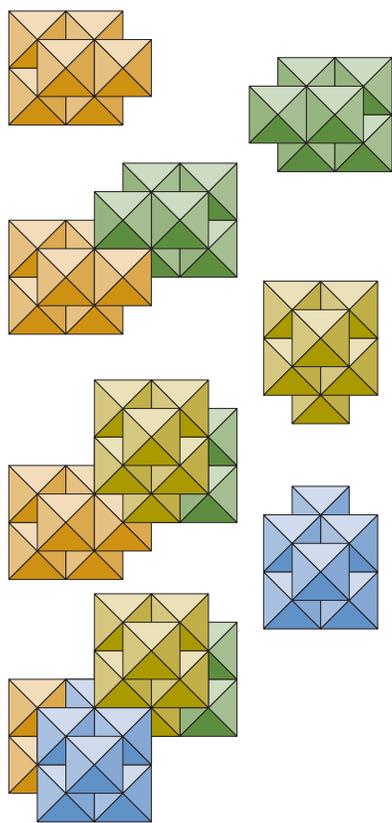
Si chain

The third cleft is available for cleft joins with Si-atoms of an identical chain if the chain is rotated one half turn about the chain axis and crosses the first at 90° .



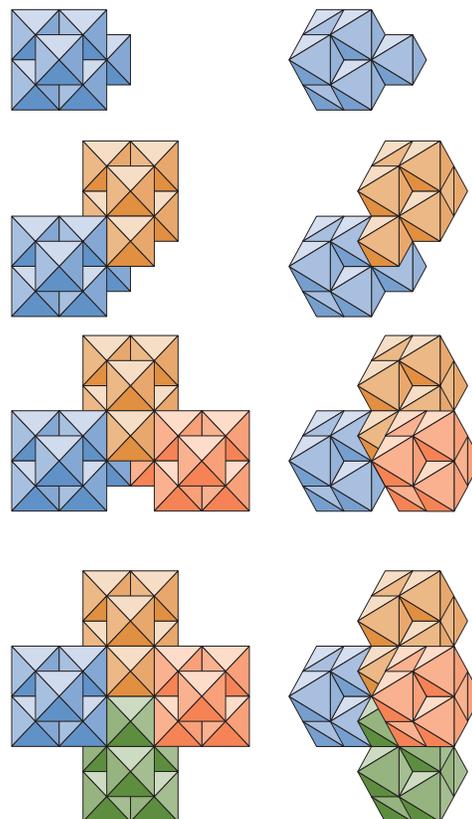
Adjoined Si chains

The parallel chains in one vertexial plane are thereby structurally included by parallel chains in an adjoining plane provided that the chains in the second plane are normal to those in the first. The outer surfaces of this paired plane of chains match up with the surface of an identical paired plane which is rotated one quarter-turn about a normal to the plane.



Joined Si of crossing chains

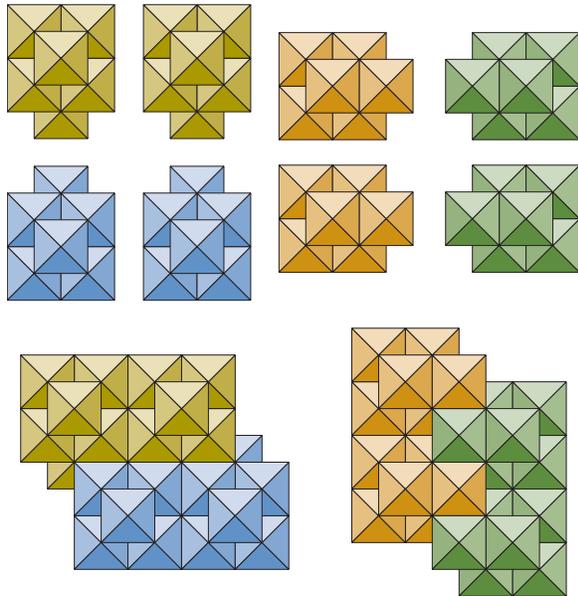
Two Si-atoms are cleftly joined to two Si-atoms of the adjoining chain. These four Si-atoms are in the form of a ring.



Si₄-ring assembly.

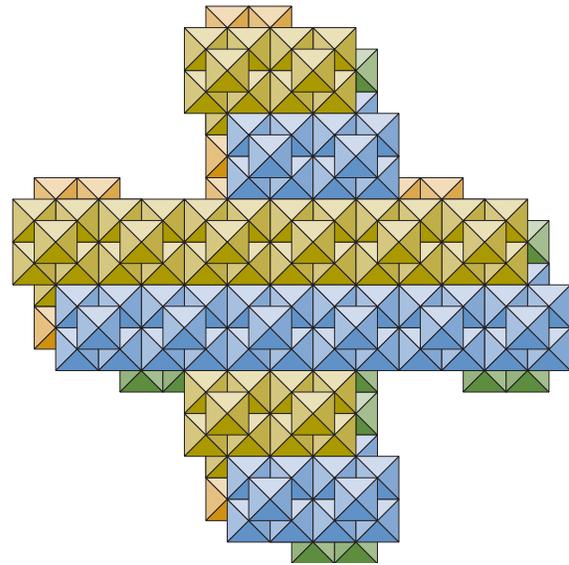
The left column shows the assembly of the Si₄-ring along the ring axis. The right column shows the assembly of the ring from another angle.

A paired-plane unit is formed by adding four Si-atoms to the Si chain junction. There is one Si-atom cleft for each join direction.



Paired-plane unit

In the next figure, a unit has been added to the paired-plane unit in each of the join directions.



Five paired-plane forming units

Si₄ ring

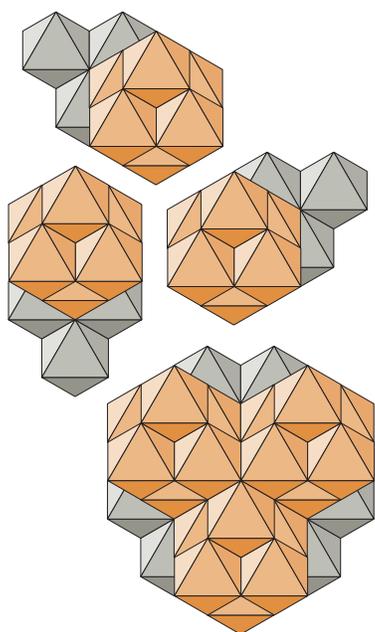
Four Si-atoms can form a ring in which each is cleftly joined to two other atoms. The Si-octas of the atoms each provide a face of a regular tetrahedron.

SiC group

3SiC group

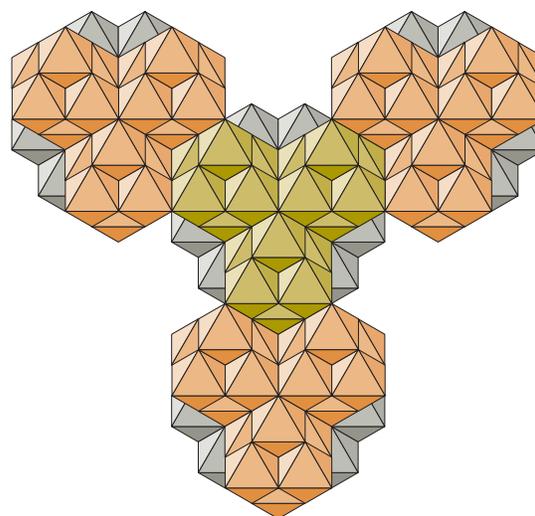
This is a ring of contiguous Si-atoms each of which is cleftly joined to each of two C-atoms each of which is cleftly joined in turn to one of the other Si-atoms. This uses two of the three clefts of each of the C-atoms and each of the Si-atoms. A cleft of each atom is left for planar join directions at 60°. The units will stack normal to the plane with the 123-faces of the C-atoms bridging the gaps between the Si-atoms. This is a hexagonal arrangement. The group is a CFU. The join length in the plane is

$4 \cdot (\sqrt{3}/2) \cdot \text{He-octa edge}$ and the join length for stacking is $3 \cdot \sqrt{2/3} \cdot \text{He-octa edge}$. This defines a volume for the cfu which is a hexagonal prism with a prism facial diameter equal to the join length in the plane and a height equal to the join length for stacking.



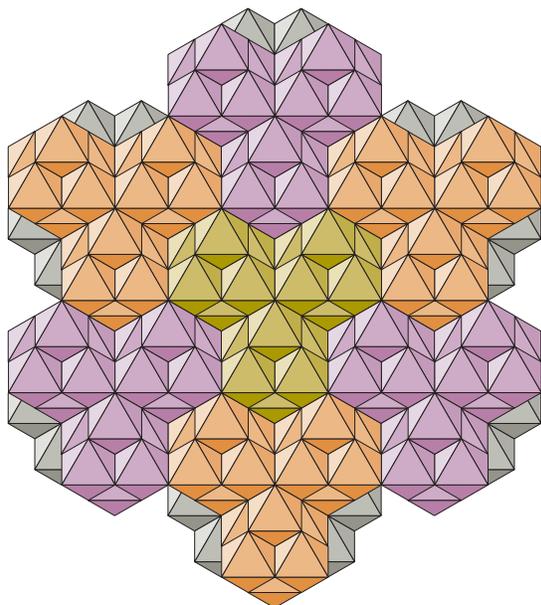
Formation of a SiC triplet.

Three SiC groups form a triplet in which their Si-atoms are cleftly joined by the C-atoms.



SiC triplets in planar formation

Each Si-atom of the yellow colored triplet is cleftly joined to a C-atom of each adjoining triplet.

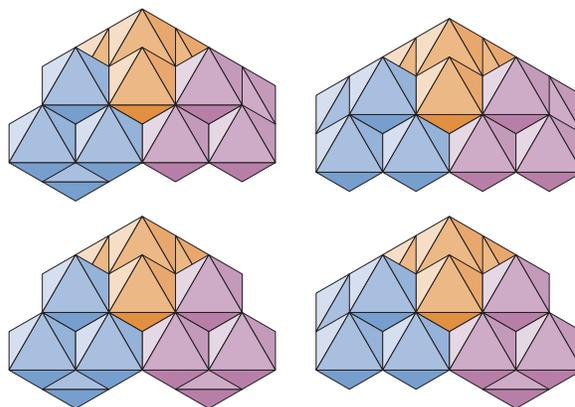


SiC triplet with six adjoining triplets.

Each of the C-atoms of the central triplet is cleftly joined to the Si-atom of each of the violet colored triplets; each of the Si-atoms of the central triplet is cleftly joined to a C-atom of each of the orange colored triplets.

SiO₂ group

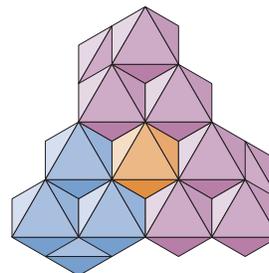
Silicon appears in the chemical analyses of rock forming minerals as SiO₂ or silica. In the next figure, there are three SiO₂ groups. They differ in the orientations of the O-atoms. In each of the two groups in the top row, the O-atoms point in the same direction, clockwise on the left and counterclockwise on the right. In the two bottom groups they point in opposite directions. There are other orientations for the O-atoms, but these are the common ring-forming orientations.



Three SiO₂ groups: cw, ccw, and mixed

SiO₃ group

The chemical analyses of minerals indicates that the SiO₃ group does not occur therein.



SiO₃ group

3SiO₃ ring not likely to exist

It is unlikely that the Si₃O₉ ring exists. Three silicon atoms can be joined so that each shares an oxygen atom with each adjoining silicon atom. A second oxygen atom attaches directly to each silicon atom but has no function in the ring formation.

The source of the SiO₄ tetrahedron fallacy

The SiO₄ seems to derive from the following. The radius ratio of the silicon ion to that of the oxygen ion indicates that 4-fold

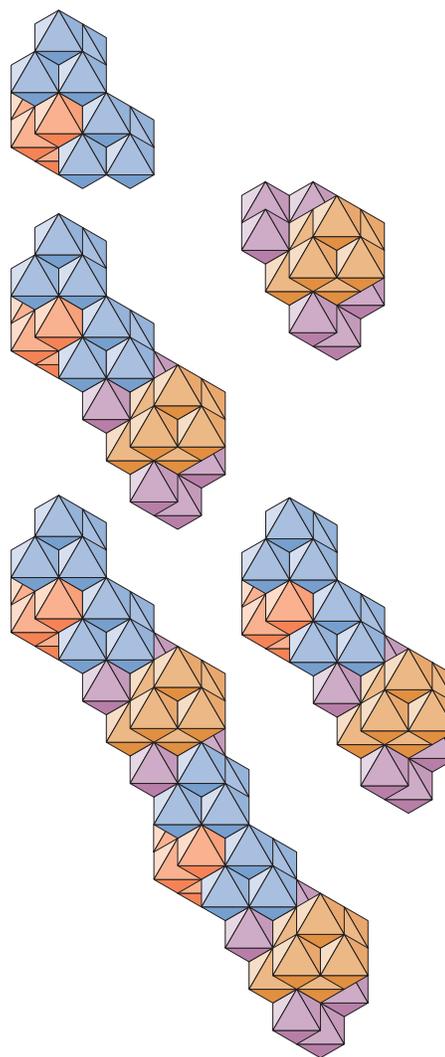
“coordination” will be the stable state of silicon-oxygen groupings. Thus, silicates are formed by a unit which has oxygen ions at the apexes of a regular tetrahedron with a silicon atom at its centroid.¹

For the octahedral atom, this reasoning is incorrect in the following ways—

- The term ion is erroneous, there being only the atom.
- The use of radius is erroneous, the atoms not being spherical.
- The chemical analyses of crystals which are supposed to contain the tetrahedra have only SiO_2 groups.
- There are three clefts per Si-atom and these are sufficient to accommodate two O-atoms and still have the third for joining with similar units.
- Coordination derives from Lewis theory which is not applicable to the crystalline atom.

SiO_2 chain

The figure shows the assembly of a chain of identical SiO_2 groups. The two O-atoms of the group have identical orientations. Adjoining groups differ in orientation; alternate groups have the same orientation. The chain assembly begins with the joining of a pair of groups. An O-atom of one group is double cleftly joined to an O-atom of the second group. The pair is the CFU for the chain and the assembly progresses with the addition of a second pair. The chain axis is parallel to a pair of edges of the octahedra.



Silica chain

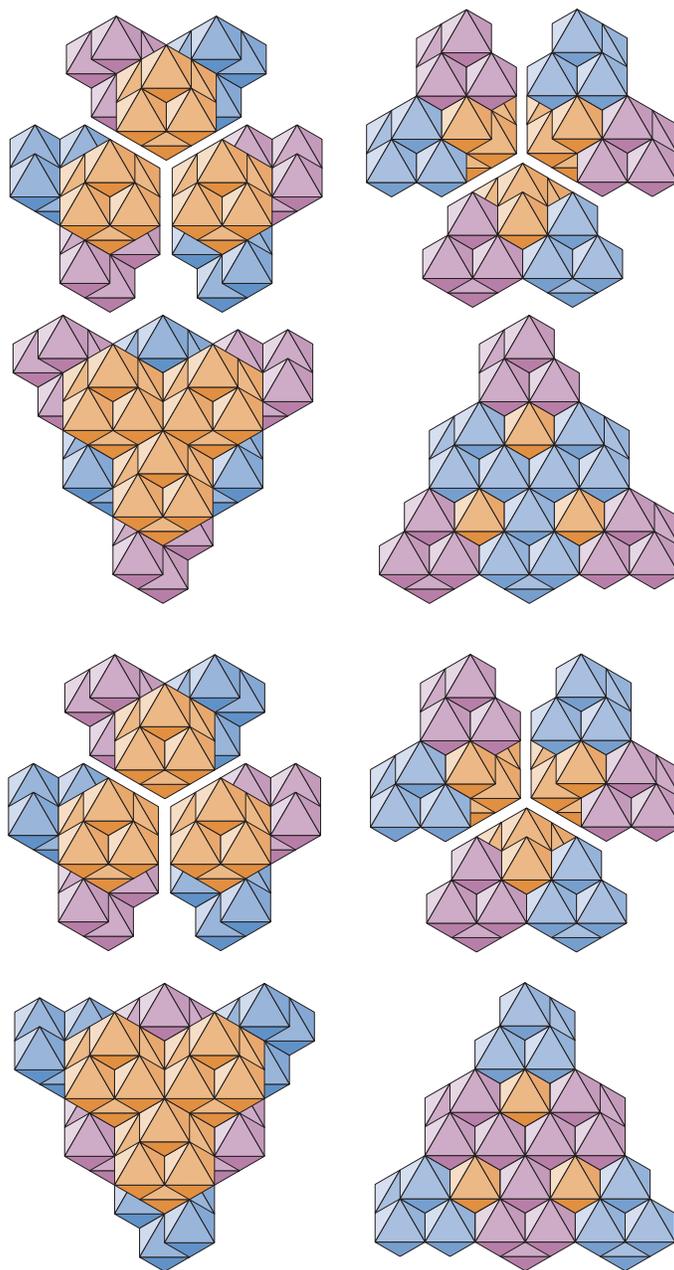
Facial SiO_2 rings

The silica group can form rings in which the axis of symmetry is parallel to a facial diameter of the octahedron.

3SiO_2 ring

The next figure shows rings formed by three identical silica groups.

1. C. S. Hurlbut *Dana's Manual of Mineralogy* 18th ed. John Wiley 1971 p. 369



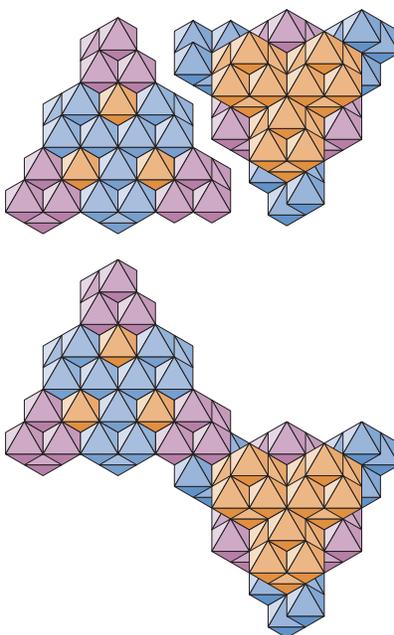
Two 3SiO_2 rings composed of identical groups.

Two rings are produced using identical silica groups. Each of the two rings is shown in two views which differ by a rotation of one half revolution about the bottom of the page. The two views are side by side. At the top, the Si-atom of one group is cleftly joined to the blue colored O-atom of another group. At the bottom, the Si-atom of one group is joined to the violet colored O-atom. The unjoined O-atoms of the top ring have a cw-sense and those of the bottom ring have a ccw-sense in the view of each ring shown in the right hand column, where the Si-octas of the Si-atoms are uppermost.

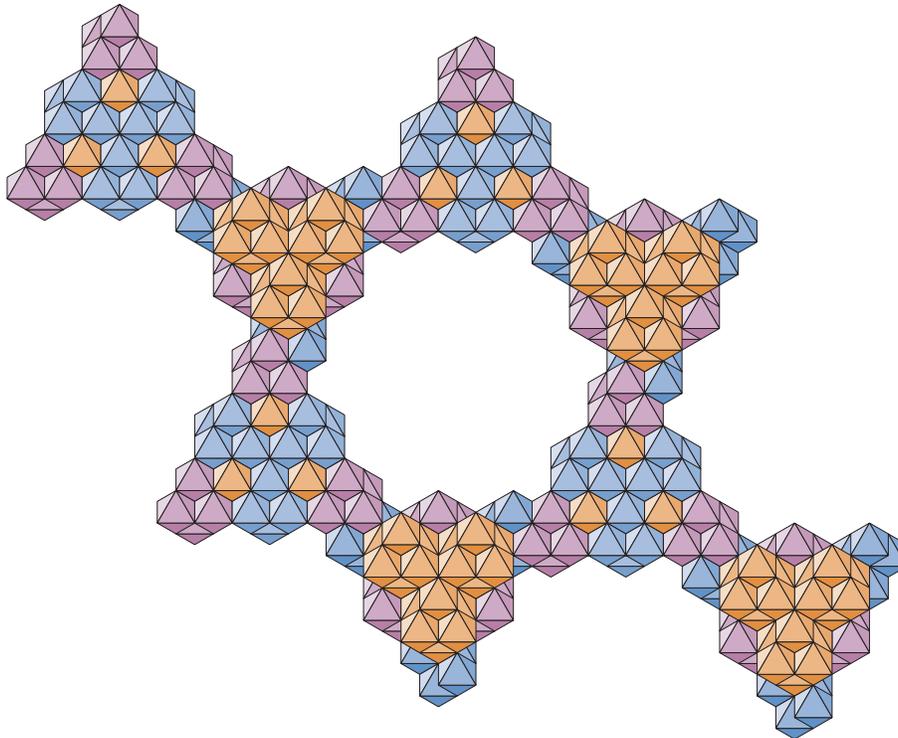
Pair of 3 SiO₂ rings, ccw & cw

A CFU can be constructed using a 3SiO₂ ring of each type. In one of the rings, the Si-octa of each Si-atom is towards the viewer; in the other ring, the Si-Octa of each Si-atom is

away from the viewer. A double clefted join between an O-atom of each ring forms the CFU. This assembly is shown in the next figure.

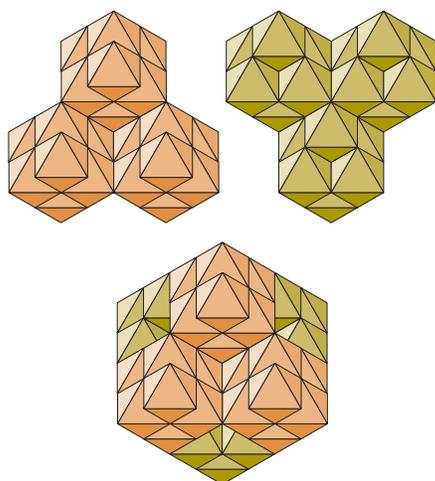
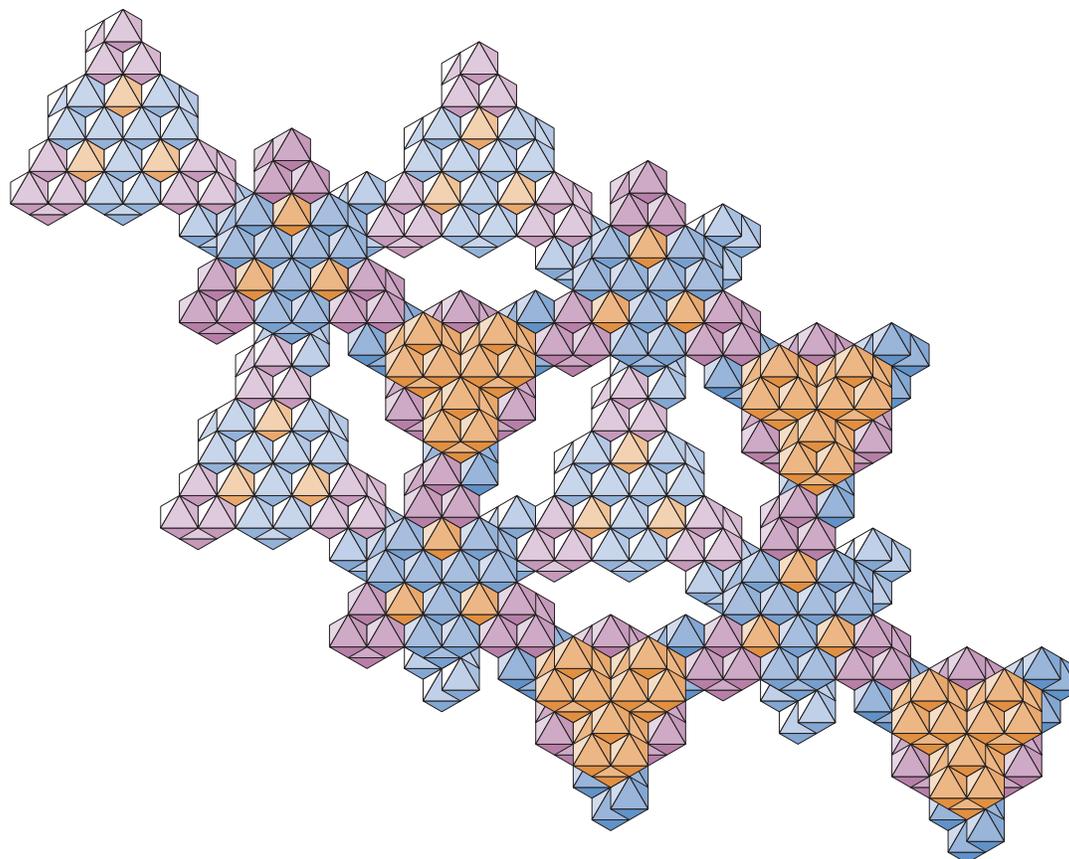


CFU formed by the pairing of 3 SiO₂ rings, cw & ccw

Planar assembly of 3 SiO₂ rings**Planar assembly of four 3SiO₂ CFUs.**

O-atoms of identical CFUs are double-cleftly joined to form a planar crystal. Four CFUs are so joined in the figure and form a ring. Within the extended crystalline plane, each CFU is joined to four CFUs and each 3SiO₂ ring is joined to three rings, one of which is the CFU of which it is a part.

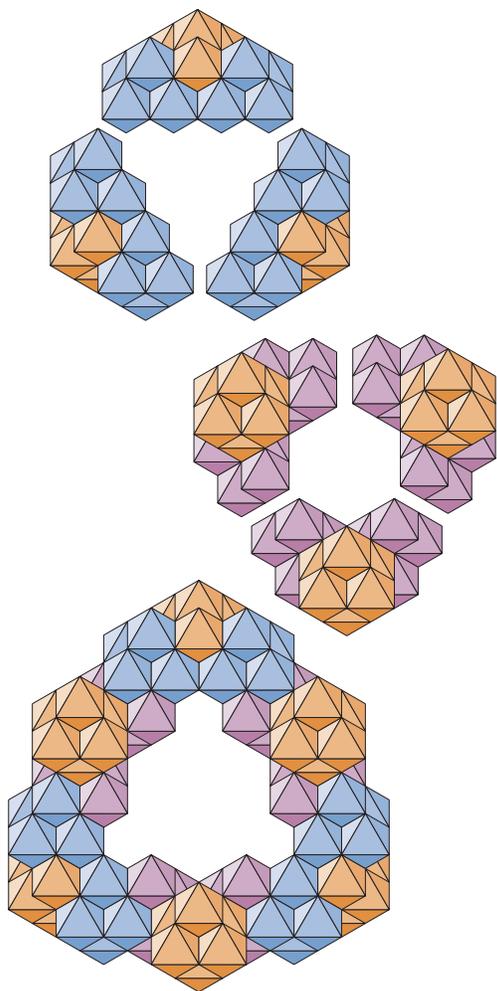
Interlayer join of 3 SiO₂ ring layers



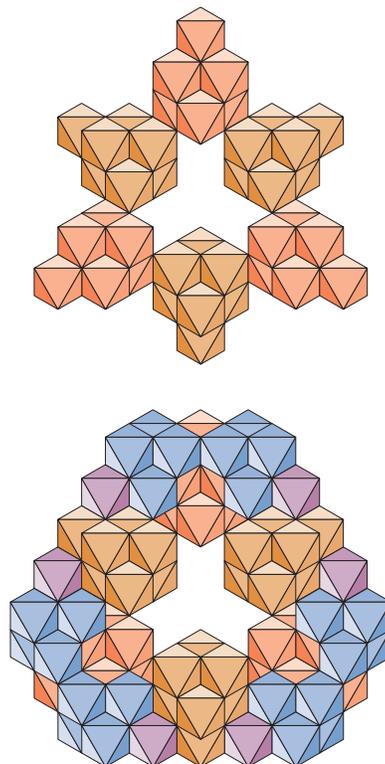
Interlayer joining of Si-atoms in 3SiO₂ crystal

The planar crystals join through the formation of octahedral groupings which result from the pairing of the Si-atom triplet of a 3SiO₂ ring of one plane with that of an adjoining plane. The figure to the left shows the relationship between the Si-atom triplets.

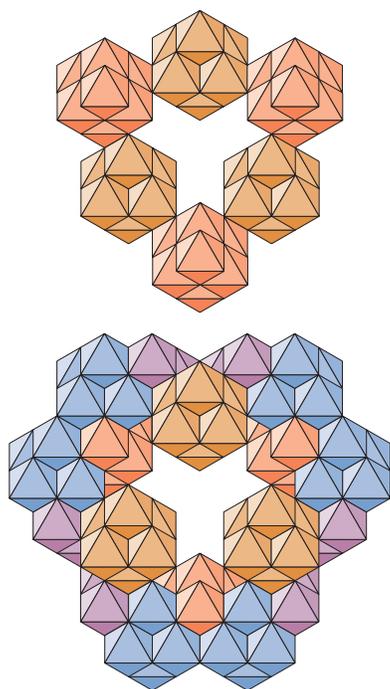
The figure above shows two planar rings of four CFUs each which are joined by the pairing of the Si-atom triplets. One of the two 3SiO₂ rings of each CFU joins with the ring of a CFU of the planar assembly above, while the other ring joins with a ring of a CFU of the planar assembly below.

6SiO₂ rings**Type I****Ring of six silica groups, Type I.**

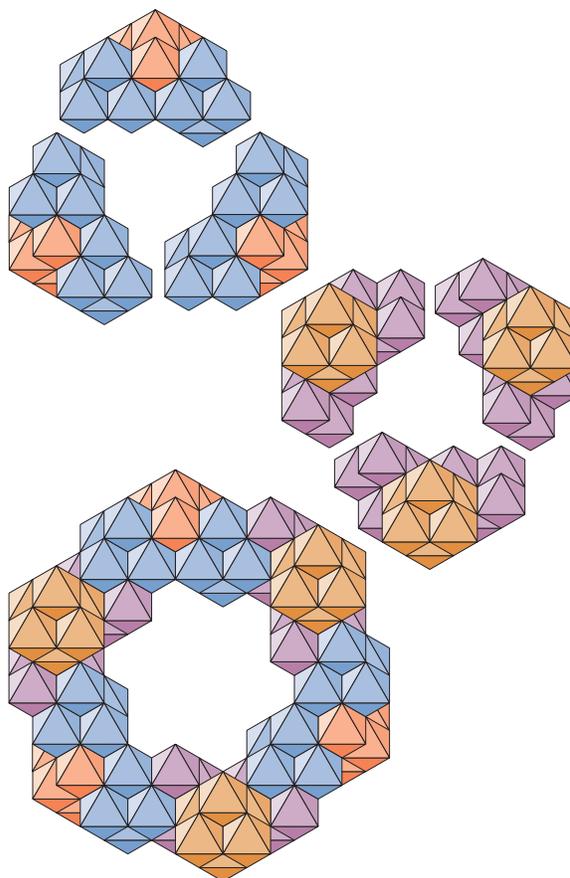
The ring is composed of two sets of three silica groups each. The groups of each set are identical except for a rotation of one-third revolution about the viewing direction. The Si-atoms of the set at the top of the figure have their Si-octas uppermost and the orientation of one O-atom orientations is the mirror of the other; they are colored blue. The other set is in the middle and the Si-octas of these Si-atoms is lowermost, they are colored violet. The silica groups are connected by a double-clefted join between their O-atoms.

Type II**Ring of six silica groups, Type II**

The Si-atoms are shown at the top as they are positioned in the ring. There are two sets of three each which are colored red or orange. The red colored Si-atoms have their 456-faces uppermost; the orange colored have their 123-faces uppermost. Within each set the orientations differ by a third of a revolution about the viewing direction. The O-atoms of each silica group have the same orientation. The O-atoms of adjoining groups are cleftly joined.

Type III**Ring of six silica groups, Type III**

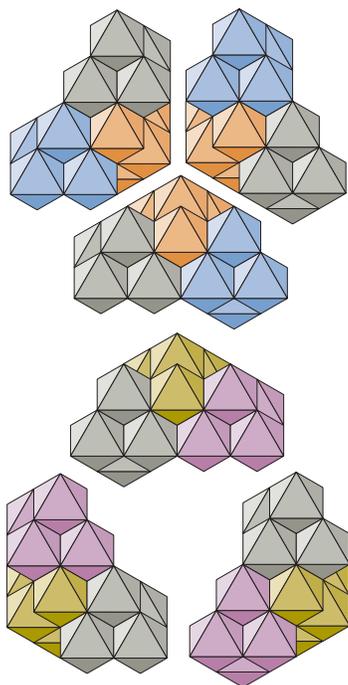
The top shows the relationship of the six Si-atoms of the ring. The red colored atoms differ from the orange colored atoms by a rotation of one-half revolution about the bottom edge of the page. The O-atoms of each group have the same orientation. The O-atoms of adjoining groups are cleftly joined.

Type IV**Ring of six silica groups, Type IV**

The two sets of three silica groups which form the ring are shown above it. The Si-atoms of each set are inverted relative to the other set. The O-atoms of the silica groups of each set are oppositely directed. Those of the top set are ccw; those colored violet are cw.

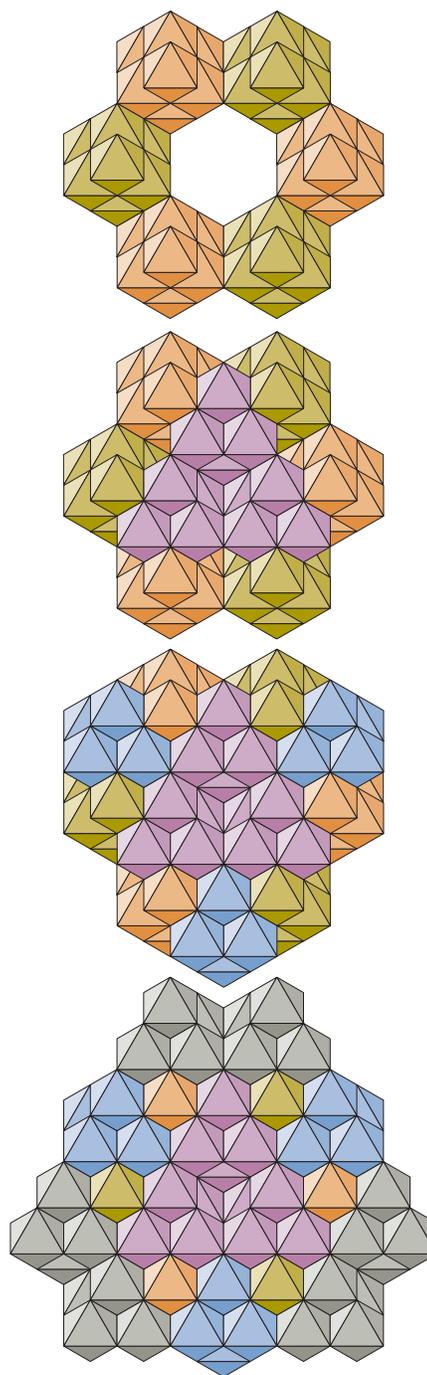
Type V

The figure on the right shows the arrangement of the atoms of a fifth type of ring composed of six silica groups. At the top of the figure, the relationship of the six Si-atoms is shown. They have a common orientation. Below them, the three O-atoms which are central are added. They are colored violet. Three more O-atoms are added which are colored blue in the next view. Each of the six O-atoms which have been added thus far are cleftly joined to adjacent Si-atoms. There remains one unoccupied cleft for each Si-atom. These clefts are filled with the six O-atoms which are colored gray that have been added at the bottom of the figure. These last O-atoms are used to join ring to ring.



Silica groups of the Type V ring.

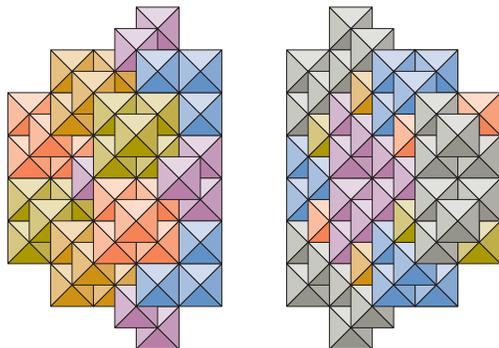
The figure shows how the O-atoms might be assigned to the silica groups. Each Si-atom has one O-atom which joins with another Si-atom to form the ring and another O-atom which is used for ring-to-ring joining.



Ring of six silica groups, Type V

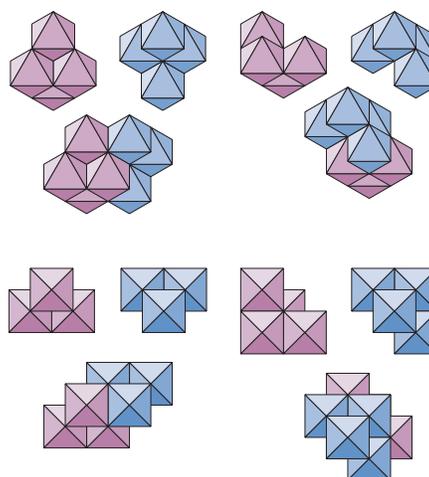
The Type V silica ring is characterized by having O-atoms available for external joins. They are colored gray.

Fourfold ring of type V rings



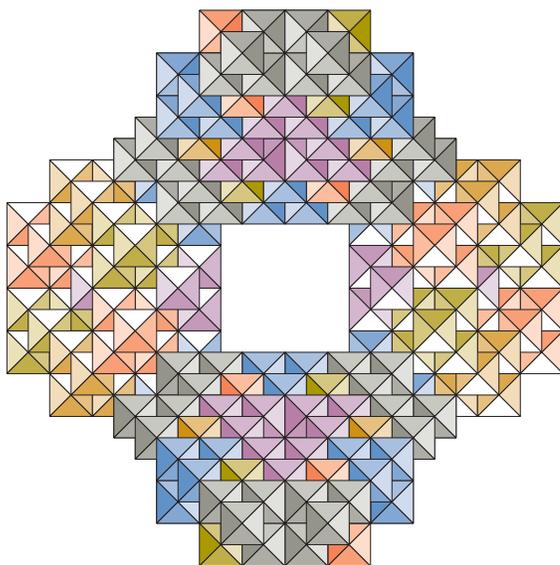
Vertexial views of the Type V ring.

One side of the ring is defined by the 143-faces of the Si-atoms, the other side is defined by three he-octas of each O-atom and the Si-octa of the Si-atoms.



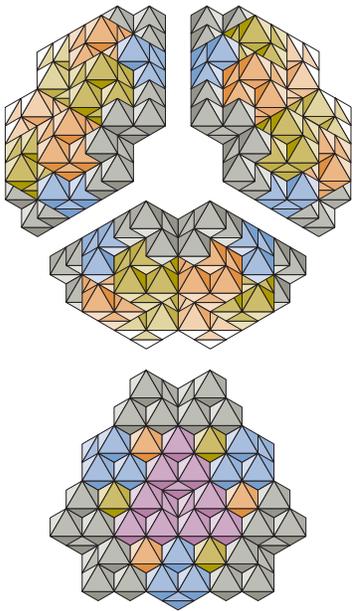
Double cleftly joined O-atoms.

Two O-atoms are shown cleftly joined in each of two assemblies. This is the join between the Type V 6SiO_2 rings.

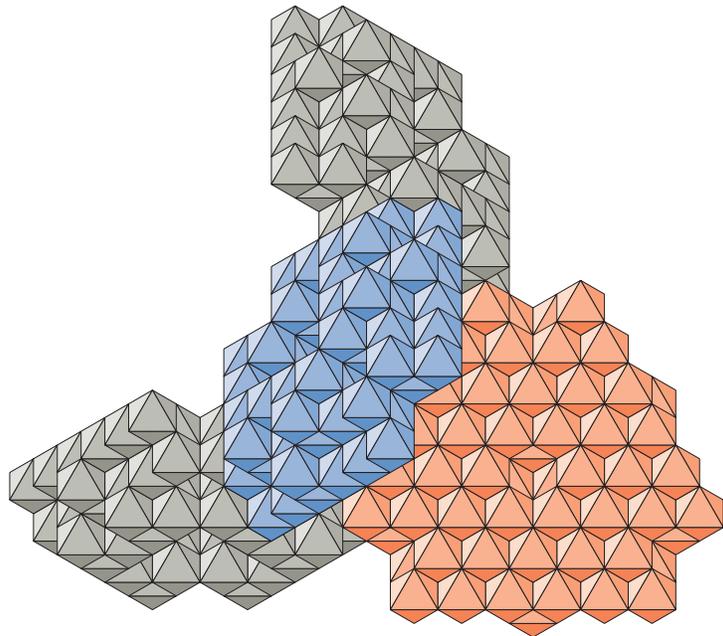


Type V tetrahedral assembly

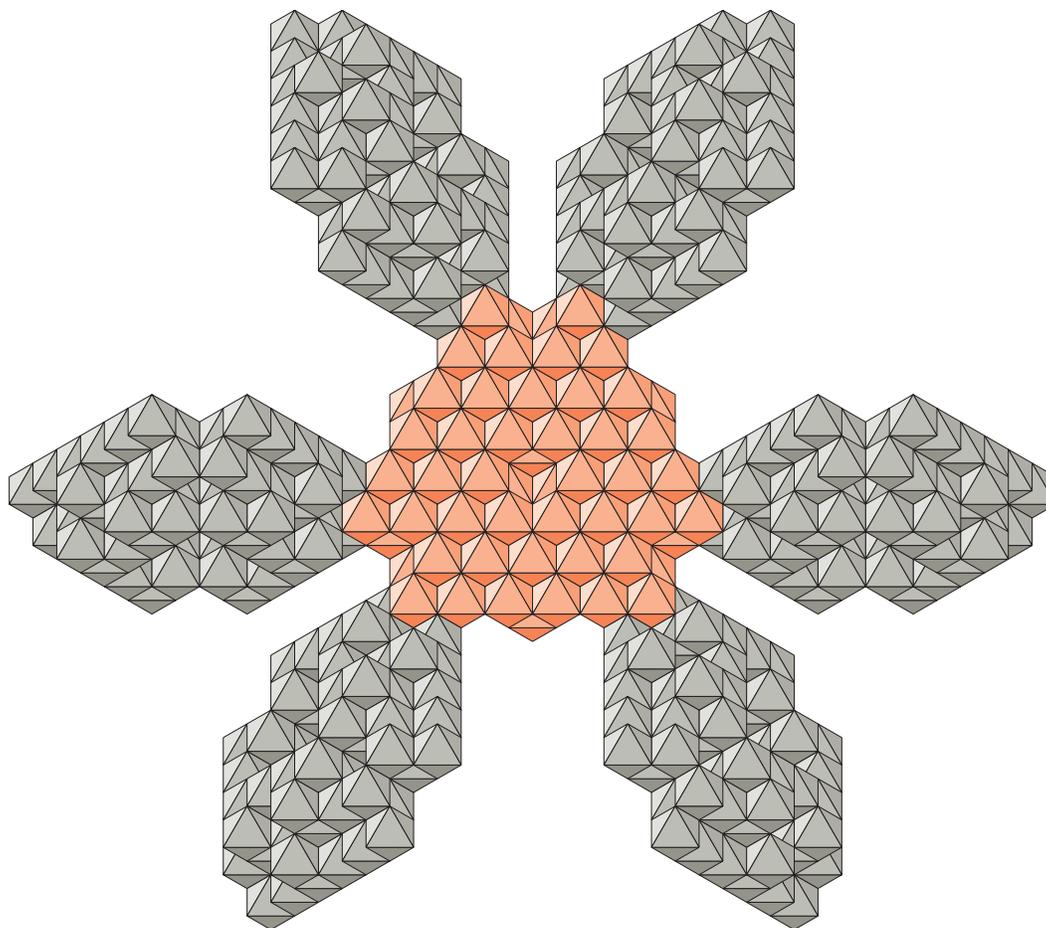
This is a ring of rings which are linked by double cleftly joined O-atom pairs. The four rings are in the four possible orientations for the facially planar rings



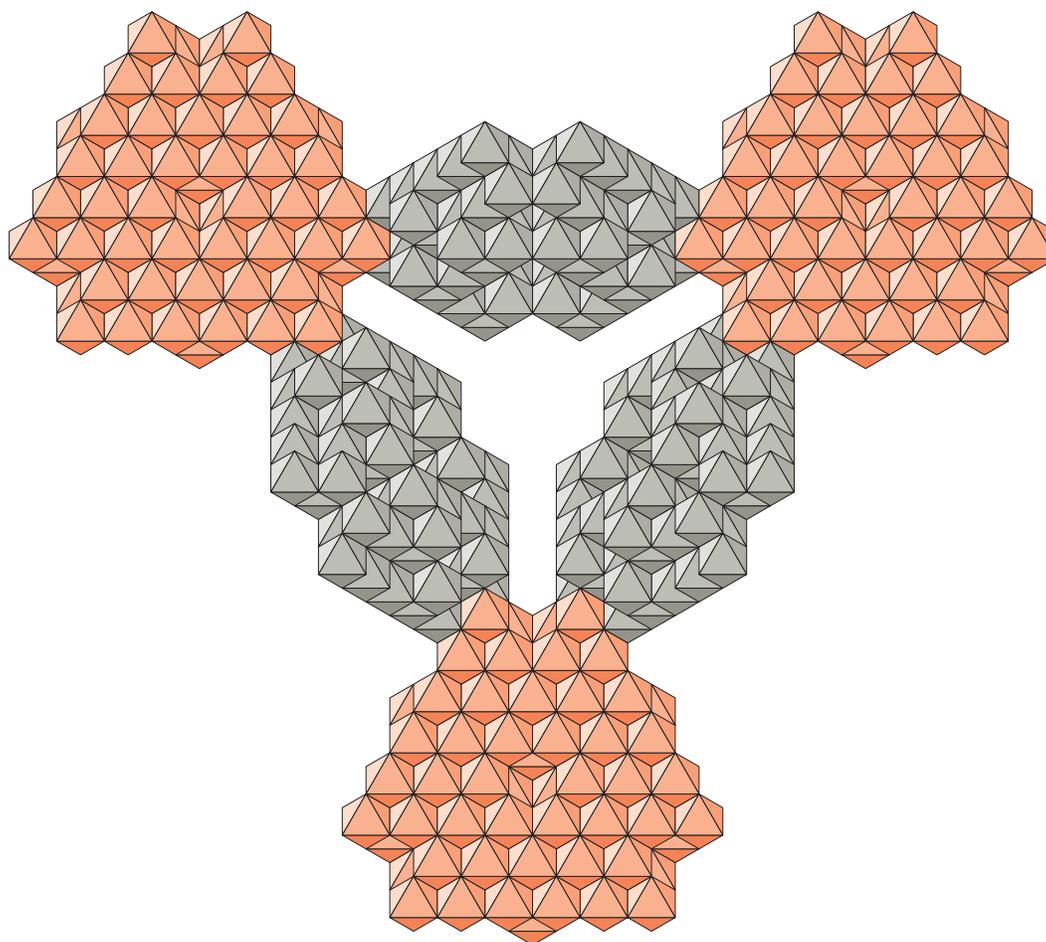
Four facial orientations of the Type V ring.



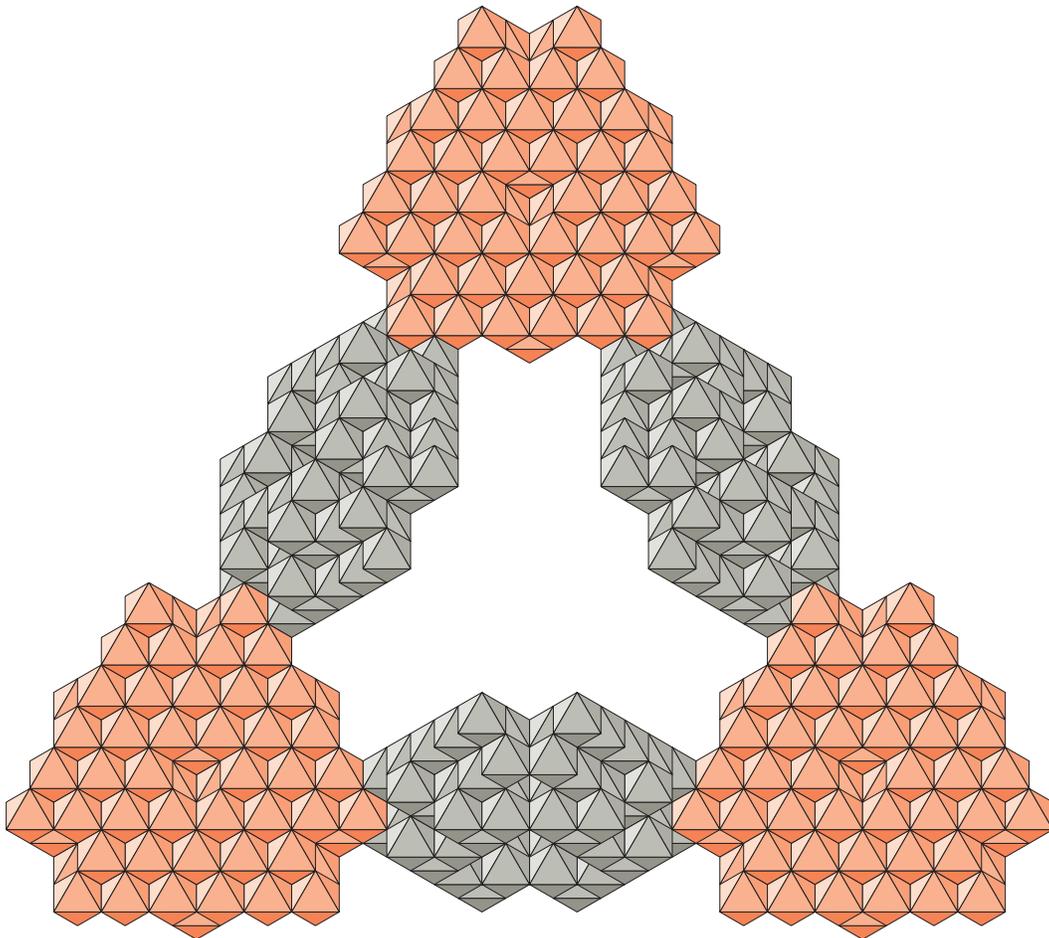
Tetrahedral assembly of Type V rings viewed facially.

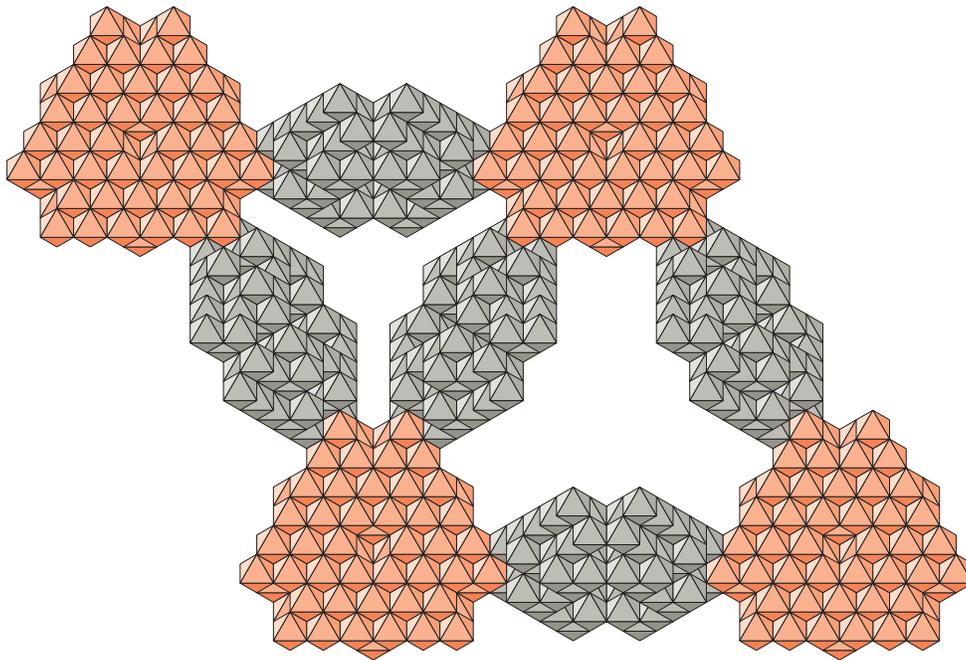
Type V crystal, symmetry center type A**Symmetry center Type A, crystal of Type V rings.**

Type V crystal, symmetry center type B



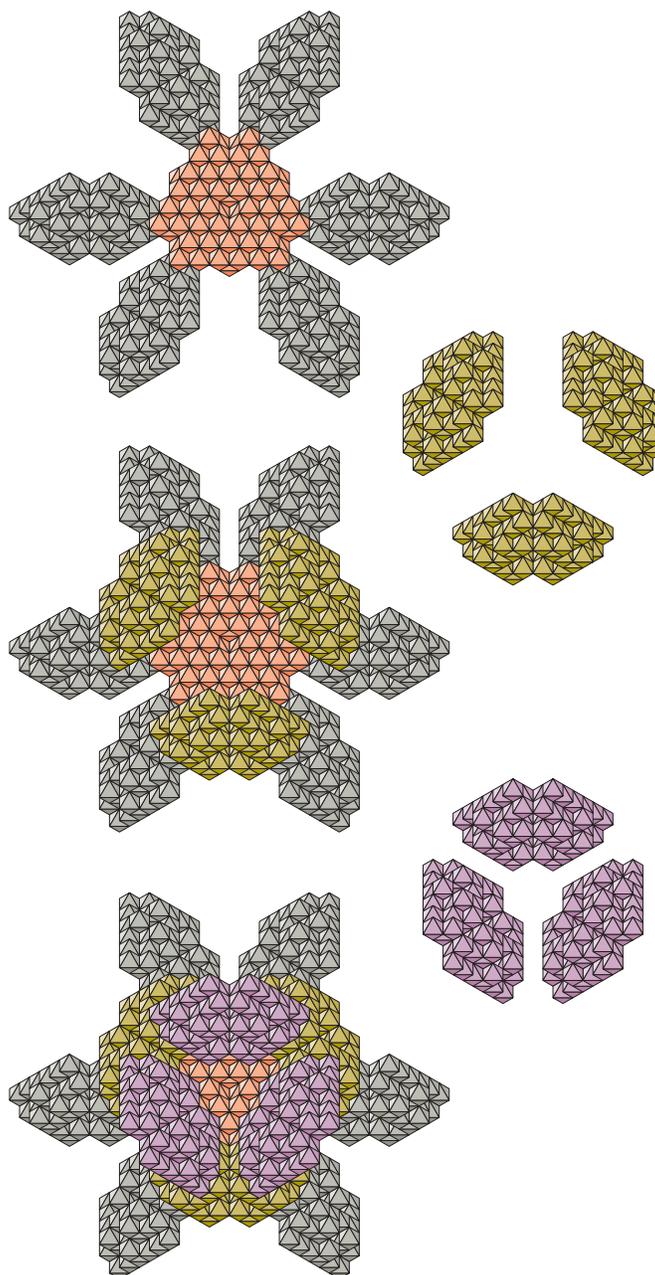
Symmetry center Type B, crystal of Type V rings.

Type V crystal, symmetry center type C**Symmetry center Type C, crystal of Type V rings.**

Type V crystal, symmetry centers B & C**Adjoining symmetry centers Types B and C**

.This figure shows two contiguous centers of symmetry. Each of the horizontal rings (colored red) is the hub of the third type of symmetry center.

Type V crystal, symmetry center stack



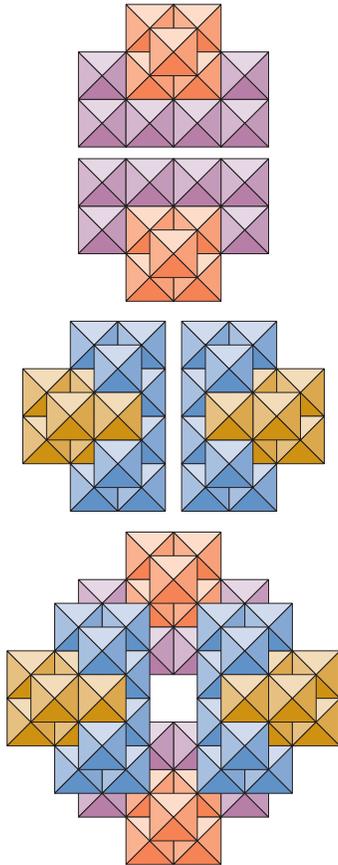
The figure shows how the three centers of symmetry are stacked one above the other in turn.

A unit composed of the type 1 center of symmetry with 3 adjacent spokes removed can form the plane with translations in three join directions at 60° . A structural stack of three such units is a cfu.

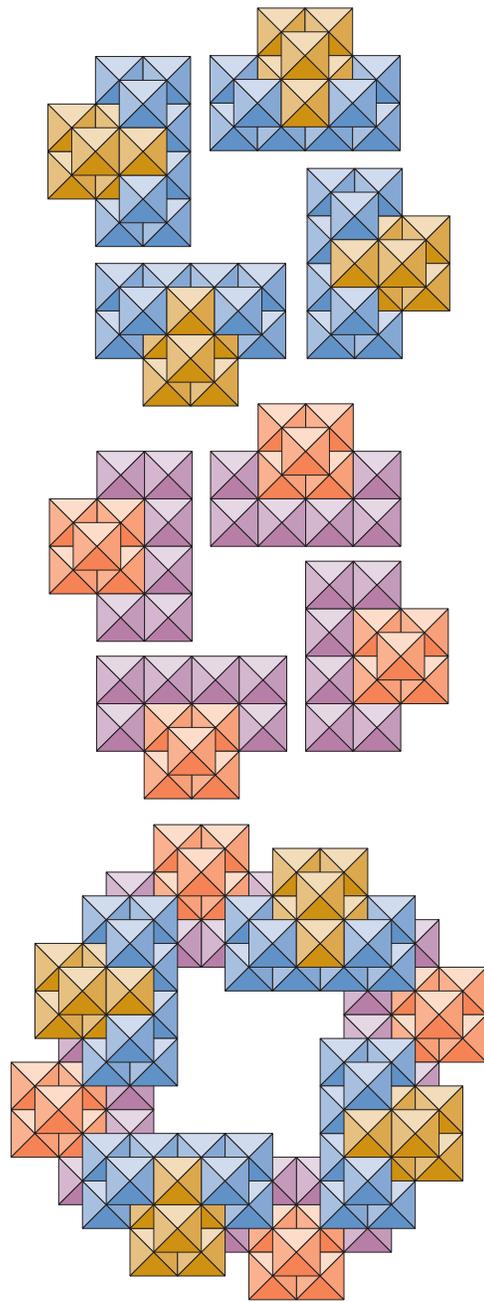
The rings are identical and identically joined to six other rings none of which has the same orien-

tation as the hub. The others have three orientations between them, two rings per orientation.

The rings with the same orientation are at 180° . The orientations are parallel to the four pairs of faces of the regular octahedron. The rings of the same orientation establish with the hub a chain which continues in either direction. The chain directions are parallel to the edgial diameters of the regular octahedron.

Vertexial SiO_2 rings**4 SiO_2 ring****4 SiO_2 ring**

This ring is composed of two pairs of SiO_2 . Each Si has one cw O-atom and one ccw O-atom and one SiO_2 is inverted with respect to the other.

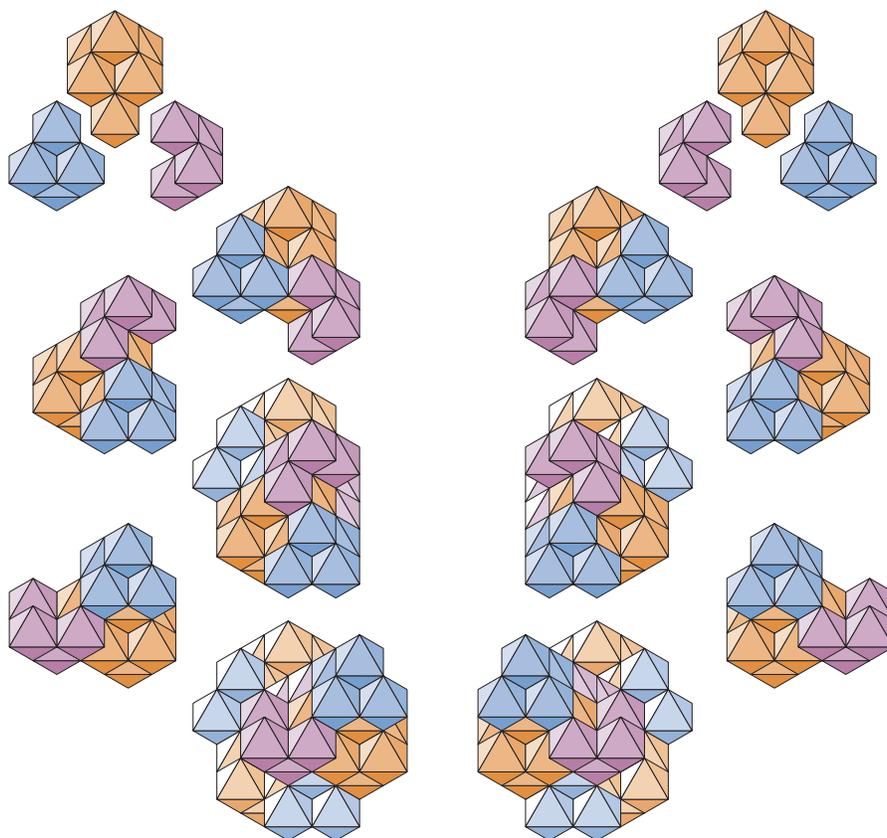
8 SiO_2 ring**8 SiO_2 ring**

This ring is composed 4 pairs of mixed O-atom SiO_2 .

SiO₂ helixes

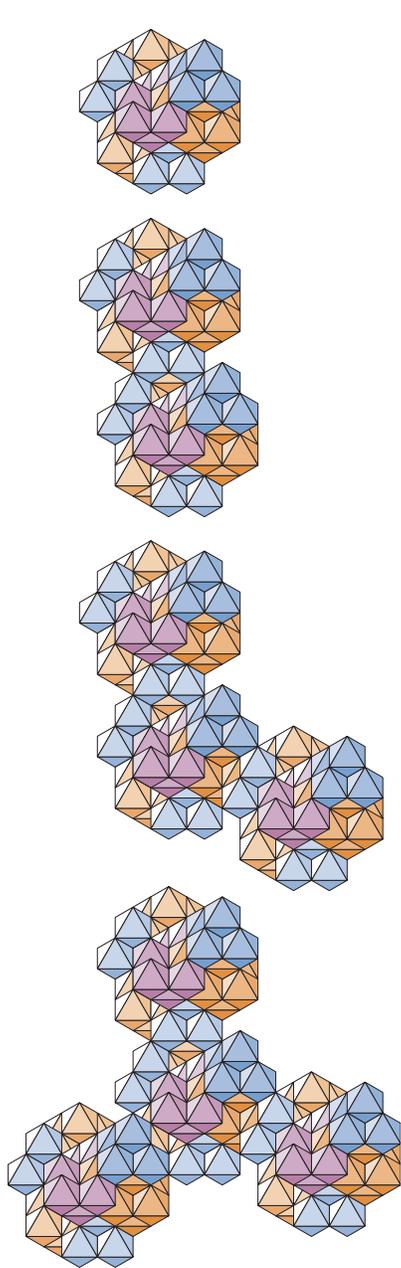
Silica groups can form helixes. In the following figure are depicted two silica helixes and the units which form them. The adjacent Si-atoms are connected by an O-atom. Each helix mirrors the other. The one on the left is

clockwise toward; the one on the right is counterclockwise toward. The second O-atom of each unit is available for joining each of the silica groups of the helix to other groups. The helixes are viewed axially, from opposite directions, and each is a single turn.



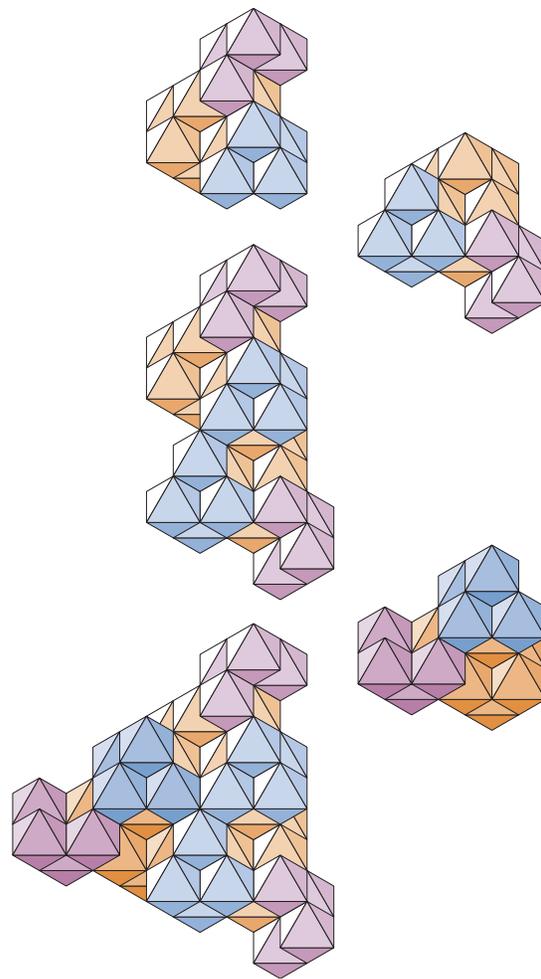
Two SiO₂ helixes, cw and ccw, toward, Type A.

The helical axis is facial and in its direction relative to the Si-atom is **456**, **125**, or **236**. Just one O-atom of each silica group is used for the intrahelical join.



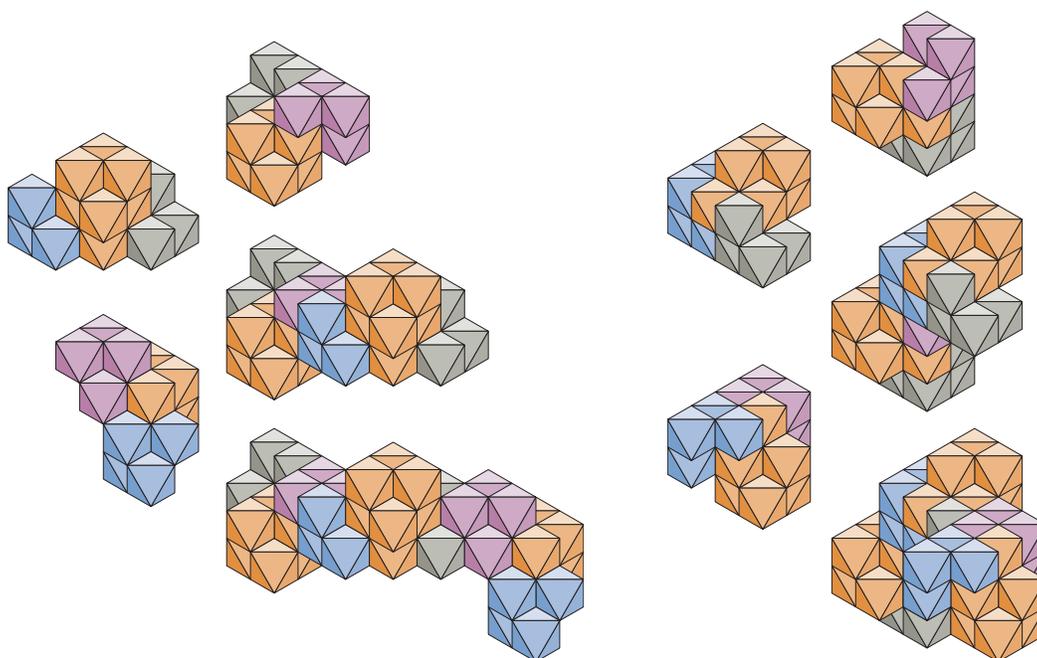
Joins between cw-toward Type A helices.

The C-octa of a Si-atom of one helix occupies a void of an O-atom of an adjoining helix.



Detail of the interhelical join between three cw-toward Type A helices.

Each of the three silica groups which join to form the assembly at the bottom of the figure belong to a different helix. Each group is rotated one-third of a revolution with respect to the other two.



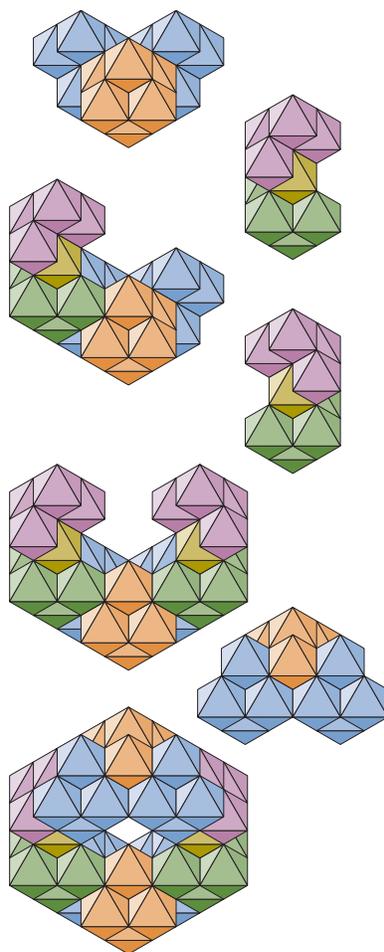
SiO₂ helix Type B, oblique view.

SiO₂ helix Type B, axial view.

The helical axis is facial and in the direction relative to the Si-atom **456**, **125**, or **236**.
The intrahelical join is between an O-atom of a silica group and an O-atom of an adjoining silica group.

Silica groups linked by H₂O pairs

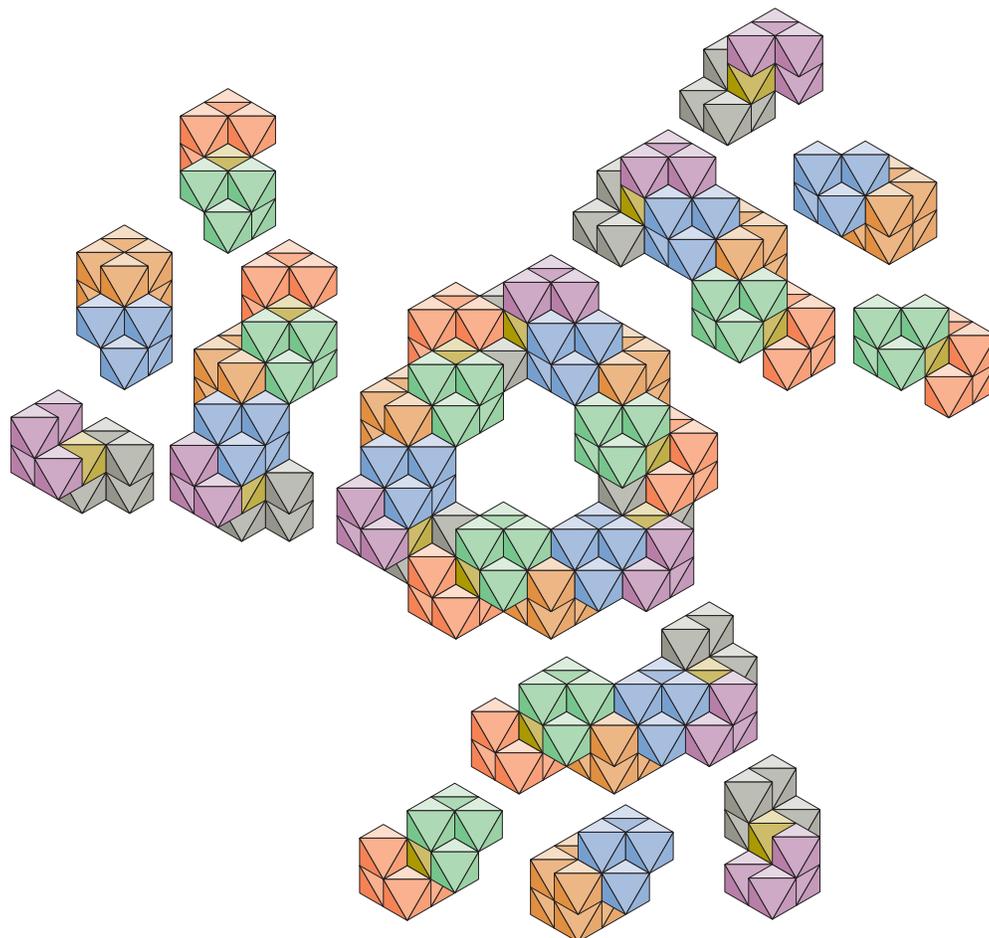
2[SiO₂•(H₂O)₂] ring



Two silica groups linked by paired H₂O groups.

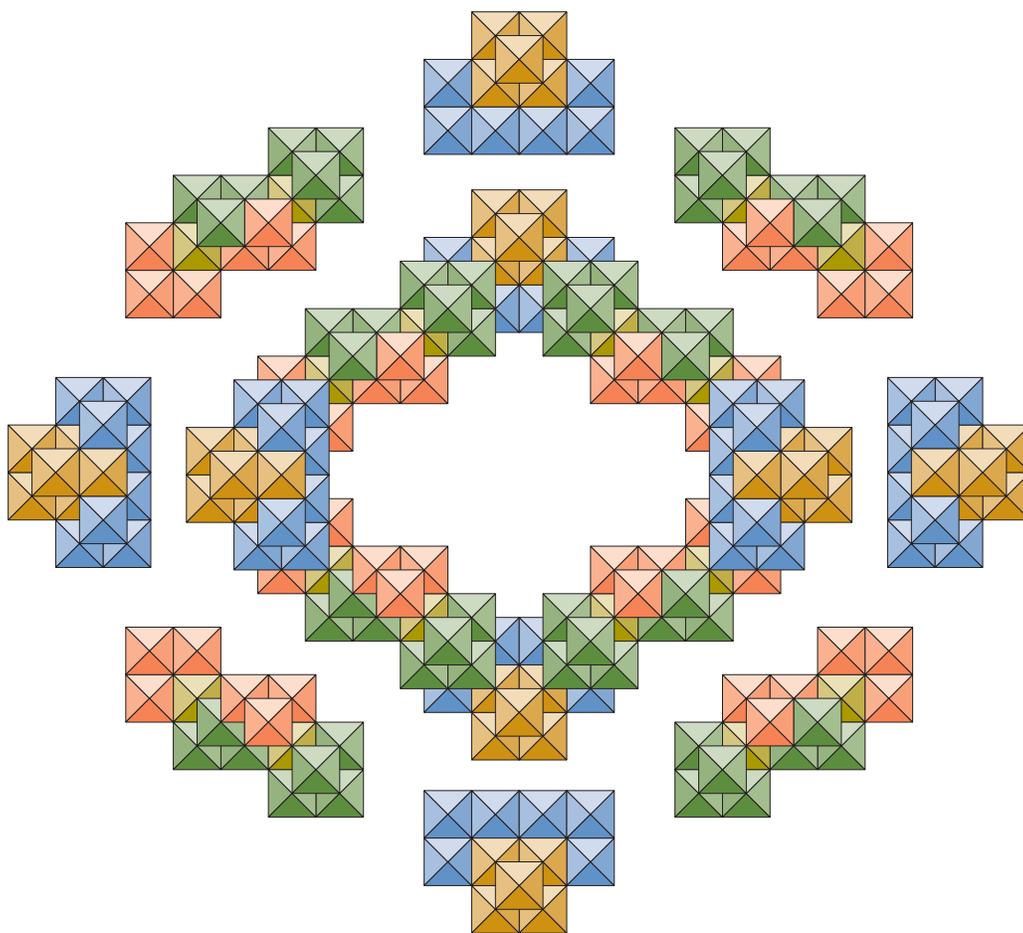
The figure shows the assembly of a ring composed of two silica groups linked by two paired H₂O groups. The top group is a silica group with the Si-atom colored orange. The assembly commences with the addition of paired H₂O groups and terminates with the addition of the second silica group.

$3[\text{SiO}_2 \cdot 2(\text{H}_2\text{O})_2]$ ring



Three silica groups linked by two paired H_2O groups.

The completed ring is at the center of the figure. Just outward from the assembly are the three identical subassemblies which produce the ring. The components of the subassemblies form the outermost groups. Each of the silica groups is depicted without one of its two O-atoms which fits in the remaining cleft of the Si-atom

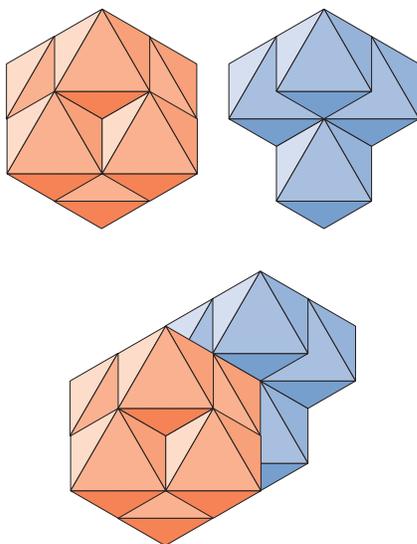
4[SiO₂•(H₂O)₂] ring

Four silica groups linked by two paired H₂O groups.

The completed ring lies at the center of the figure. It is surrounded by the four silica groups and the four paired H₂O groups which constitute it.

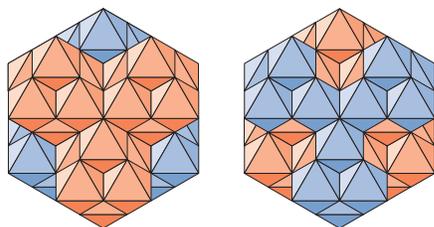
MAGNESIUM

MgO group



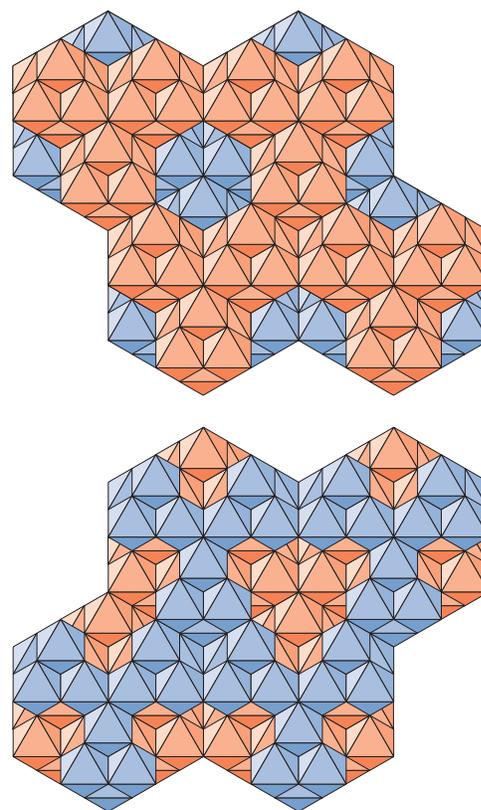
MgO group

A Mg-atom is shown at the top in red. To its right is an O-atom. They are combined to form a MgO group. This is called *magnesia*.



3MgO assembly.

Three MgO groups can form a triplet. Each group is rotated one third revolution about an axis normal to the page relative to its neighbors. The two views shown here differ by a rotation of one half turn about an axis parallel to the bottom of the page.



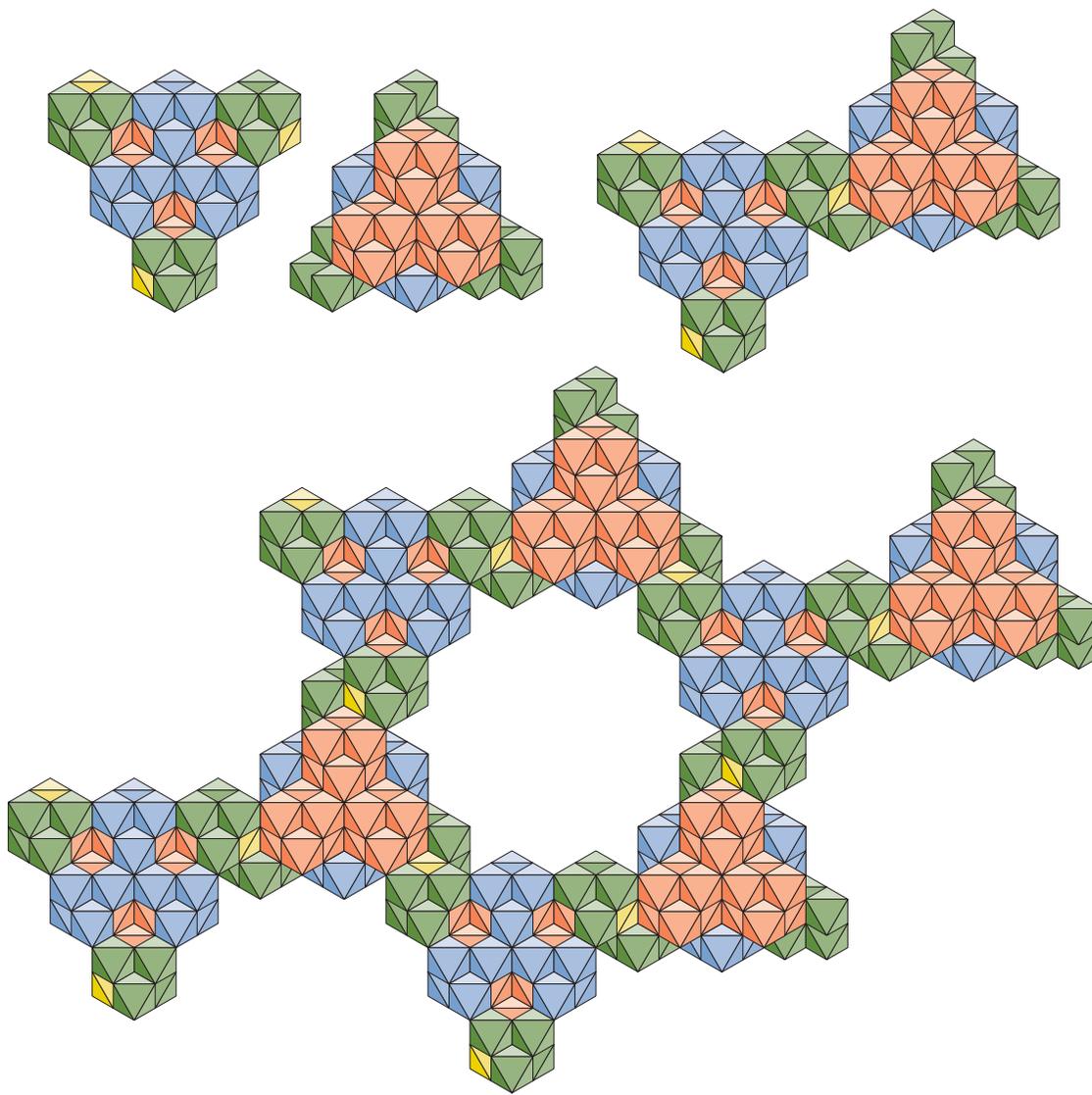
Four 3MgO groups.

The 3MgO groups can join in planar groups in the manner of hexagons. They can stack normal to the viewing plane. The two views differ by a rotation of one half turn about an axis parallel to the bottom of the page.

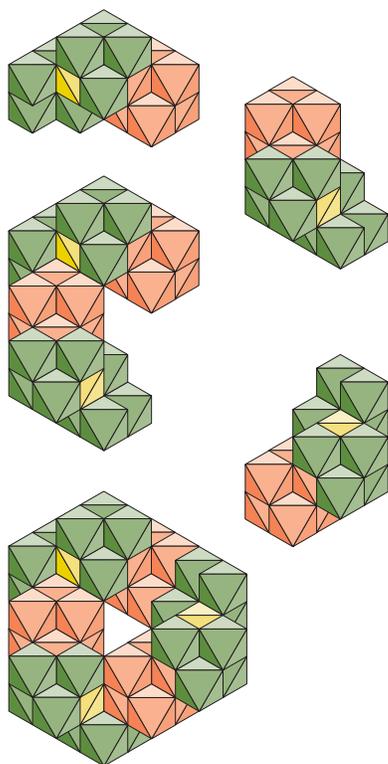
Brucite crystal

The formula for the mineral brucite is MgOH . The analysis is $2\text{MgO} + \text{H}_2\text{O}$. It is assumed that the H_2O groups are the links between the MgO layers with the H_2 groups pairing as if they were triplets. That is, the H_2O groups are like F-atoms and they pair like F-atoms. The MgO groups are assumed to be cyclicly arrayed in groups of three with O-atoms linking Mg-atoms. To model this crystal

in this manner, two molecular groups are used. Each is a 3MgO group with an extra O-atom on each Mg-atom. One group has an additional He-octa attached to each of the extra O-atoms which represents the 2H_2 groups. The two units link so that the 2H_2 group is shared by a pair of the extra O-atoms of the two groups.

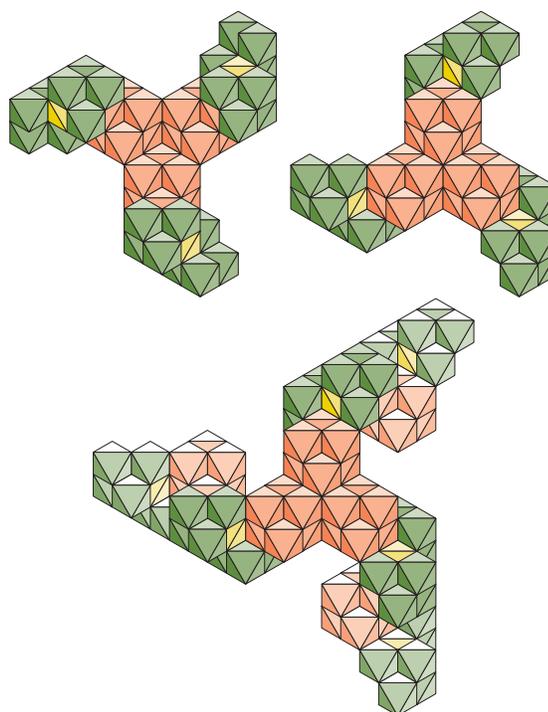


MgF₂ group



MgF₂ helix

A MgF₂ group is shown at the top of the left column. This is joined by an identical group which is at the top of the right column which is rotated one third revolution about an axis perpendicular to the viewing plane relative to the first group. This is combined with the first to produce the first two units of a three fold helix which is counter-clockwise towards the viewer. The third group is shown at the bottom of the right column. The completed turn is shown at the bottom of the left column.



MgF₂ chain assembly

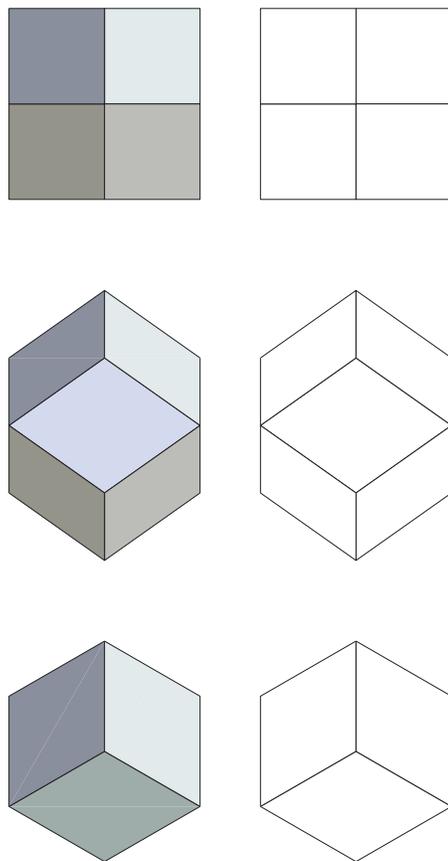
At the top of the figure, a triplet of MgF₂ groups is shown in two orientations. They differ by a rotation of one half revolution about an axis parallel to the bottom of the page. At the bottom, each of the group of the right hand triplet have been joined by an identical group in identical orientation to produce a three chain hub. This pattern is extensible.

Biological Assemblies

DNA

Structure of DNA

Twentyfold symmetry, tenfold symmetry, and fivefold symmetry are not found in regular crystals. Fivefold and tenfold symmetry is demonstrable in quasicrystals. It is reported to be so for viral coats. It is not found in regular crystals. The Laue photograph showing an X-pattern is compatible with those which would be produced by a set of pyramids with geometrically similar and concentric rhombic bases,



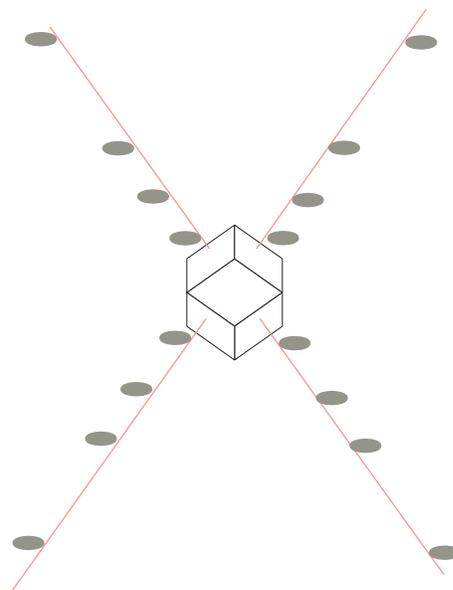
Rhombic dodecahedron.

The three views are 4-face vertexial, facial, and 3-face vertexial. Each view is shown with faces both colored and uncolored.

with a common altitude. The Laue spots are parallel to the sides of an $\tan^{-1}(\sqrt{8})$ rhombus. This is the same as the profile of the regular octahedron when viewed in the direction of a mid-edgial diameter.

The x-pattern of the DNA x-ray photograph suggests a rhombic dodecahedral crystal which is oriented so that one of its facial axes is perpendicular to the film plane.

The reflecting faces are parallel to a pair of edges of one of the dodecahedral faces and the line of spots are normal to these edges.



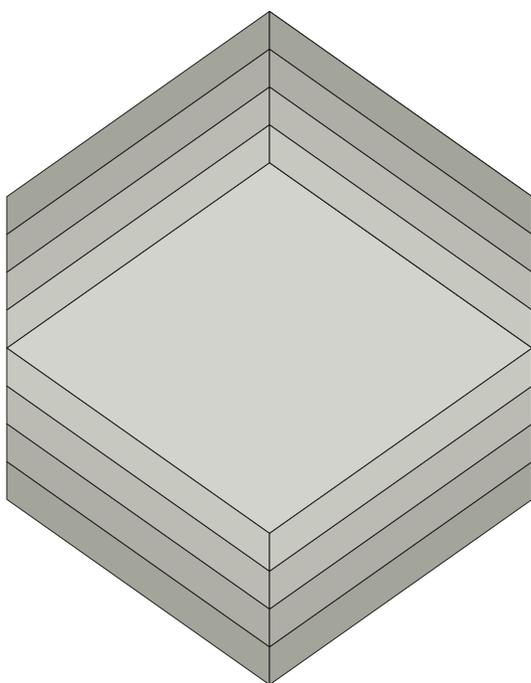
DNA crystal: rhombic dodecahedral nature of DNA diffraction pattern.

The spots are reflections from crystal faces which are modifications of the dodecahedral faces.

Relationship of diffracting planes to the rhombic dodecahedron

The faces of the rhombic dodecahedron are defined by the edges of the regular octahedra

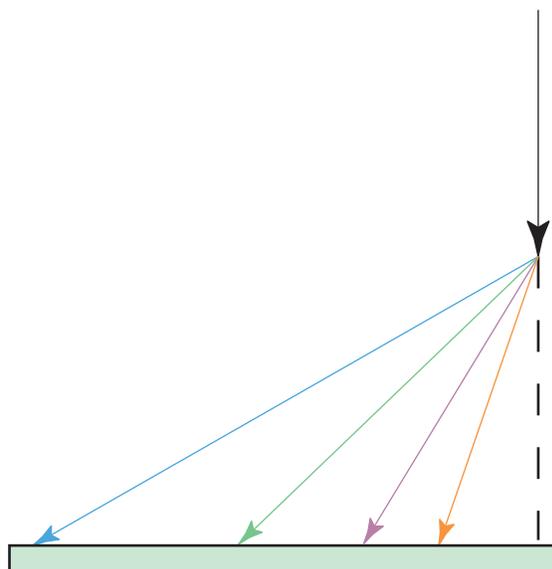
which form the DNA groups. When these octahedra are viewed in a direction parallel to the face and in a direction that is parallel to the photographic plane, the octahedra are seen in a facial view. The modifying faces are defined by a vertex of the octahedron.

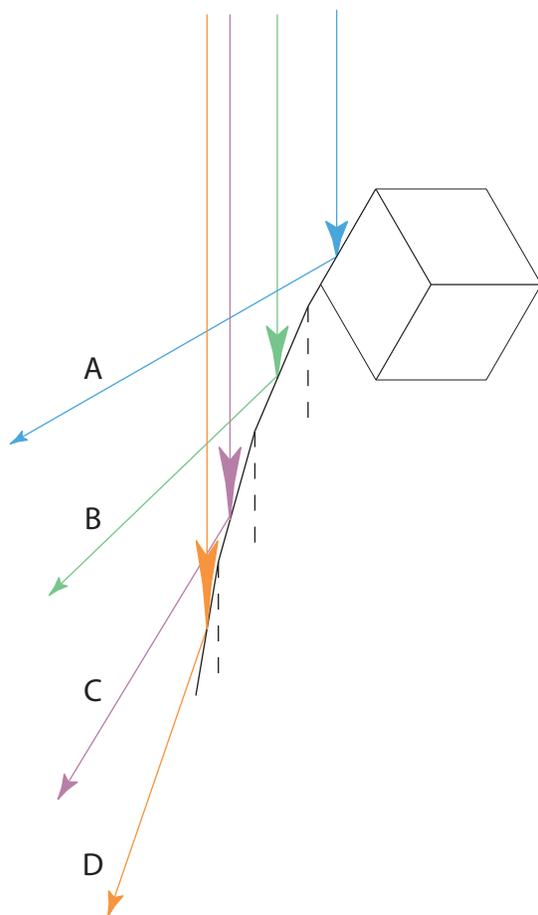


DNA crystal: rhombic dodecahedron with four of its faces modified.

The plane of the photon trajectory from each of the additional faces is parallel to that of the original face.

DNA: photon trajectories from a rhombic dodecahedral crystal

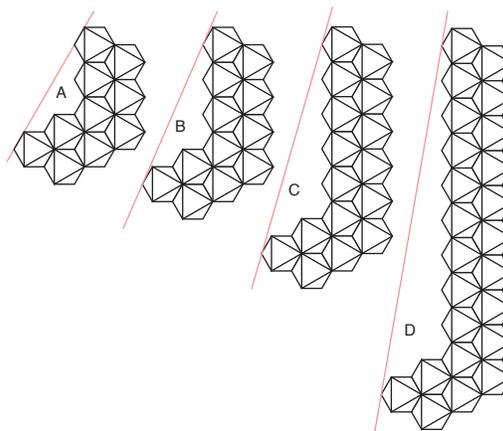




DNA crystal: photon trajectories from a rhombic dodecahedral crystal viewed parallel to a reflecting face.

Octahedral relationships which form the diffracting planes.

If the x-ray beam is in the direction of the DNA axis, and this is a pair of chains, then the chains are not helical. They are parallel edgial chains. This axial orientation is compatible with the right-angled "L" shape of t-RNA which is built of similar units.



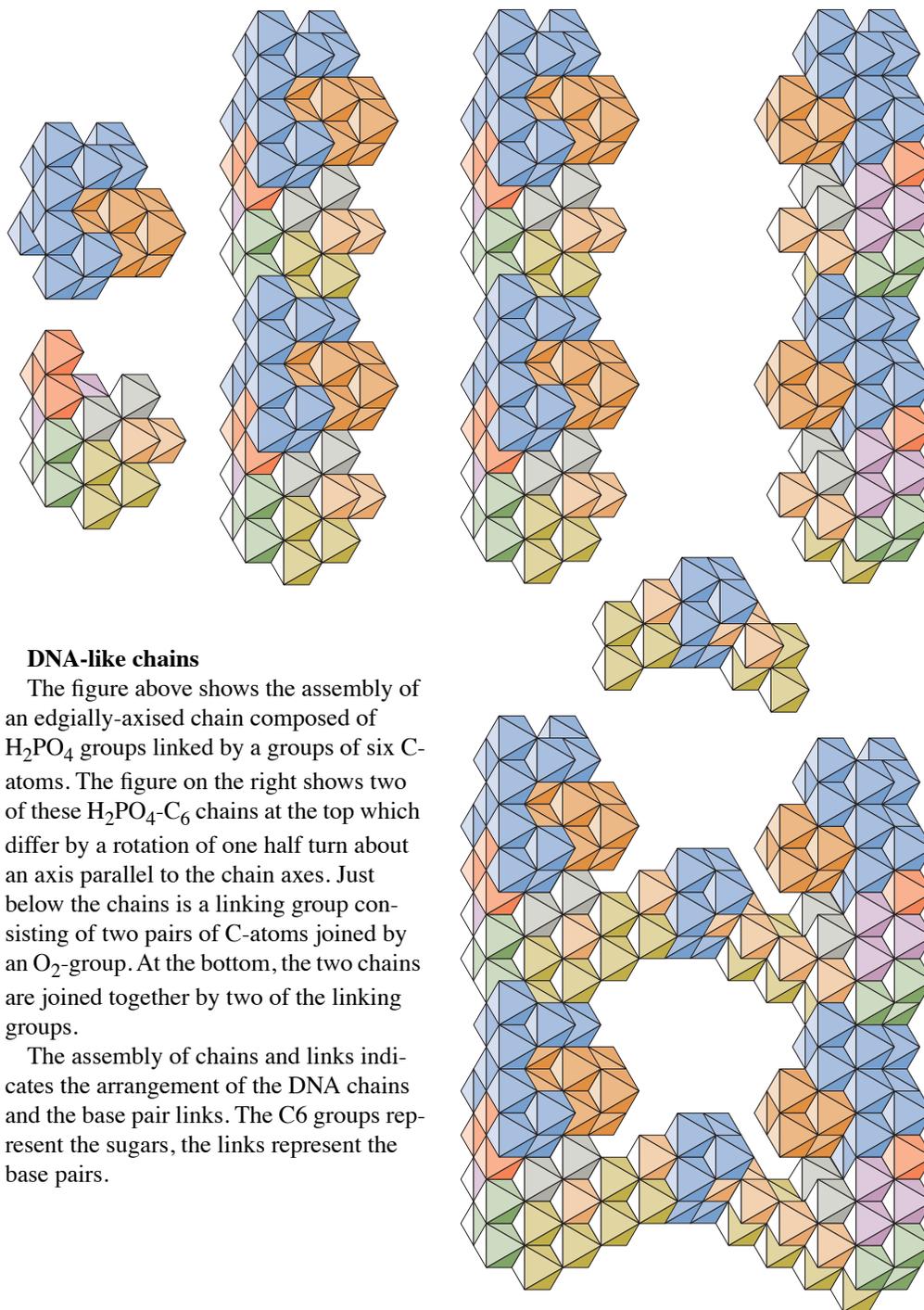
DNA crystal: four planes defined by octahedral assemblies.

The planes are perpendicular to the picture plane. Plane A is the face of a rhombic dodecahedron and is defined by octahedral edges. The others are modifications of the rhombic dodecahedral face and are defined by octahedral vertices. This set of planes will reflect x-rays in the manner that is shown in the DNA photographed by Rosalind Franklin.

Evidence for edgially axised chains

1. Permits contact or pairing of base atoms.
2. Provides two chains that are separable without unwinding.
3. Permits a solid structure using the elements described-- H_2PO_4 , C_6 , base.
4. Opposed sugars are inverted.

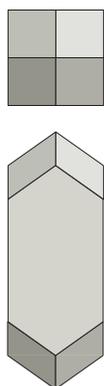
DNA-like chains



PROTEIN

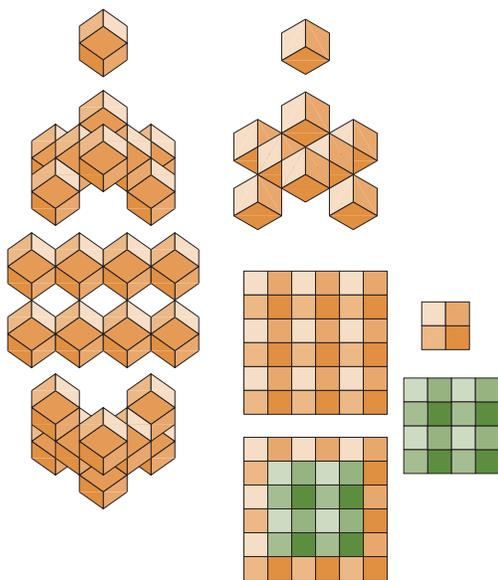
Crystalline form¹ of cytochrome

1. A. L. Lehninger, *Biochemistry* 2d ed., Worth, 1975, <Figure 3-1 Crystals of horse cytochrome C>, p. 57



Cytochrome crystalline form.

The top view is along the fourfold axis. The bottom view is of a prism face and is normal to the fourfold axis. The crystalline form is that of a rhombic dodecahedron which is elongated along a fourfold axis. Each face of the crystal is defined by octahedral edges.

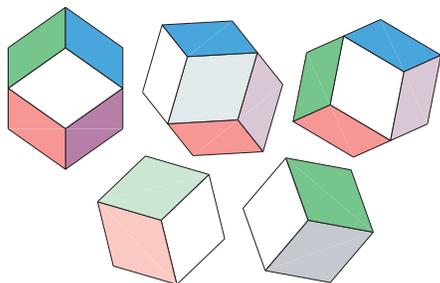


The cytochrome crystal can be formed of identical rhombic dodecahedral units. The left column show three assemblies of rhombic dodecahedra. The first assembly defines the two pyramidal faces of the crystal shown at the top of the facial view of the crystal form in the previous figure. To its right the same assembly is shown in an orientation which is rotated slightly. The second assembly shows the arrangement of the rhombic dodecahedra which define the prism plane of the crystal. The bottom assembly defines the two faces of the pyramid which are visible at the bottom of the facial view.

The relationship of the rhombic dodecahedra normal to the fourfold axis is shown in the lower right. The first layer is a three by three square. The second layer is a two by two square. The positions of the dodecahedra in alternate layers differ by an a translation in the fourfold axial direction..

Crystalline form of neuraminidase

A photograph of neuraminidase crystals obtained from an influenza virus shows that their common form is that of the rhombic dodecahedron.¹ The prominence of the rhombic dodecahedra suggests a CFU of the same shape.



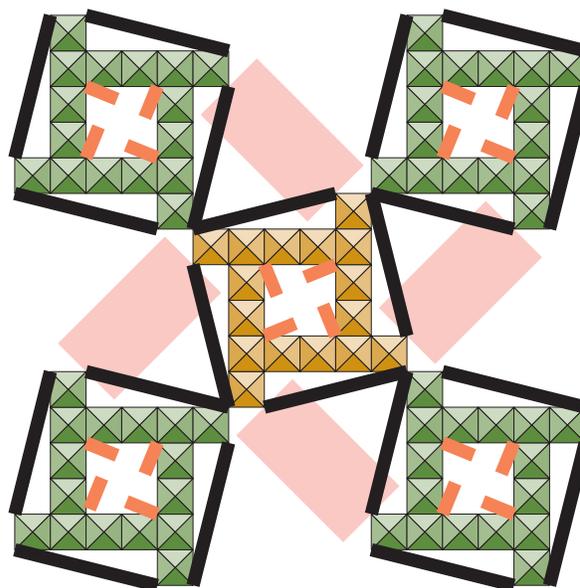
Neuraminidase crystals.

Rhombic dodecahedral forms in orientations suggested by a photograph of neuraminidase crystals. The top row shows three units in facial view which differ by a rotation about the viewing axis. The bottom row shows two units in threefold-axial view which differ by a rotation about the viewing direction.

Myelin protein P₀

A computer-generated image of crystals of myelin protein P₀ suggests the structure shown

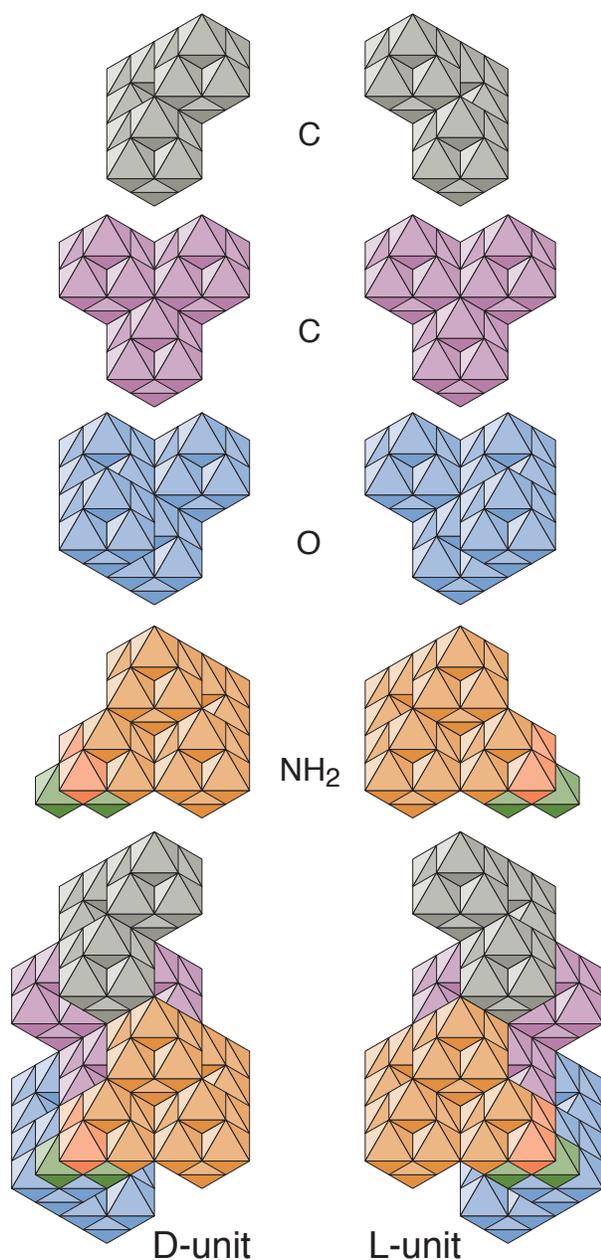
schematically in the figure. The heavy black



borders represent the boundaries of the squares delineated by what appear to be protein strands. The broad pink bands represent the parallel strands which link the central square to the outer squares. The short red lengths within the square represent the four chains which extend from the square periphery into the square area in each of the square formations. These chains and the angular relationships between the square units show that the central unit is equivalent to the four outer units except that it is inverted. The whole pattern is consistent with a vertexial projection of the regular octahedron. The octahedral assemblies in each of the squares are a minimum representation of how the sides of the squares are defined. Each broad black line is defined by a vertex of two octahedra. The borders of the four pink bands are parallel to the two vertexial diameters of the regular octahedron in the viewing plane.

1. W. Graeme Laver *et al*, Disarming Flu Viruses, *SciAm* Jan 1999, pp. 78-87. See the photograph of the rhombic dodecahedral crystals on page 82.

AMINO

**Amino main chain unit.**

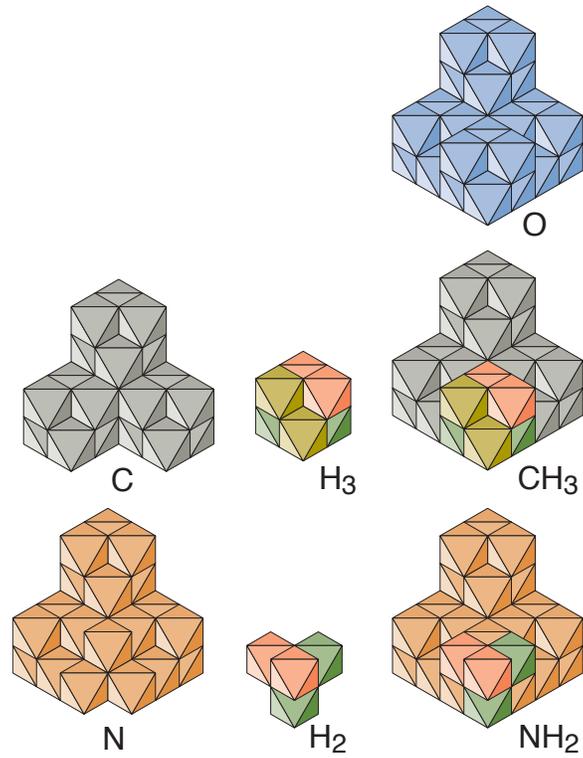
The figure depicts the assemblies of the main chain portions of both D- and L- units. The D-unit is on the left and the L- unit is on the right.

Amino acids

The forms of the amino acids are determined by the forms of the atoms and the joins between them. The principal substructures of the proteins are defined by the backbone or mainchain conformation. An examination of the alpha helix, the epsilon helix, the pleated sheets, and the beta annulus, reveals that there is an association of two C-atoms and an NH₂O group which is invariant in each of the structures. It is this invariant unit in regular association with identical units which defines the structures. This invariant unit is the base for the side chains which define each of the amino acids in the form in which it is a link in the main chain of a protein. This invariant unit is inflexible, it is rigid, it has no hinges, it has no swivels. The NH₂ group has the form of an O-atom and the NH₂O portion is essentially a “socket” for the He-octa “ball” of the carbonyl C-atom. Each of the residues in each of the structures has an NH₂O group in identical orientation with a pair of lefthandedly cleftly joined C-atoms.

In the aminos depicted below, each of the N-atoms has been depicted as an O-atom, as if each was an NH₂ group. This is because the sidechains of asparagine and glutamine terminate with an NH₂O group which suggests that each of these side chains can make the same kind of join as exists between the main chain units. Each of these two residues could link directly with a C-atom terminus of alanine, valine, isoleucine, leucine, proline, tryptophan, or phenylalanine. Aspartic acid and glutamic acid terminate with an OO-group that could make a similar join with an NH₂-group of lysine, arginine, tryptophan, or histidine.

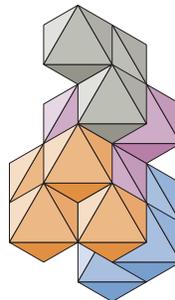
Since it is expected that the OO-group will combine so that an O-atom is replaced by an NH₂ of another sidechain, only one O-atom is



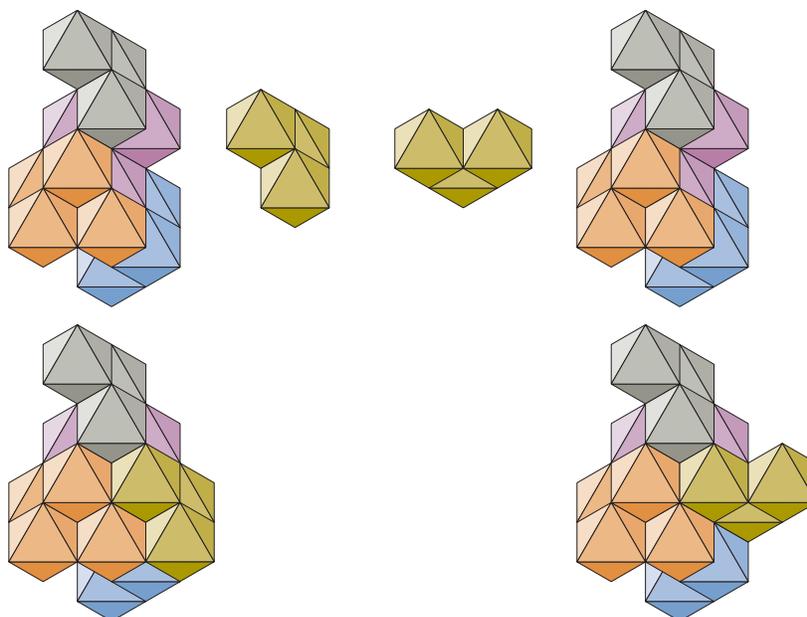
O-atom homomorphs.

The assemblies are shown on the right and their constituents are to their left,

Glycine.



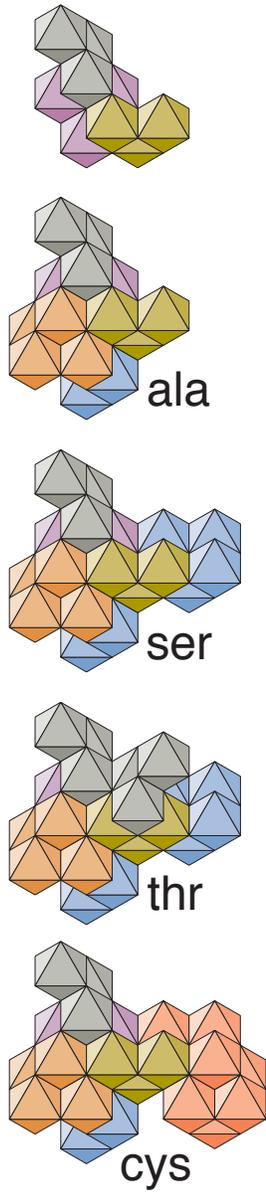
C₃ family of aminos.



The first C-atom of the side chain.

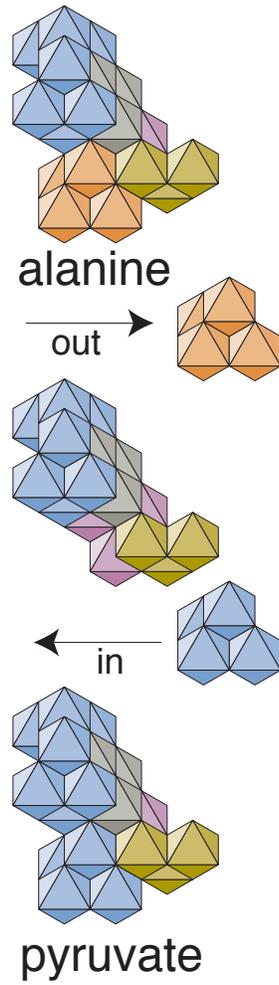
The figure depicts the only two possible assemblies of a C-atom and a main chain unit. In the top row are two main chain units with two C-atoms between. The C-atom on the left is oriented so as to make a right-hand join with the alpha C-atom of the main chain unit. The C-atom on the right is oriented for making a left-hand join. The completed assemblies are shown in the bottom row. The C-atom joined right-handedly to the alpha C-atom abuts the NH₂-group so that it cannot make a join with another atom. The C-atom that is left-handedly joined has two clefts available for joining with other atoms. The latter, then, is the manner in which a third C-atom is added to the amino acid.

The C₃ aminos ready for chaining.



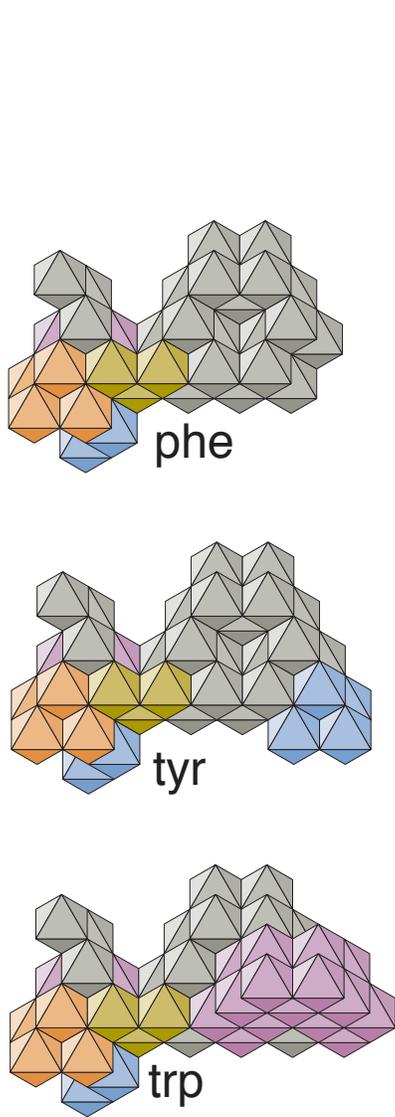
C₃ family of aminos.

Conversion of alanine to pyruvate

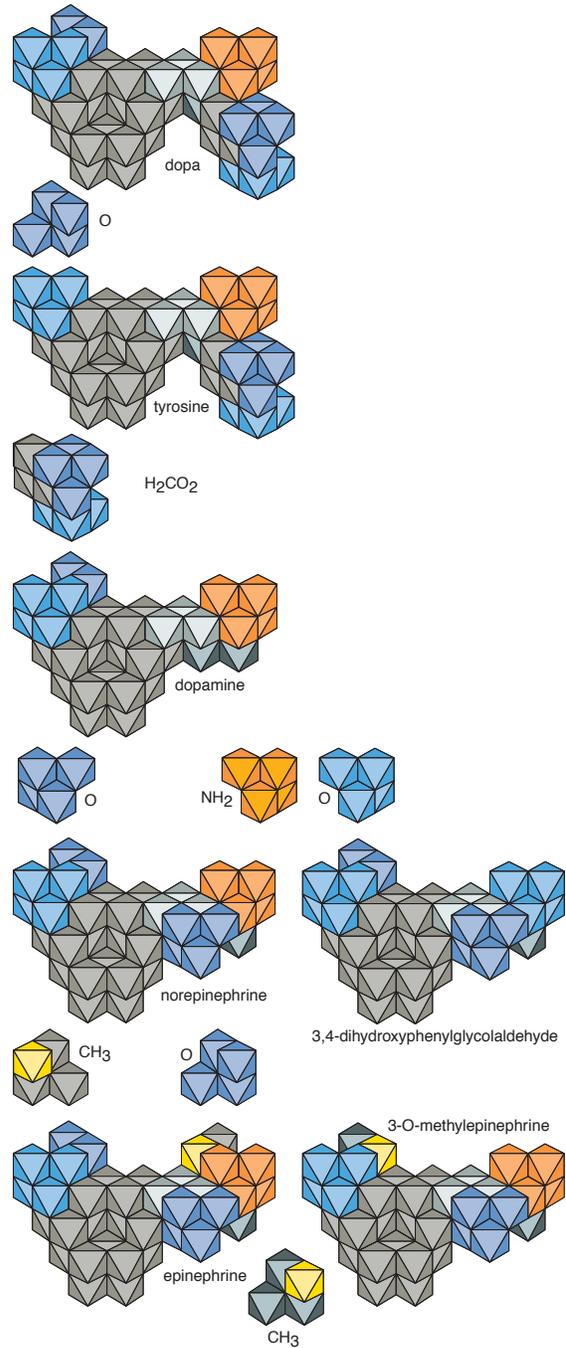


Alanine to pyruvate.
 Alanine conversion involves removal of the NH₂ group and replacement with an O-atom.

Aromatic aminos

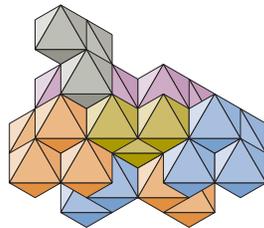
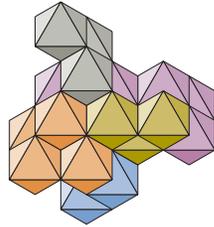
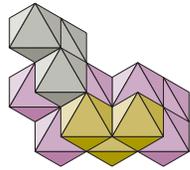


Aromatic aminos.



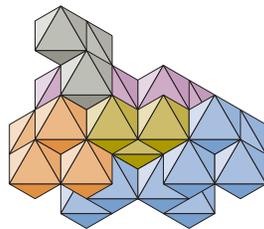
Pathway: Tyrosine and the catecholamine neurotransmitters.

C₄ family of aminos

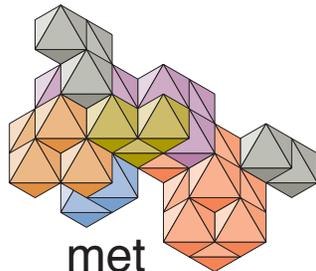


asn

C₄ family of aminos.



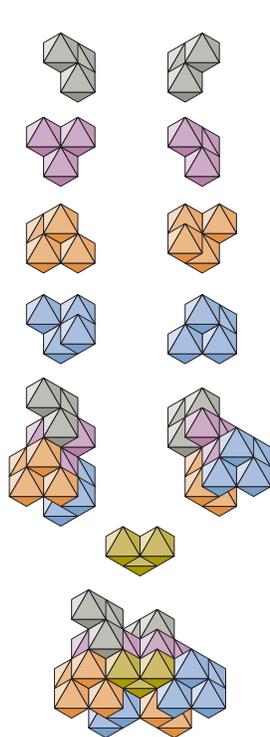
asp



met

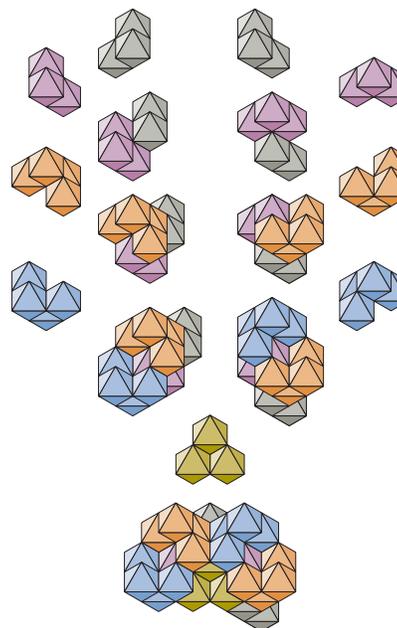
C₅ family of aminos.

The relationship between the five C-atoms of the amino acids of the C₅ family is established by the conversion of histidine to glutamine. The conversion results in the main chain group shifting from one end of the five C-atom chain to the other. That fixes the conformation of the chain as that between two main chain groups sharing a common C-atom side chain.



Histidine to glutamate.

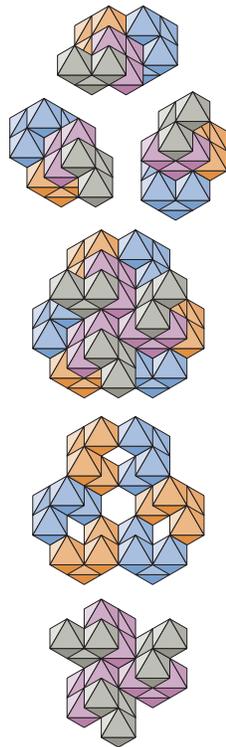
The conversion of histidine to glutamate shows the five C-atoms which the two have in common must be in the configuration of two main chain units sharing a single C-atom side chain. The figure shows the assembly of each of the main chain units in the left and right columns and their linkage by the C-atom at the bottom.



Two main chain units linked by a C-atom.

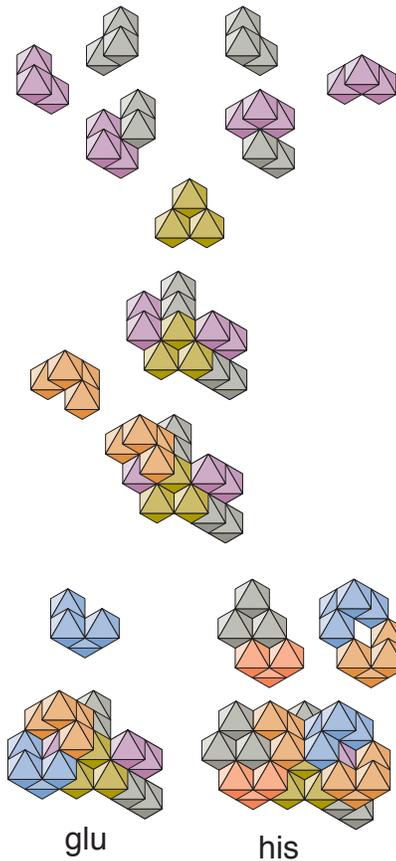
Two main chain units are assembled at the top and then joined together by a C-atom at the bottom. This is the relationship suggested by the conversion of histidine into glutamate.

Relationship of histidine and glutamate



Three main chain units in epsilon helical orientations.

At the top of the figure, the three main chain units are depicted separately. Each differs from its two circumferential neighbors by a 120° rotation about the viewing direction. The three are shown as joined in the next view. The next to last depiction is of the NH_2O groups of the three units and the bottom depiction is of the C-atoms of the three units.

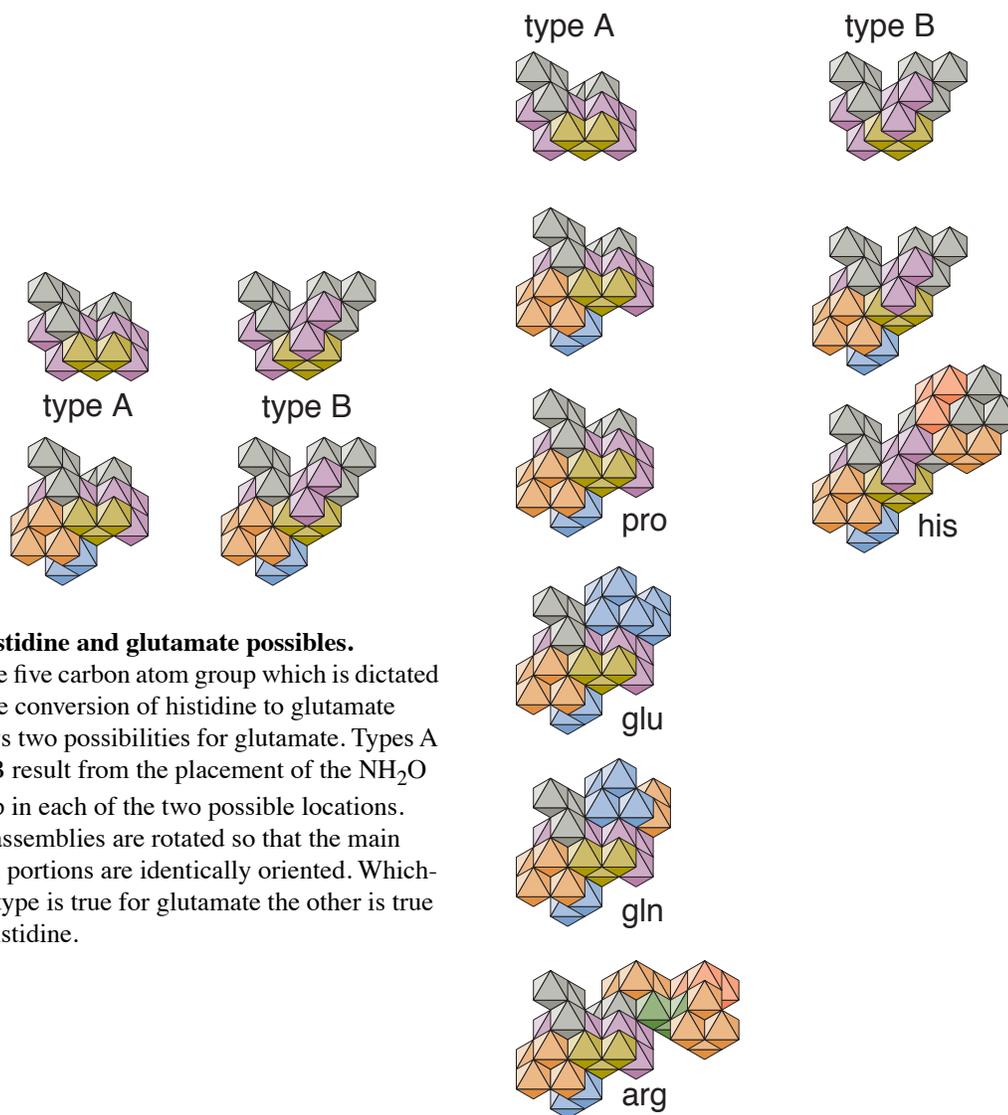


Assembling glutamate and histidine.

At the top, two identical pairs of C-atoms are formed which differ by a rotation of 120° about the viewing direction. The pairs are then joined by another C-atom to make the five C-atom group common to glutamate and histidine. An NH_2 group is then added and this assembly provides the base for the two aminos.

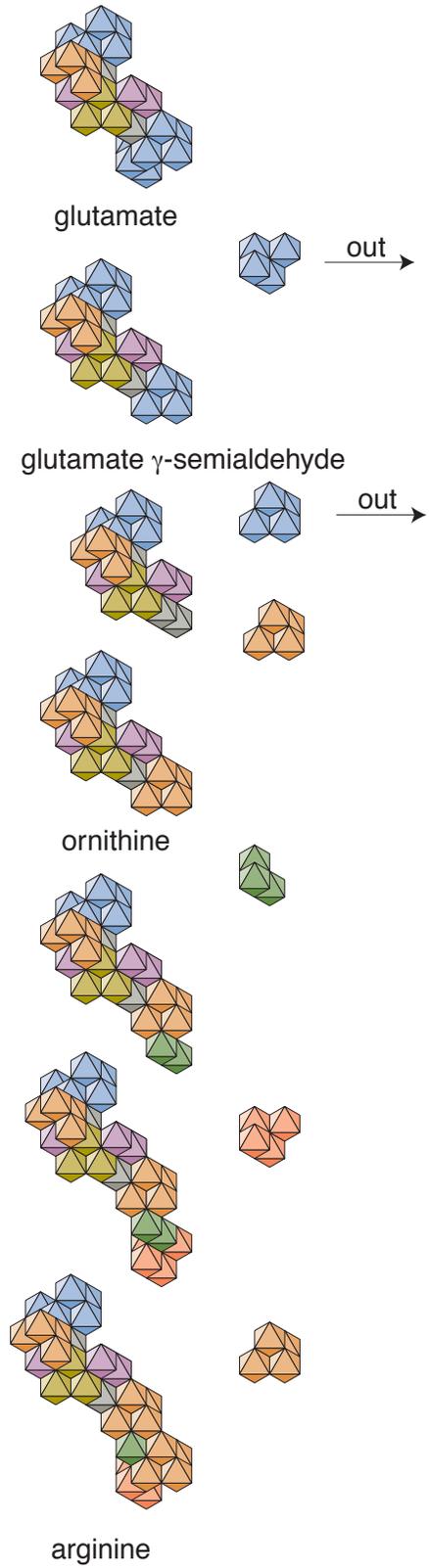
An O-atom addition provides a glutamate assembly shown at the bottom on the left.

An addition of a CNH_2 group and an NH_2O group to the base produces a histidine assembly at the bottom on the right.

C₅ family of aminos**Histidine and glutamate possibles.**

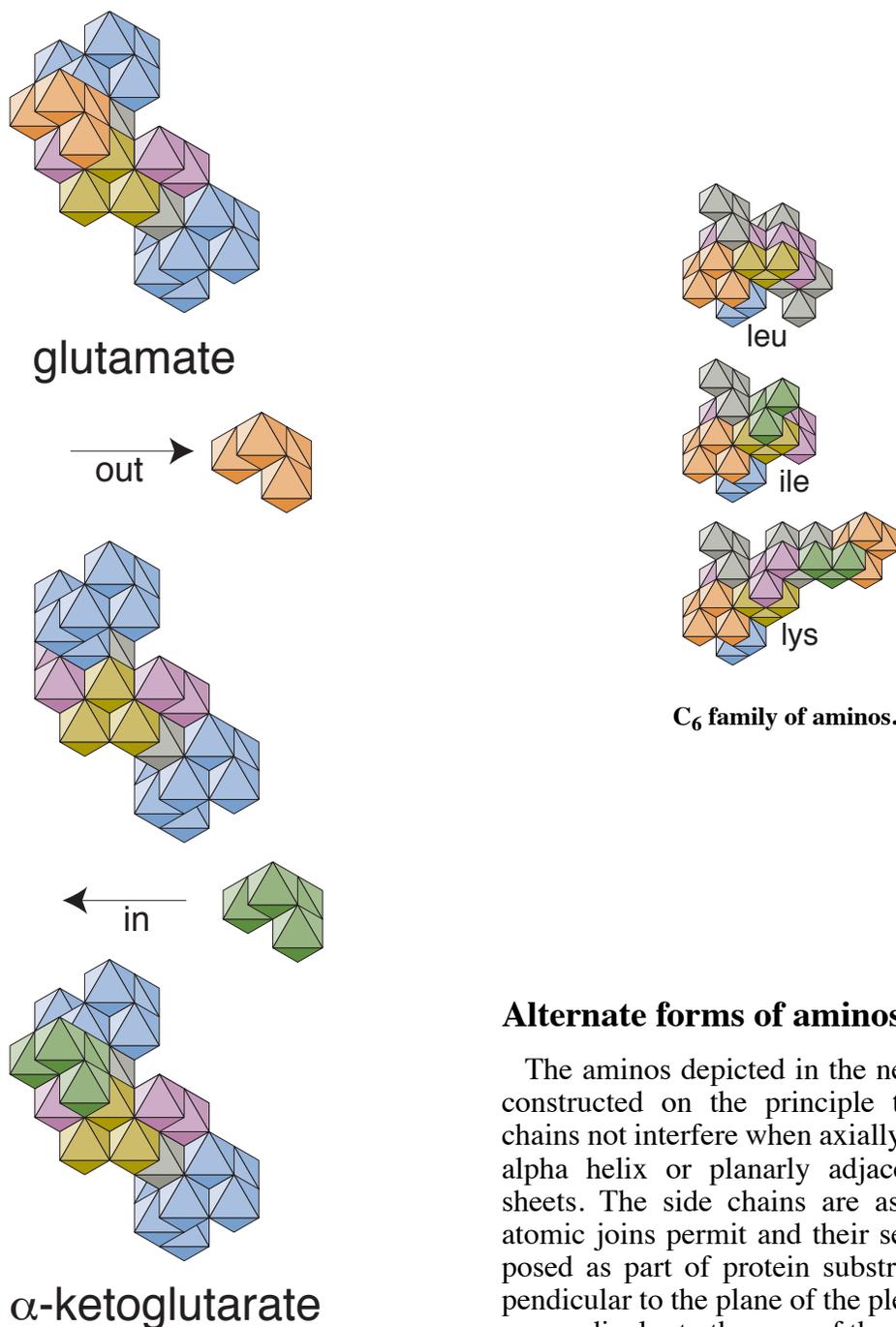
The five carbon atom group which is dictated by the conversion of histidine to glutamate allows two possibilities for glutamate. Types A and B result from the placement of the NH₂O group in each of the two possible locations. The assemblies are rotated so that the main chain portions are identically oriented. Whichever type is true for glutamate the other is true for histidine.

C₅ family of aminos.



Pathway: Glutamate to arginine

C₆ family of aminos



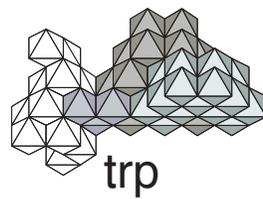
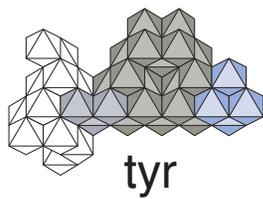
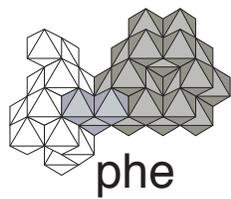
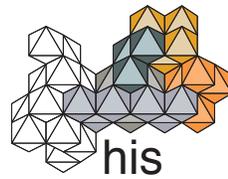
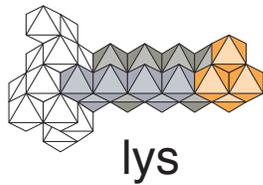
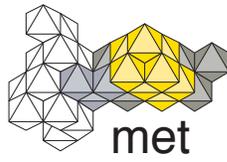
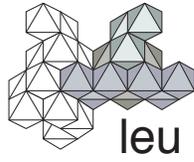
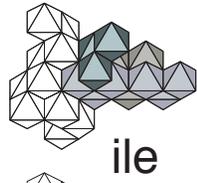
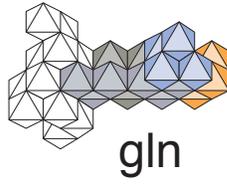
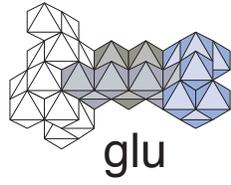
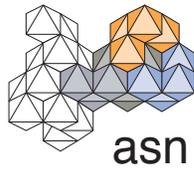
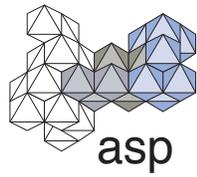
Glutamate to α -ketoglutarate.

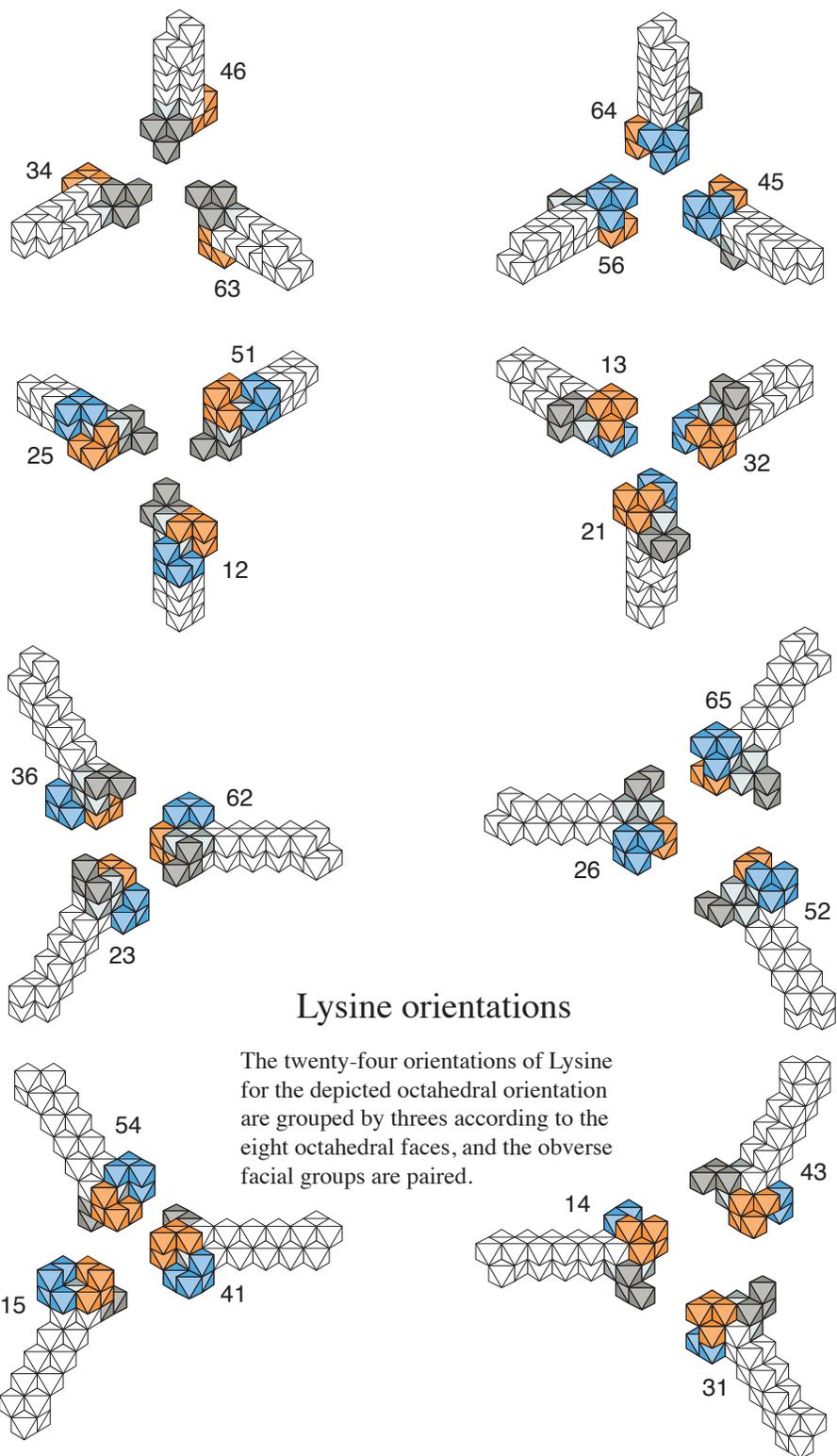
The figure shows the removal of an NH₂ group from glutamate and its replacement with an O atom.

Alternate forms of aminos

The aminos depicted in the next figure were constructed on the principle that their side chains not interfere when axially adjacent in an alpha helix or planarly adjacent in pleated sheets. The side chains are as linear as the atomic joins permit and their sense when disposed as part of protein substructures is perpendicular to the plane of the pleated sheet and perpendicular to the axes of the alpha and epsilon helices.

The lysine of this group is shown in each of the twenty-four possible orientations which are possible in a simple protein which is viewed perpendicularly to a face of the octahedron. Lysine was chosen from this group of aminos because of its long straight C-atom chain.





PROTEIN CHAIN

The main chain unit

A He-octa of a C-atom of one main chain unit fits into a space in the NH₂O group of an adjoining unit like a ball into a socket to form a protein chain. There are six such joins for a pair of main chain units. In each of the six joinings, the He-octas of each of the atoms of the pair are in identical orientation. If units are repetitively added to form a chain by using just one of the six joins the resulting form will be an alpha-helix or an epsilon-helix or a 1/2-turn-beta chain or a 1/4-turn-beta chain or a 3/2-chain, or a 4-helix. The six joins are depicted in the next figure. The adding unit is shown on the right and the joined pair is shown on the left. In each pairing, the first unit of each of the pairs is in the same orientation as shown in the previous figure. It is uncolored in each of the joined pairs. The adding unit is joined to the female end of the first unit.

No change in the atomic arrangement of the main chain unit is required to produce these joins. If the relationship of any part of a crys-

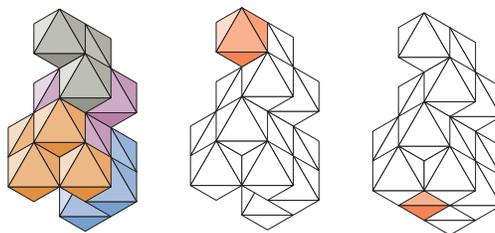
talline group relative to the remaining portion group is altered, the group is no longer the same entity. Any change in the main chain unit precludes its use in the structures.

Peptide joins

Each of the joins between peptides in a chain, excepting perhaps proline, when the chain is stably and crystallinely folded, requires a rotation between adjoining units which produces a helix.

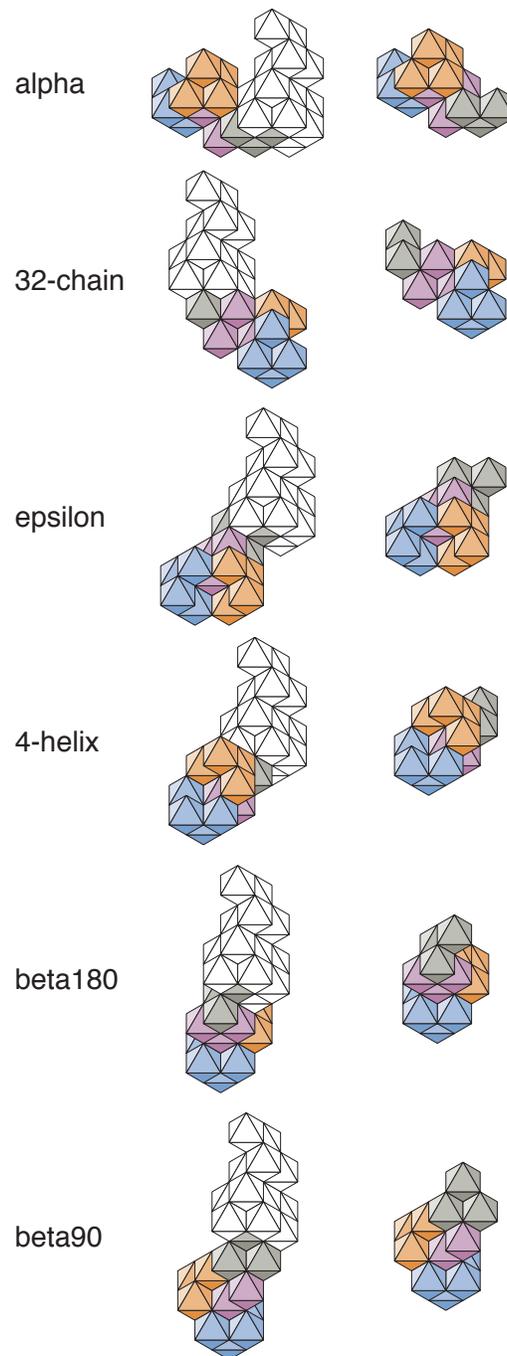
Table 15: Peptide chain joins

Join	Axis	Rotation	Occurrence
beta180	vertexial	half	pleated sheets
beta90		quarter	
4helix		quarter	beta annulus
3/2chain	edgial	half	
alpha	facial	third	alpha helix
epsilon		third	epsilon helix



Amino joining octa.

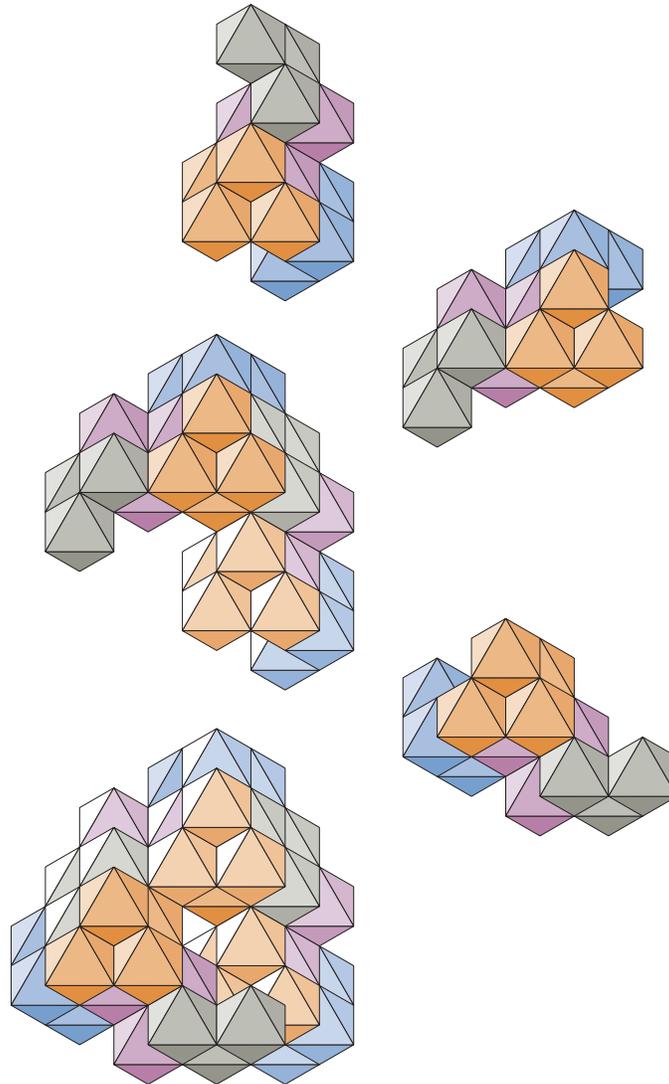
The drawing on the left is the main chain portion of an amino acid. The middle drawing shows the joining octa colored red. The right hand drawing shows a joining octa occupying the socket formed by the NH₂O group.



Amino main chain joins.

The figure depicts the six ways that two main chain units can join. The pairs are shown on the left and the joining units are shown on the right. The base unit is uncolored and is in the same orientation in each of the pairings.

Alpha helix

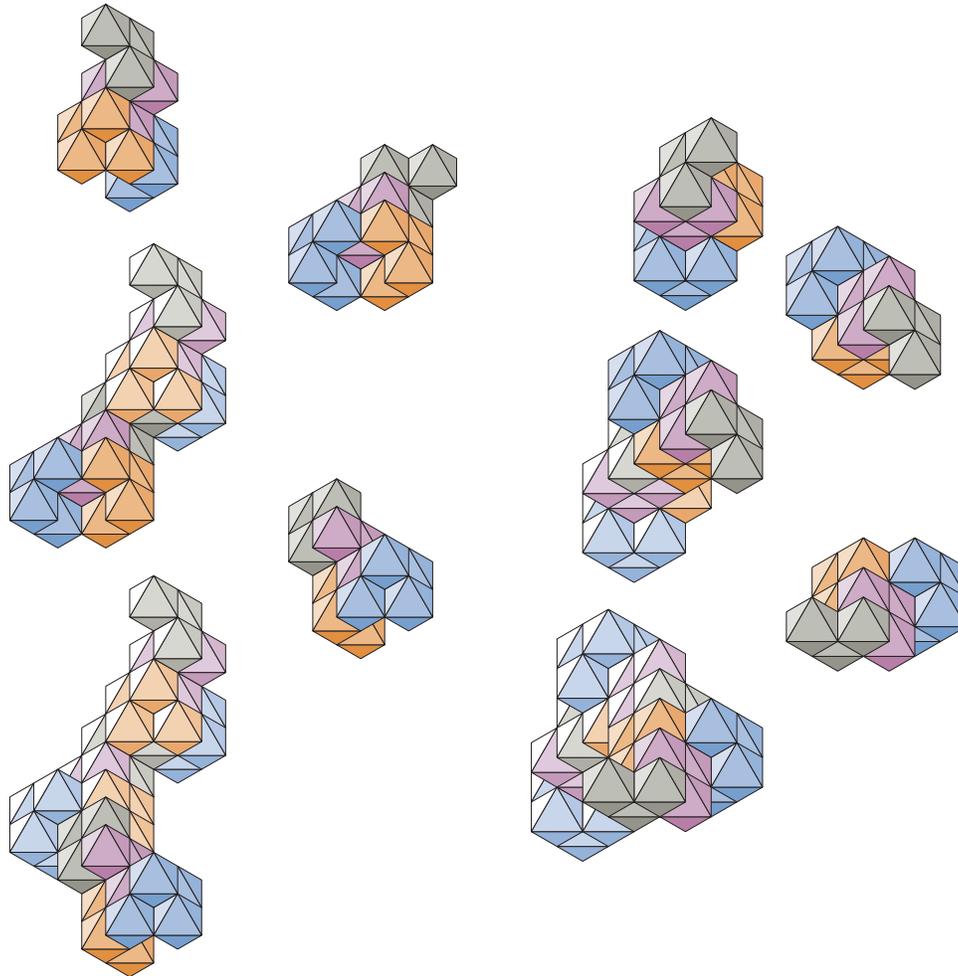


Protein substructure: Alpha helix.

The assembly of one turn of an alpha helix is depicted in the figure. The growth direction is towards the viewer and in a counter-clockwise sense. The units are added to the male end of the growing helix.

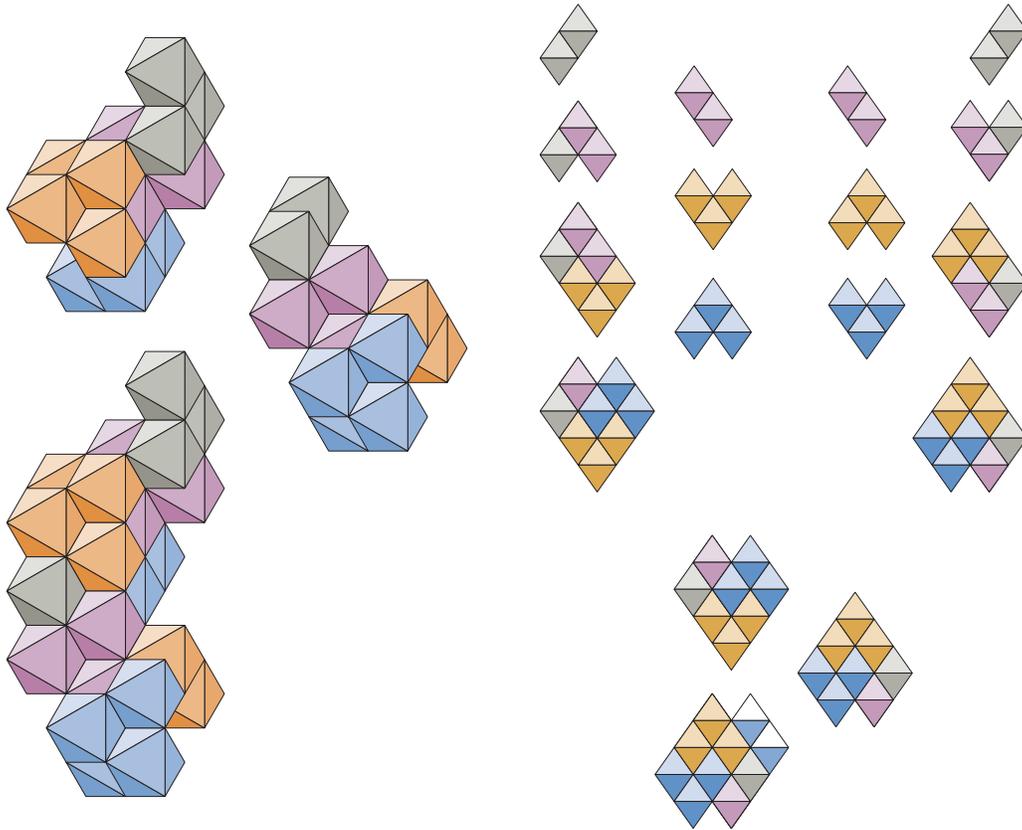
Adjoining units differ by a rotation of 120° about the helical axis.

Epsilon helix



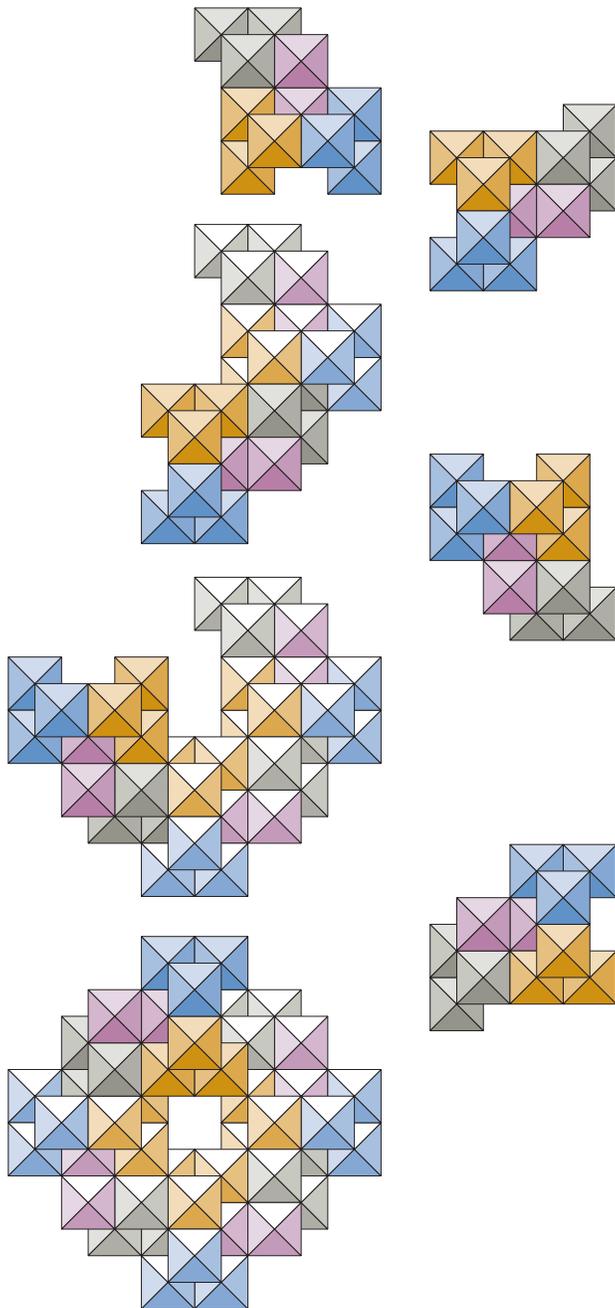
Protein substructure: Epsilon helix

The assembly of one turn of an epsilon helix is shown in the figure on the left. The growth direction is towards the bottom of the page and obliquely towards the viewer. Adjoining units differ by a rotation of 120° about the helical axis. The figure on the right shows the assembly of an epsilon helical turn as viewed along the helical axis from the male terminus.

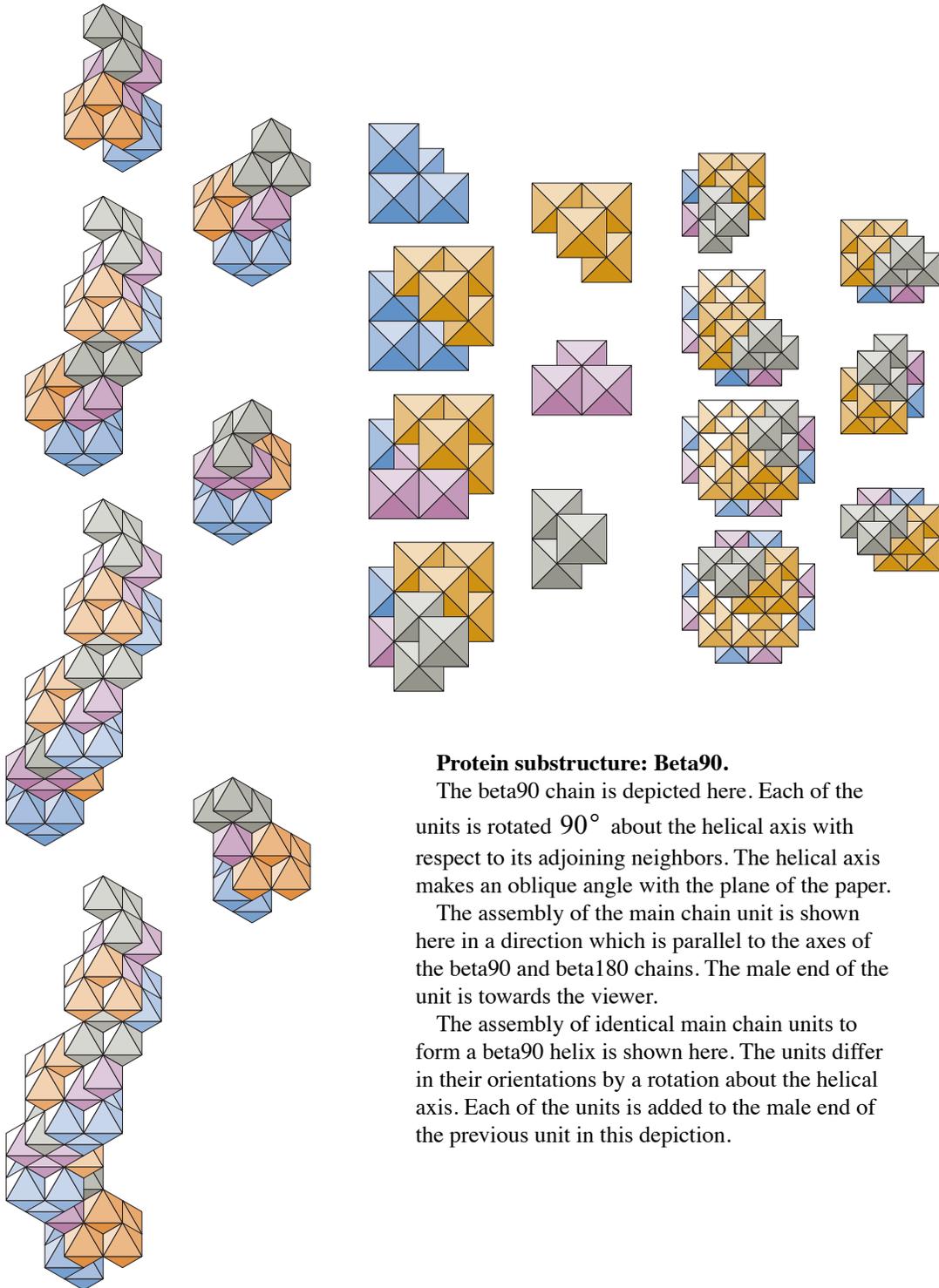
32chain**Protein substructure: 32chain**

The figure on the left shows the assembly of the 32-chain. The repeat unit consists of two main chain units which are rotated 180° relative to each other about the chain axis. The axis is parallel to the plane of the paper.

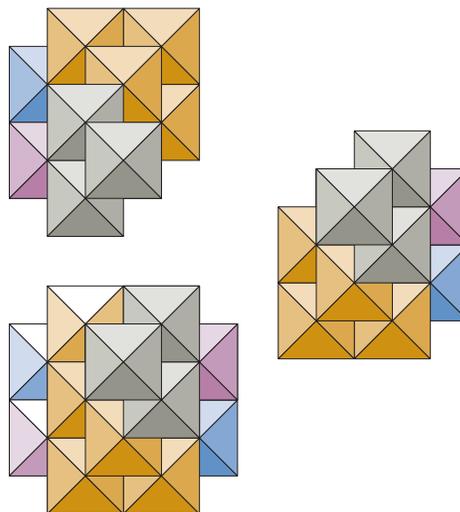
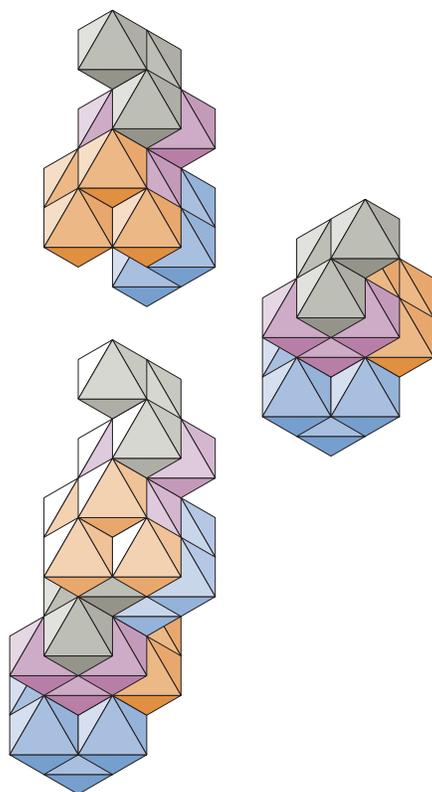
The edge views on the right show the assembly of the residues and their assembly in turn to form the 32-chain in a view which is parallel to the chain axis.

4helix**Protein substructure:
4helix.**

The figure depicts the assembly of a turn of a 4helix. Adjoining units are rotated 90° to the helical axis. The axis makes an oblique angle with the plane of the paper.

Beta90

Beta180



Protein substructure: Beta180

The assembly of one turn of beta180 helix is depicted here. Adjoining units are rotated 180° about the helical axis. The axis makes an oblique angle with the plane of the paper.

The next figure shows a beta180 turn as viewed along the helical axis.

Orientations of chain units.

Orientations of the regular octahedron

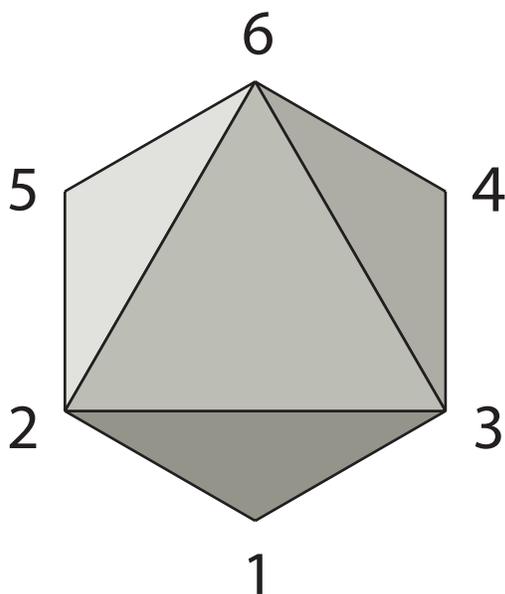
Each of the twenty-four orientations of the regular octahedron results in a different arrangement of its vertexes. Looking at the octahedron facially, each of the vertexes lies on the perimeter of a regular hexagon. The numbers of the vertexes can then be read in counter-clockwise order about the perimeter for each of the twenty-four orientations. The first and the last digit are adjacent, since the vertexes lie on the perimeter of a polygon. Each of the digits refers to a specific vertex. Any pair of adjacent digits defines an edge. Any pair of digits separated by a single intervening digit also defines an edge. The orientation of any unit relative to another unit is

defined by specifying the vertexial numbers of an identical edge. These will be in the same digit location for each of the orientation numbers.

A pair of digits which are separated by two intervening digits are diametrically opposite.

Table 16: Orientation numbers

125643	236451	463215	512364
132654	213465	456231	541326
143625	346521	415263	645123
154632	314562	431256	634152
251436	321546	564312	623145
265413	362514	526341	652134



Facial view of a regular octahedron with its vertices numerically labelled

The relative orientations between a pair of joined units can be specified by the numbers of the two vertices of any common edge in either of two orders. Since there are twelve edges and two orders for each edge, then there are twenty-four ways of specifying the same relative orientation between a pair of units. In the example of a pair of beta180,m joined units the combinations are listed below.

Table 17: Twenty-four ways of specifying the same relative orientation

15,65	54,52	46,21	63,13	32,34	21,46
51,56	45,25	64,12	36,31	23,43	12,64
14,62	56,51	43,23	62,14	31,36	25,45
41,26	65,15	34,32	26,41	13,63	52,54

The direction numbers relative to the reference orientation define the x, y, and z directions.

The moves for a residue added to the female terminus of the reference residue are not affected by the type of join because the reference He-octa for the residue occupies the

Table 18: Relative location of added residue

Join	Orientat ion	Move	x	y	z
reference	154632		0	0	0
beta180,m	652134	3,2	41,1	4	-1
beta90,m	251436	3,2	21,1	4	1
alpha,m	321546	1,2	52,1	-1	1
32chn,m	645123	2,2	31,1	1	4
epsilon,m	415263	2,2	36,1	1	4
4helix,m	314562	1,2	32,1	1	1
beta180,f	652134	5,2	41,1	-4	-1
beta90,f	456231	5,2	41,1	-4	-1
alpha,f	463215	5,2	41,1	-4	-1
32chn,f	645123	5,2	41,1	-4	-1
epsilon,f	541326	5,2	41,1	-4	-1
4helix,f	564312	5,2	41,1	-4	-1
para41	154632		41,2	0	-2
para62	154632		62,2	0	2
anti41	236451	5,2	41,3	-4	-3
anti62	236451	5,2	62,1	-4	1
32stack	541326	45,2	41,1	-2	-3

socket which is defined by the He-octas of the reference residue and whose location is fixed relative to the location of reference residue. But the female terminus of the added residue is defined by the type of the join, with each join providing a new female location that is unique for that join.

For the residue which is added to the male end of the reference residue, the location of its male He-octa is defined by the orientation of the added residue and this is determined by the type of the join.

INTERCHAIN JOINS

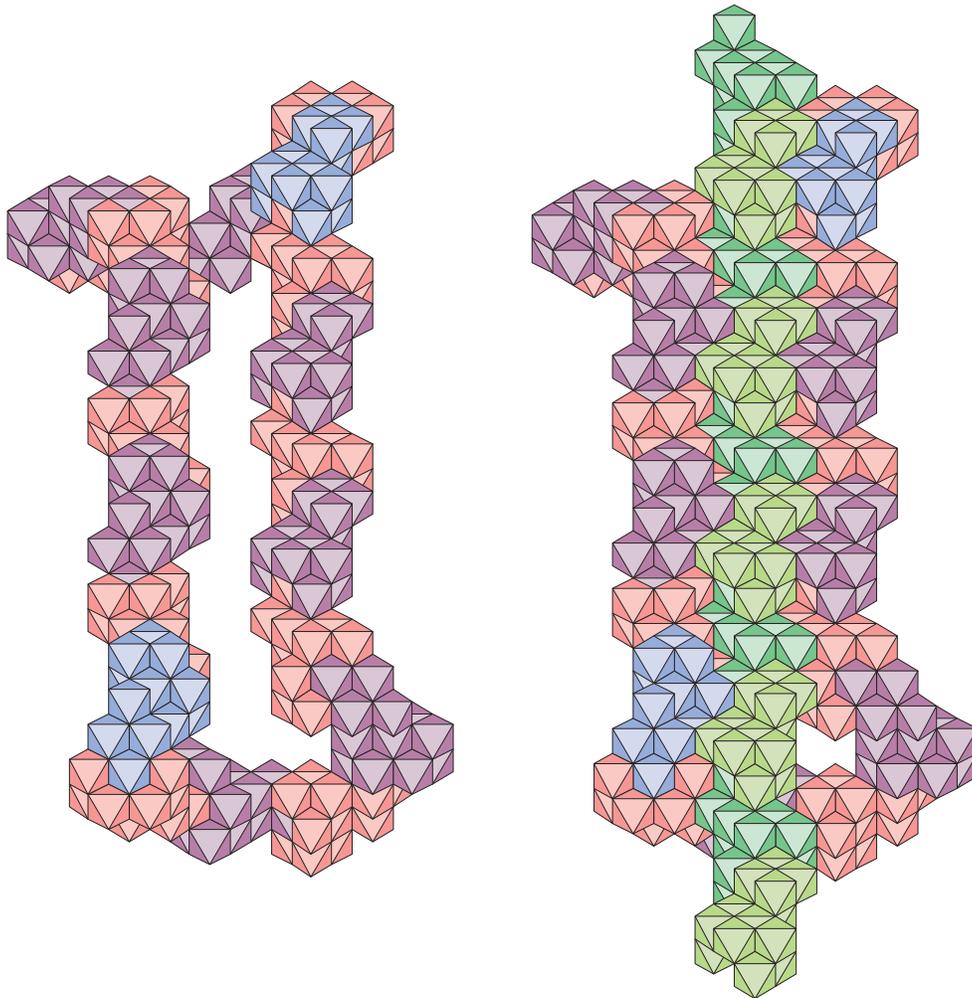
Pleated sheet

Cyclic peptide sheet joined with beta chain

A cyclic peptide can be formed which has a pair of extensible beta180-chain segments

which are separated by the width of a beta180 chain.

A second chain can form a sheet with the two beta-chains of the cyclic peptide and extend beyond the end turns without interference. The cyclic peptide is shown in this figure with a beta180 chain joined to its two beta180-chain segments to form a three chain pleated sheet. The sheet join is antiparallel on the left side of the added chain and parallel on its right

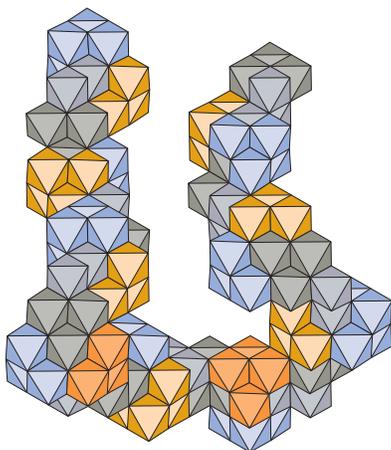


Cyclic peptide sheet joined with beta-chain

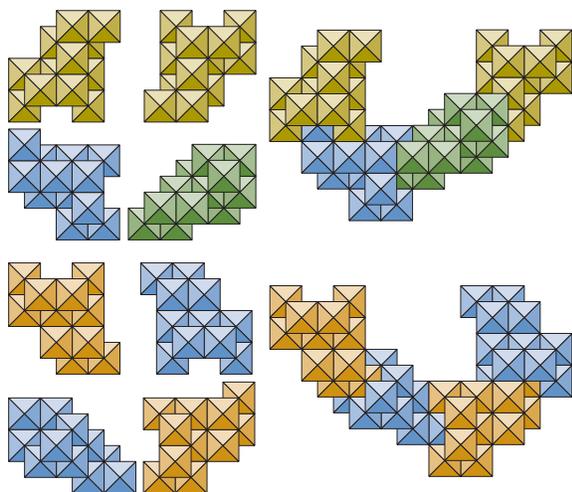
The cyclic peptide on the left consists of two beta180 chains linked by identical at either terminus. The separation between the chains accommodates a length of beta180 chain to form a three chain pleated sheet. This is shown in the figure on the right.

side.

The beta180 chain segments are joined at either end by the turn shown below. The turn is



examined in detail in the next two figures. The first of these shows the assembly of each of the



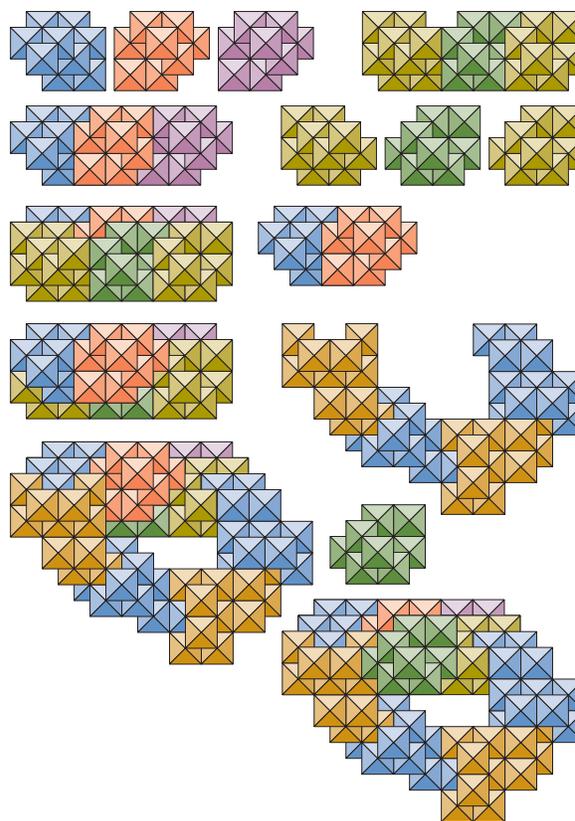
turns of the previous loop from a direction parallel to the axes of the beta180 chains which form the sheet. The two turns are in the right hand column and the units which form them are grouped on the left side of the figure. The top turn is the far turn which appears at the top of the loop figure. The bottom is the near turn and appears at the bottom of the loop figure. The turns are identical except for their orienta-

tions. They differ by a half revolution about an axis parallel to the rightmost edge of the octahedron of which they are composed.

The joins between the units in the top turn are 4helix between the yellow and blue, epsilon between the blue and green, and beta90 between the green and the second yellow.

The joins between the units in the bottom turn are 4helix between the blue and the orange at the male end of the turn, epsilon between the orange and the second blue, and beta90 between the blue and the orange at the female end of the turn.

The next figure shows the relationship of the



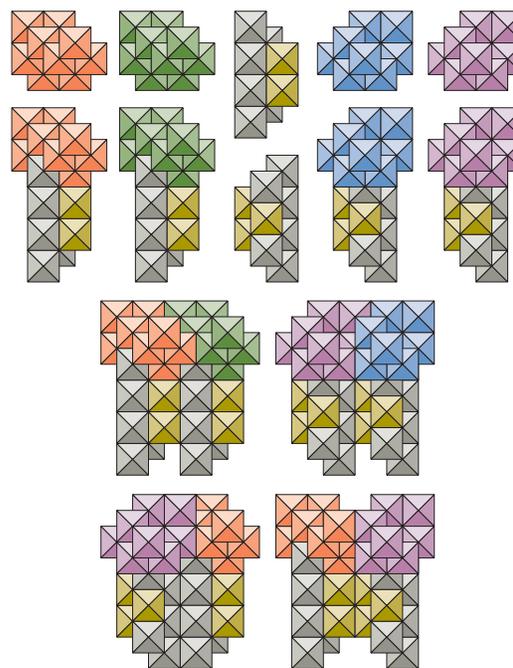
beta180 chains which form the sheet. The center chain is the added chain and the outer chains are part of the loop. The chain on the left is antiparallel to the other two chains. Its male terminus is towards the viewer. In the top left of the figure, three units are shown separated from one another which are colored blue, red, or violet. Just below them they are shown

sheet joined. To the right a second set of units is shown separated and in a sheet join which are colored yellow or green. These units are rotated one half turn about the beta180 chain axes relative to the first set of units. The two sets are combined to form a sheet consisting of one turn each of three beta180 chains on the left side of the third row of the figure. The red and blue units on the right of the third row are in the same orientation as those of the same color in the first set of units. These extend the left two chains when they are added as shown in the fourth row on the left side. The near turn is shown on the right side of the fourth row. This is joined to the sheet assembly in the bottom of the left column. The middle chain is extended by the addition of the green unit in the bottom of the right column.

The join between the blue unit of the beta180 chain on the left and the orange unit of the female end of the turn is alpha helical. The join between the yellow unit of the beta180 chain on the right and the blue unit at the male end of the turn is 32chain.

The alpha C-atom of the unit and the beta C-atom of the sidechain establish a chain direction which is normal to the plane of the sheet. Extending the chain with an identical pair of C-atoms shows the arrangement of the side chains as seen in the axial view of the beta180 units which make up the sheet. The top row of the figure shows identical main chain units in two different orientations. The red and green units are in the same orientation. The blue and violet units are in the same orientation, too. The different orientation between the two pairs of units allows antiparallel sheet joining. Between the pairs of units in the top row is a three C-atom chain which is to act as the side chain for the red and green units. Directly under it is the side chain for the blue and violet units. The chains are identical except for their orientations.

The second row shows the units with side chains attached. In the third row the red and green units are joined in parallel sheet. The blue and violet units are also paired as parallel sheet units. In the bottom row the red and violet units are paired as antiparallel sheet units. These pairs are not identical. The gray colored



C-atoms are in contact where the violet unit is to the left of the red unit; the yellow C-atoms are in contact where the violet unit is to the right of the red unit.

In the next figure, the side chains are viewed along the C-chain axes towards the main chain units to which they are joined.

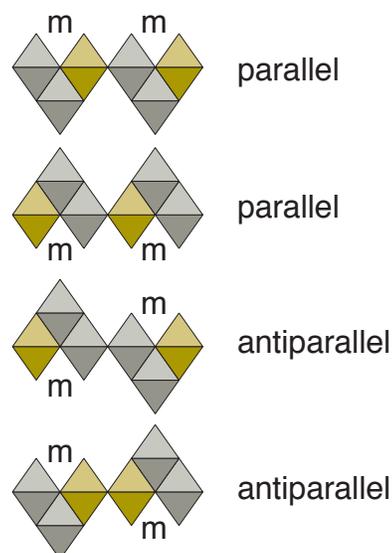


Table 19: Possible join adjacencies upon termini of sheet chains

	Sheet	beta180	beta90	alpha	32chain	epsilon	4helix
beta180	mp41m	*					*
	fp41f	*	*	*	*	*	*
	mp62m	*	*	*	*	*	*
	fp62f	*		*			
	ma41f	*		*			
	fa41m	*	*	*	*	*	*
	ma62f	*	*	*	*	*	*
	fa62m	*					*
beta90	mp41m	*	*	*	*		*
	fp41f		*	*	*	*	*
	mp62m		*			*	
	fp62f	*	*	*			
	ma41f	*	*	*			
	fa41m		*	*	*	*	*
	ma62f						
	fa62m	*					*
alpha	mp41m	*					*
	fp41f	*	*	*	*	*	*
	mp62m		*			*	
	fp62f	*	*	*			
	ma41f	*	*	*			
	fa41m	*	*	*	*	*	*
	ma62f						
	fa62m	*					*

Table 19: Possible join adjacencies upon termini of sheet chains

	Sheet	beta180	beta90	alpha	32chain	epsilon	4helix
32chain	mp41m	*					*
	fp41f						
	mp62m		*			*	
	fp62f	*	*	*		*	
	ma41f	*	*	*			
	fa41m						
	ma62f						
	fa62m	*					*
epsilon	mp41m	*	*	*	*		*
	fp41f				*		
	mp62m						
	fp62f	*	*	*			
	ma41f	*	*	*			
	fa41m						
	ma62f						
	fa62m	*					*
4helix	mp41m	*					*
	fp41f						
	mp62m	*	*	*	*	*	*
	fp62f	*	*	*			
	ma41f	*	*	*			
	fa41m						
	ma62f	*	*	*	*	*	*
	fa62m	*					*

Key to table

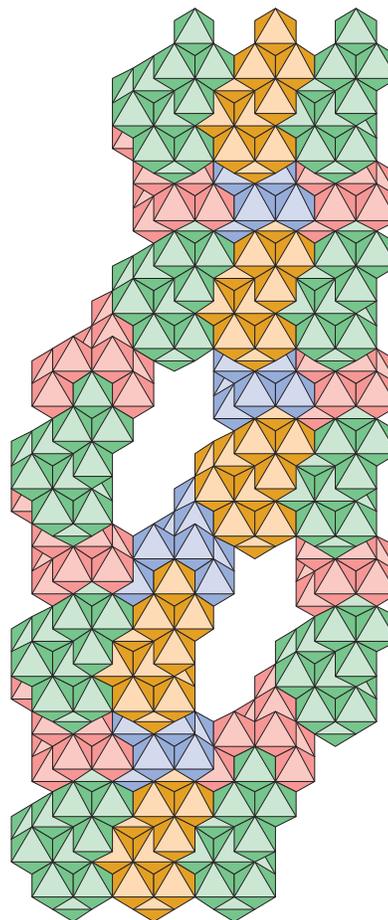
- m** male end of chain
- f** female end of chain
- p** parallel sheet
- a** anti-parallel sheet
- 41** direction relative to the columnar residue join
- 62** direction relative to the columnar residue join
- *** denotes adjacency for the pair of joins is possible

Linking chains of pleated sheet

A residue may be joined to either terminus of a solitary beta-chain with any of the six possible joins. When the beta-chain is part of a sheet, the type of join is limited, because a residue of one type of join on one chain may occupy a portion of the space required by a residue in one or more joins on an adjacent chain of the same sheet. Each of the combinations for each type of join and each type of sheet association is tabulated above.

A sheet offset

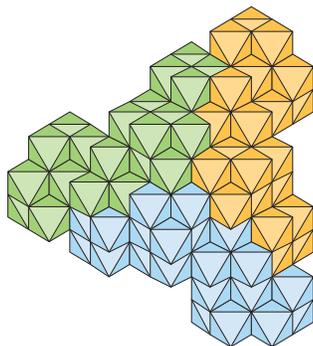
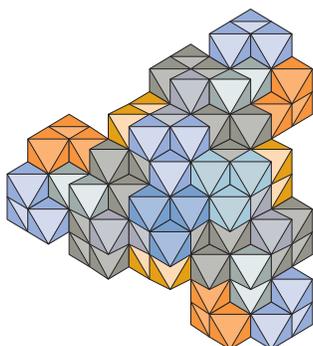
Three parallel strands can participate in the formation of multiple sheets which are offset from one another and define separate planes. The 32chn-join permits this. The offset requires pairs of 32chn-joints within each chain. The chain at the extreme 62-side of the sheet must be offset first. The chain next adjacent continues with a pair of beta180-joints and then it is offset by a pair of 32chn-joints. A sheet of any number of parallel chains may be offset in this manner. The 62-direction of the sheet is determined by the orientation of the terminal residues at the commencement of the offset from the male ends. If the offset commences from the female termini, then the chain at the extreme 41-side is offset first. The offset from the male direction is in the 32 direction and from the female it is in the 54-direction.

**Pleated sheet offset**

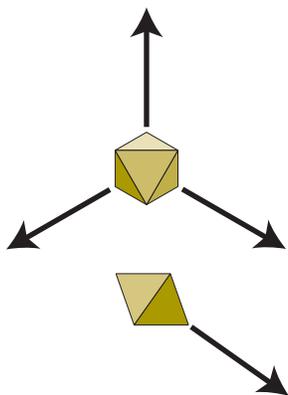
Three beta-chains forming two parallel sheets

Beta annulus

Three anti-parallel chains can form three sheets with a common junction. Each of the chains is sheet joined to each of the other two chains. Two depictions of the beta annulus viewed parallel to its axis of threefold symmetry are shown in the next figure. The He-octas of the top view are colored to differentiate the atoms; those of the bottom view are colored to differentiate the three chains. Each of the depicted chains consists of just two main chain units. The join between them is 4helical. The sheets are anti-parallel.



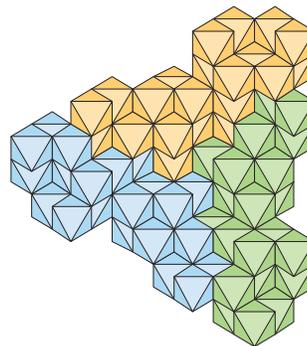
The three axial directions of the sheet chains relative to the octahedral orientation are shown in the facial view of the figure. Each of the



directions is parallel to a vertexial diameter of the octahedron. The arrows proceed away from the octahedron and away from the viewer. The edgial view shows one of the sheet directions in a view normal to the facial view.

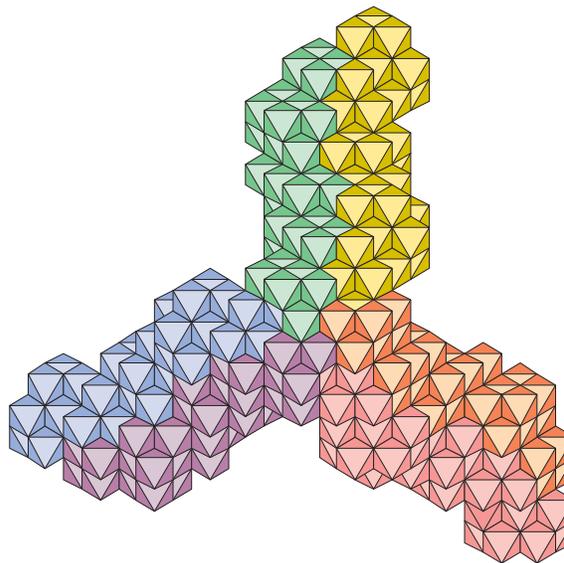
The annulus is shown here from a direction that is opposite to that of the previous figure. The annulus is rotated 180° about an axis par-

allel to the top of the page.



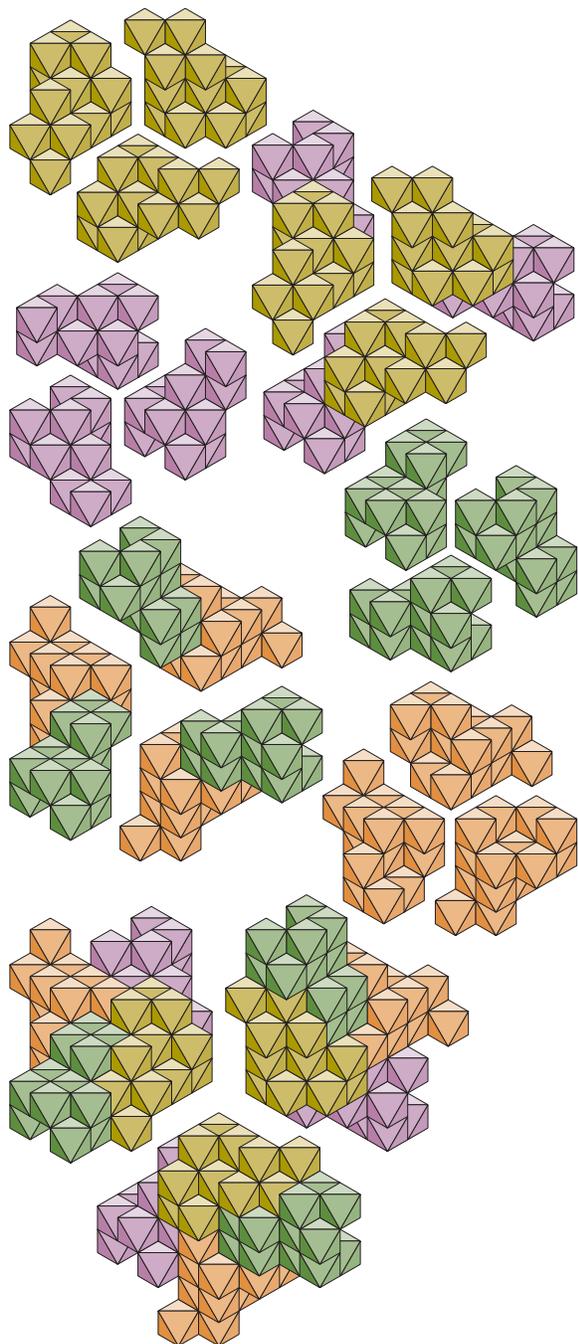
Three sheet junction

The coloration in the next figure differentiates the portions of each chain which belong to the three sheets. The chains have been extended. The green chain and the yellow chain are one sheet, the blue and violet another, and the red and orange a third. The red and yellow are one chain, the green and blue another, and the violet and red are a third.



Three sheet junction, extended

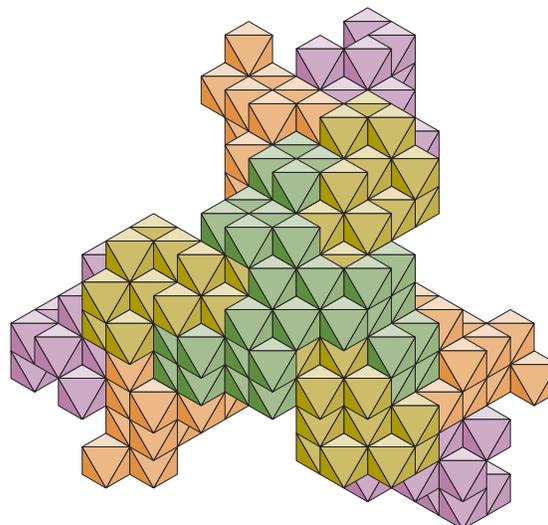
The beta annulus requires main units in twelve orientations. These are shown in the next figure which details the assembly of the



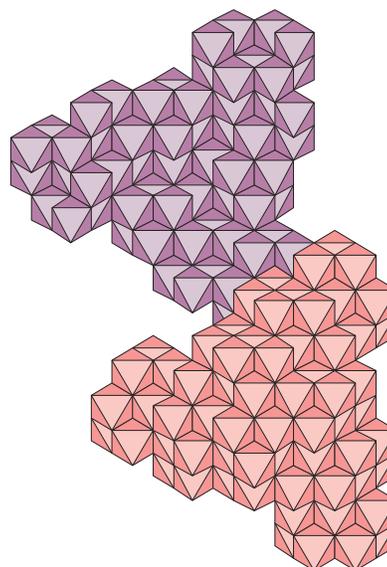
annulus. Within the colored groupings, the units differ by an orientation of one third of a revolution. The orange group is the obverse of the yellow group and the green group is the obverse of the violet group. The yellow and violet units form three beta180 pairings as do the green and orange groups. The yellow-vio-

let pairs and the green-orange pairs form three pleated sheets which are shown at the bottom of the figure

The three sheets are joined as an annulus in the next figure.



Annulus assemblies

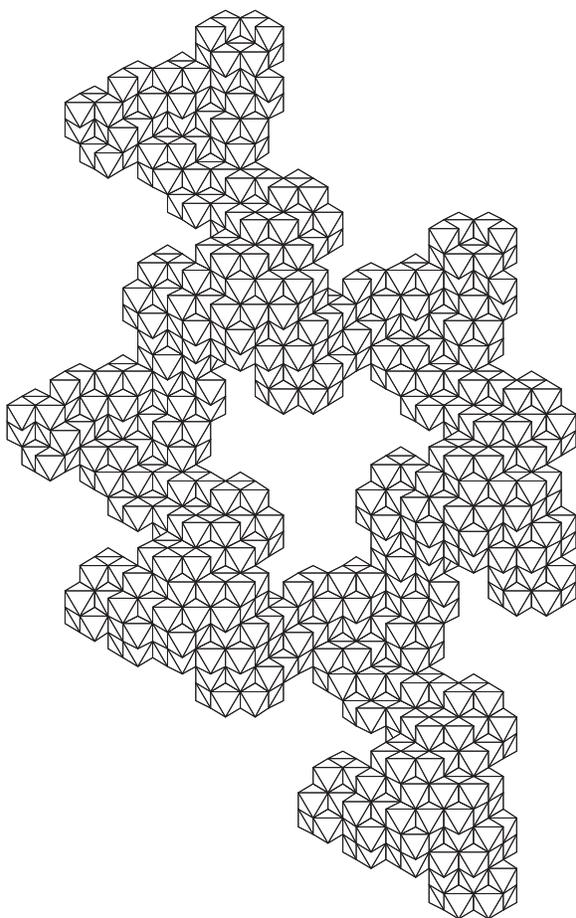


Pair of three sheet junctions

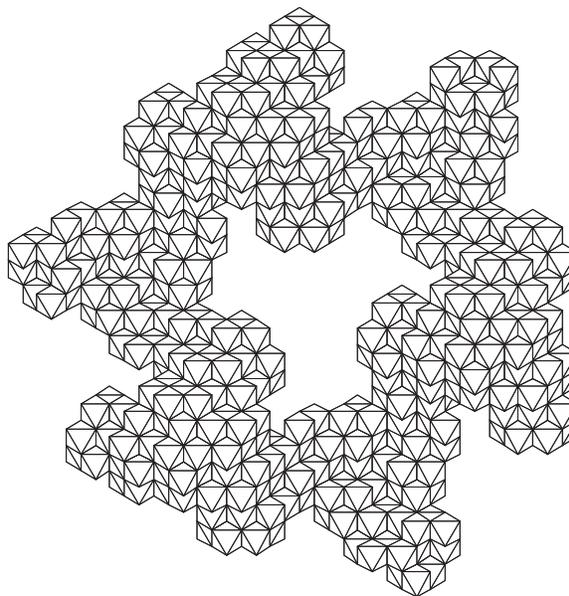
One beta annulus can join to another so that the male terminus of one of its chains joins to the female terminus of another. This is depicted in the figure which shown an inverted annulus colored purple joined to another annu-

lus colored red.

The pair can join with like pairs in the same manner to produce a planar crystal. The figure shows four pairs joined and this is extensible throughout the plane.



The ring which appears when the four pairs are joined is shown separately. This ring consists of six annuluses. Alternate annuluses are in the same orientation. Adjacent annuluses are inverted one to the other.

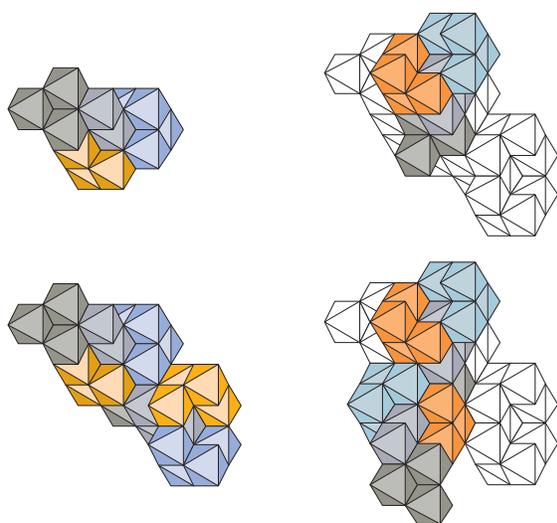


Assembly of beta annulus pairs.

The group on the left is composed of four identical beta annulus pairs indicating the formation of a planar crystal. The ring which is formed can exist as the separate structure shown on the right. It is composed of two groups of three beta annuluses each. Adjoining annuluses are inverted to one another.

32chain stack assemblies

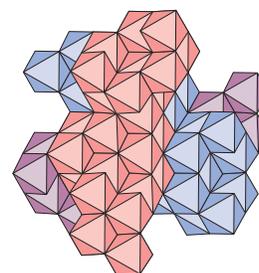
The edgially axised 32chain lies between a pair of parallel planes which are defined by the He-octa faces of the peptides. The planes are separated by three facial diameters of a He-octa. The thickness of the chain perpendicular to these planes is at regular intervals only two facial diameters of a He-octa. The chain alternates between contacting first one plane and then the other. The space between planes is a pocket into which an identical chain crossing at 120° fits. The axes of the two chains are separated by two facial diameters of a He-octa. The next figure shows the assembly of a two



pair stack. The leftmost figure is a projection of an amino-main. The figure to its right is the same except for the addition of a second peptide to the female end of the first in a 32chain join. The pocket is towards the viewer, and lies between the two groups of He-octas on the nearest plane of He-octas. One group of four belongs to the first residue, and the second group of four belongs to the added residue. In the third figure from the left, a third residue has been placed in the 32-stack join which fills the pocket while its male-He-octa protrudes and is available for joining the fourth residue in a 32chain join. The rightmost figure is the completed two-pair stack. The second pair is rotated $1/3$ turn counter-clockwise about an axis perpendicular to the plane of the paper.

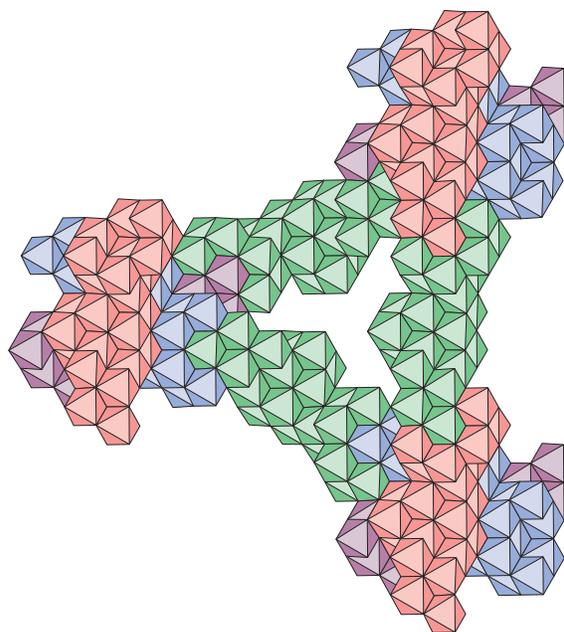
A third pair of 32chain joined residues added

atop the first two pairs is rotated $1/3$ turn counter-clockwise to the second pair and a fourth pair atop the three is rotated in the same manner and results in an orientation for the pair which is identical with the first pair. The stack is a helical. The pitch is two facial diameters of a He-octa in $1/3$ revolution. The stack is shown in the next figure in a view parallel to the helical axis.



Helical stack of 32chain pairs

Identical stacks can be joined by pairs of 32chain joined residues. The stacks differ only by a translation perpendicular to their axes. The joining pair extends the 32chain of one stack through the pair in identical orientation and identical axial elevation in another stack. In the following figure, the three stacks are



joined so that the axes of the three extended

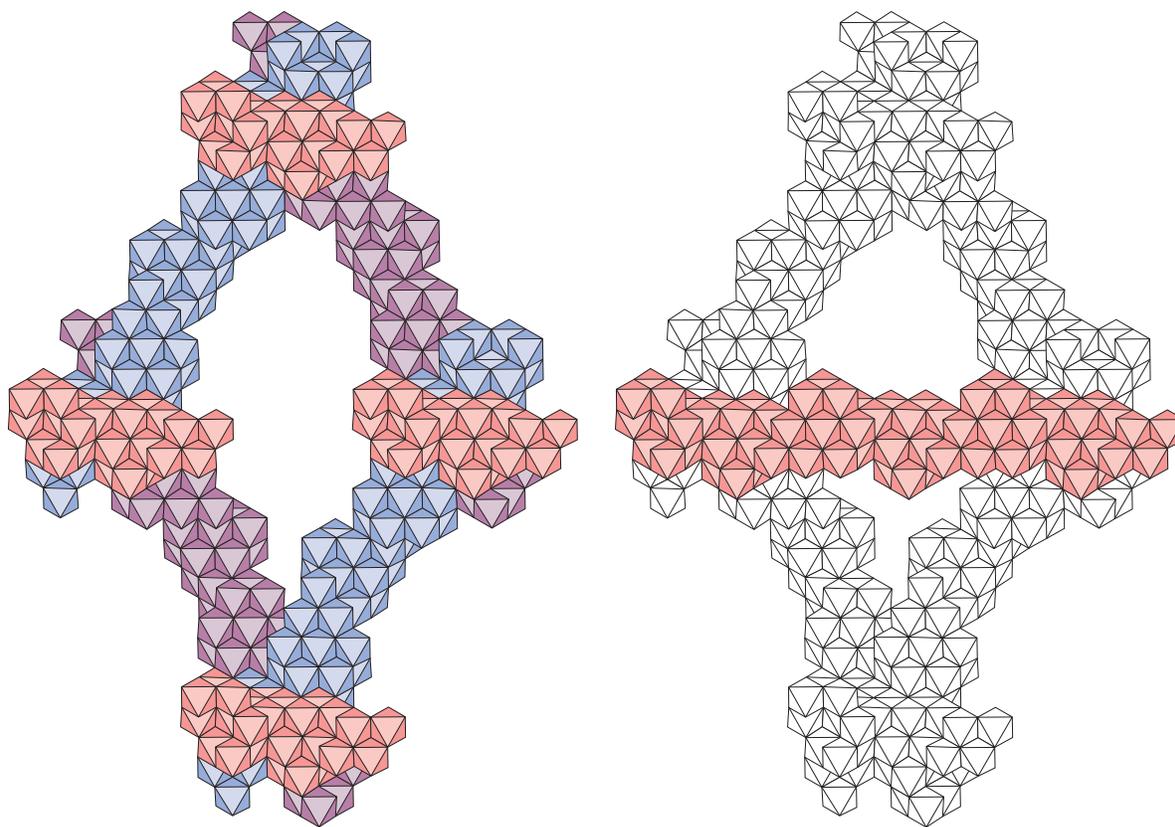
chains project as an equilateral triangle.

The chains which are identically oriented lie on the same plane or are axially translated in multiples of six facial diameters of a He-octa. Parallel chains in the same plane do not abut like the beta-chains do in the sheet formations. When the stacks are separated by pairs of residues, the separation increases. The effect is shown in the next figure in which four stacks are joined by four pairs of residues. The axes of the chains project as a 60° rhombus.

Four stacks can be joined by five pairs of residues so that the rhombus is divided into two equilateral triangles. This is shown in the next figure.

The triangles are of two types, open or closed, depending upon whether the NH_2O groups protrude into the triangle. Open trian-

gles share their sides only with closed triangles and vice versa. This triangular pattern can be extended perpendicularly to the helical axes and axially by stacking. Each chain is formed by 32-joints and the linkage between chains is the stack. The chain may be extended by additions to either its male terminus or its female terminus. The stacks differ in a translation in each of the six chain directions by five edgial-diameters of a He-octa for each pair of residues between their axes. These directions define a regular hexagon. The stack dimension is six facial-diameters of a He-Octa per revolution. These are the dimensions of a regular hexagonal prism which could be the cfu for a hexagonal crystal. In the next figure, the pairs of the four stacks are directly joined without the intervening pairs.

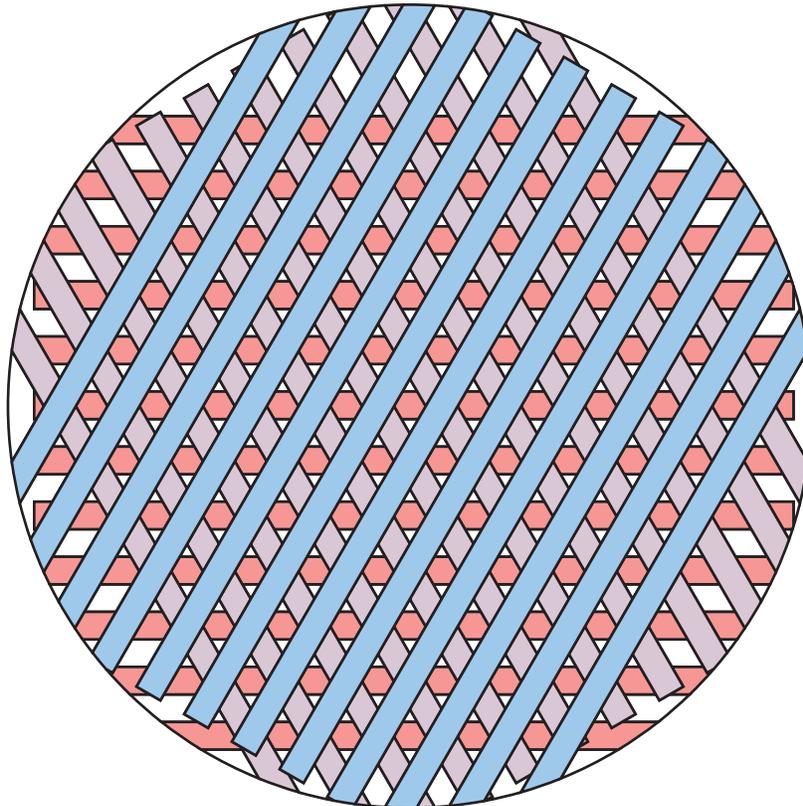
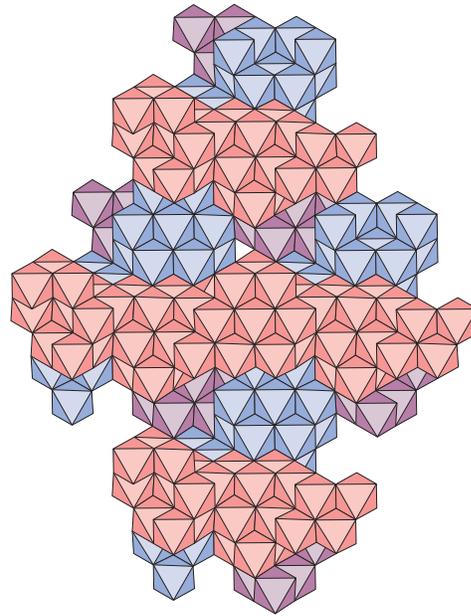


Four stacks joined by 32chain pairs rhombally

The figure on the left shows four 32chain stacks lined by 32chain pairs. The figure on the right shows the red chains of the middle stacks joined by a 32chain pair.

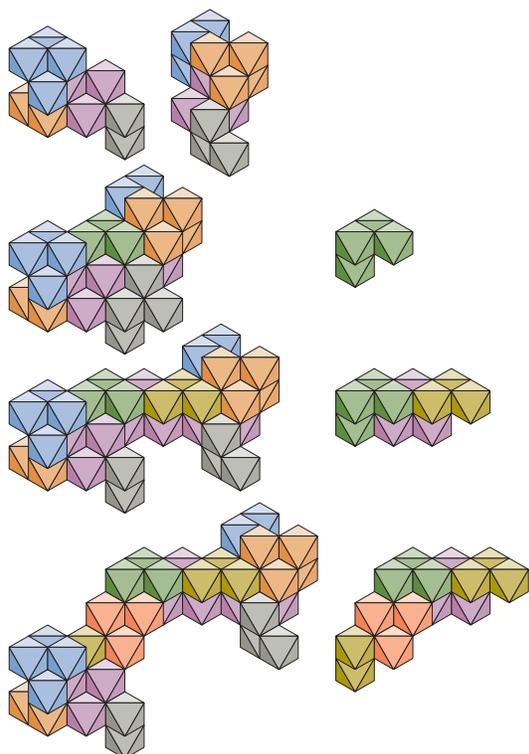
Lattice of 32chains

The four 32chain stacks when joined by additional 32chain peptide links form a lattice. The chains of a given color are parallel and lie in the same plane. The chains of adjacent planes are rotated one third of a revolution. This pattern is extensible in the axial directions of the chains and by additional chains within the plane and by additional planes of chains in the 32stack direction normal to the planes. The spacing of the stacks could vary to provide larger openings and a lighter structure. Also, the stack joins could be staggered from plane to plane.

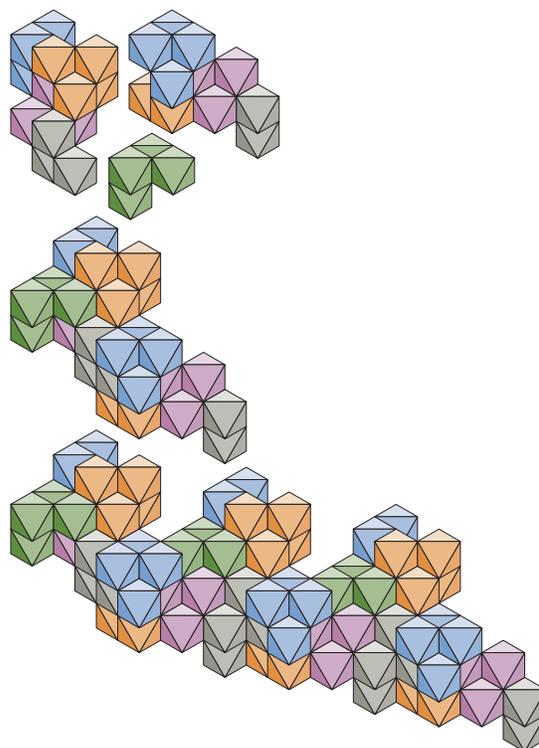


Side chain joins between 32chains.

32chains can be linked by side chains so that they form a planar crystal parallel to a pair of octahedral faces. The simplest link is an O-atom which is cleftly joined to the alpha C-atoms of two main chain units. This type linkage can be extended by the insertion of pairs of C-atoms between the O-atom and either of the main chain units. At the top of the figure are two main chain units which differ by a half revolution about the edgial axis of the 32chain. In the second row, they are linked by an O-atom. In the third row, they are linked by an O-atom to which has been added a pair of C-atoms. The bottom row shows the pair joined by the same O-atom to which has been added two pairs of C-atoms.



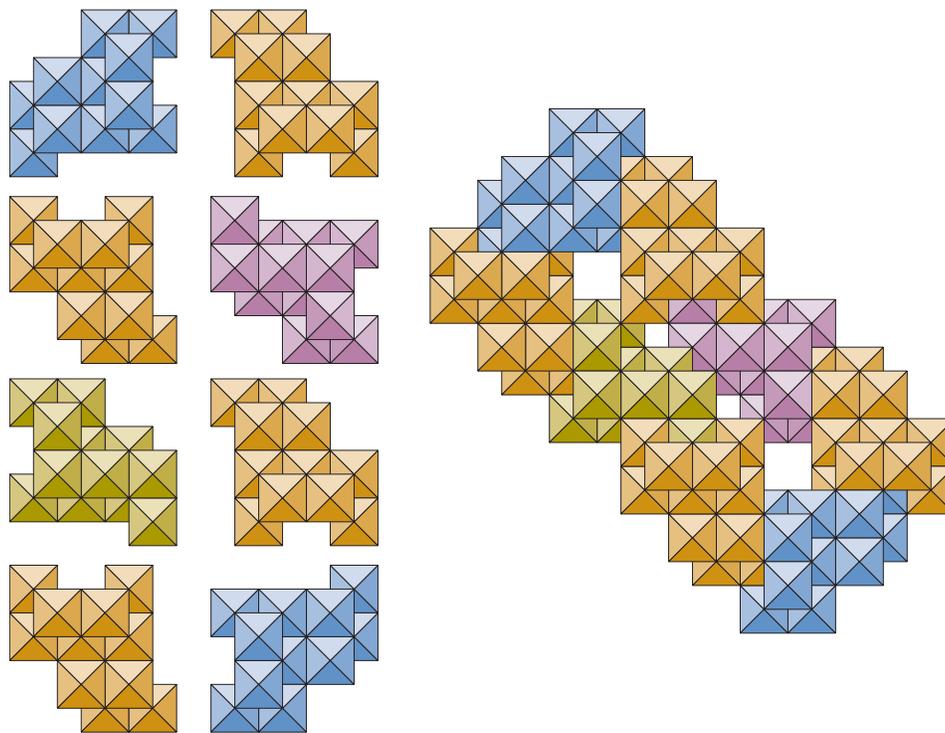
The following figure shows the unpaired main chain units at the top and an O-atom. The second row contains two main chain units joined to form a single turn of 32chain. The O-atom is attached to the unit on the left. The bottom units is composed of three identical turns of 32chain which are linked by O-atoms.



4helix assemblies

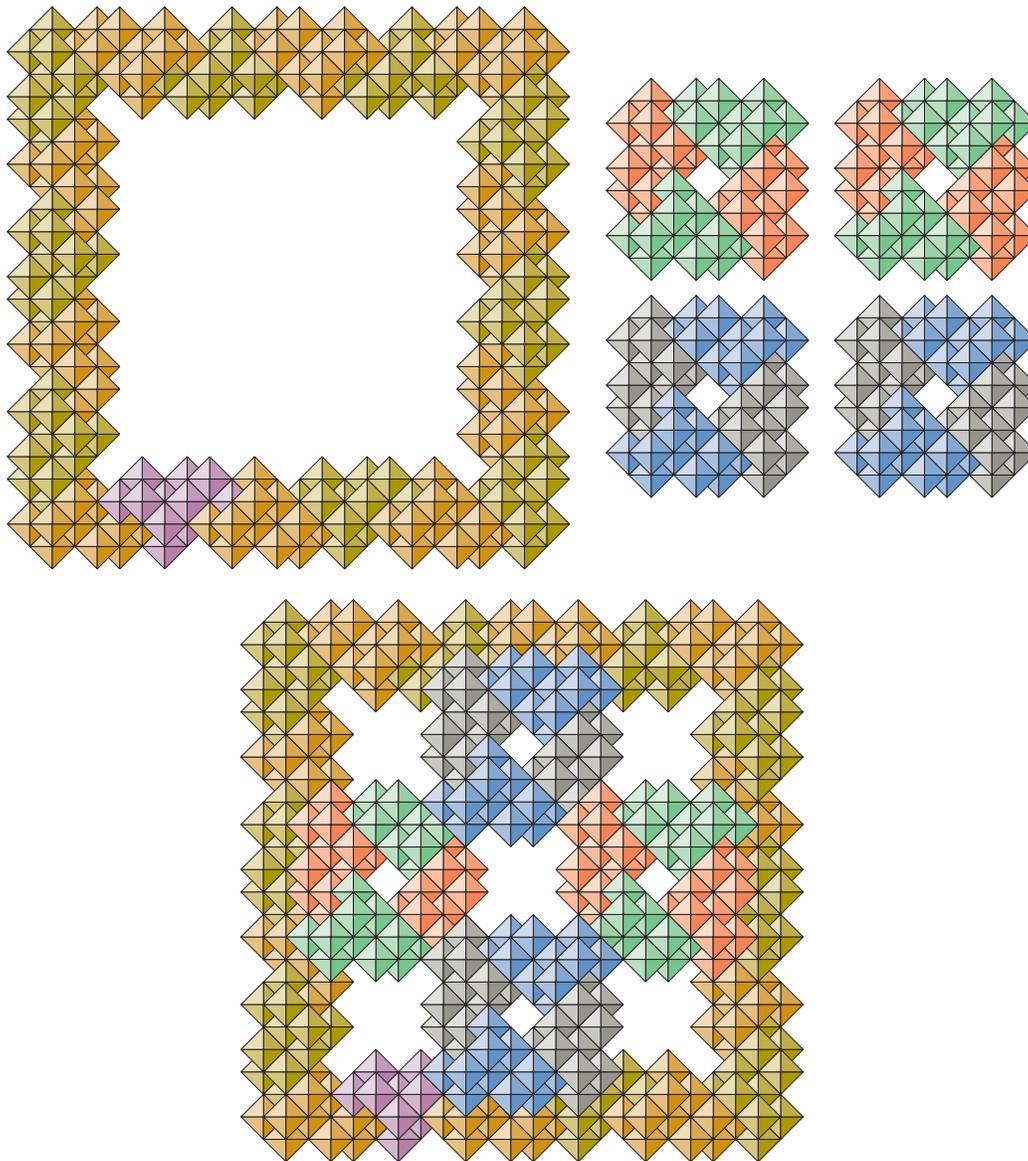
The turn of a 4helix can be extended by the addition of pairs of beta180 residues. Within a pair extended 4helix, a one residue per turn 4helix can join in sheet formation with each of the turns along one side with the central residue of the turn of the larger 4helix with parallel axes. This can be repeated for each side of the larger helix resulting in the larger helix connecting the four smaller helixes through

pleated sheet joins. Each of the smaller helixes contacts two of the other smaller helixes. Direct sheet-joins between 4helixes is not possible unless the one is within the other. The size of the helixes may be extended permitting extensive variations in size and pattern. The shape of the helix can be altered from the square to the rectangular, and this adds to the pattern variations permitted by the 4helix and the sheet-join.



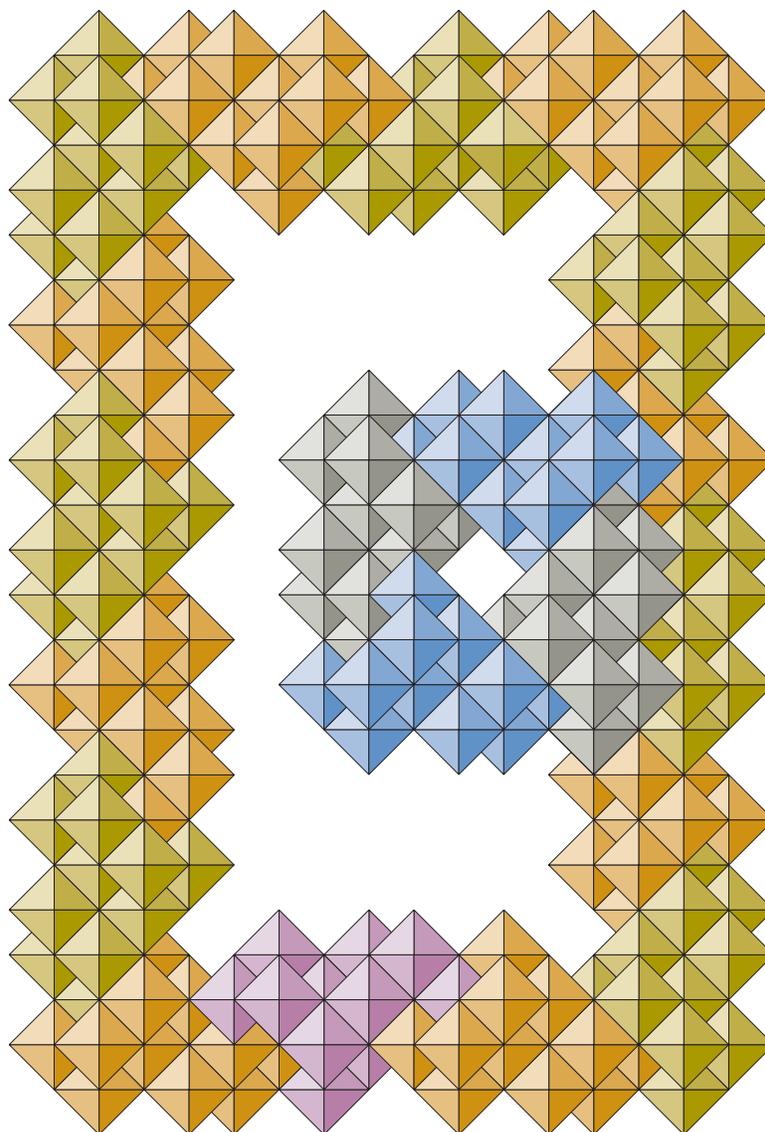
Rectangular 4helix

On the left are the eight units which form the rectangular 4helix on the right. The helix is viewed parallel to its axis. It begins with the violet colored unit and proceeds in a clockwise toward the viewer sense to the orange unit above and to the left of the violet unit.



Four 4helixes sheet-joined to larger 4helix

An extended leg 4helix is at the upper left of the figure. The residue at the near terminus of the helix is colored violet. In the upper right of the figure is a group of identical 4helixes. The near terminus of these helixes is the blue or red colored residue which is at the lower left of each helix. The inner 4helixes are sheet joined to the extended helix at the bottom of the figure.

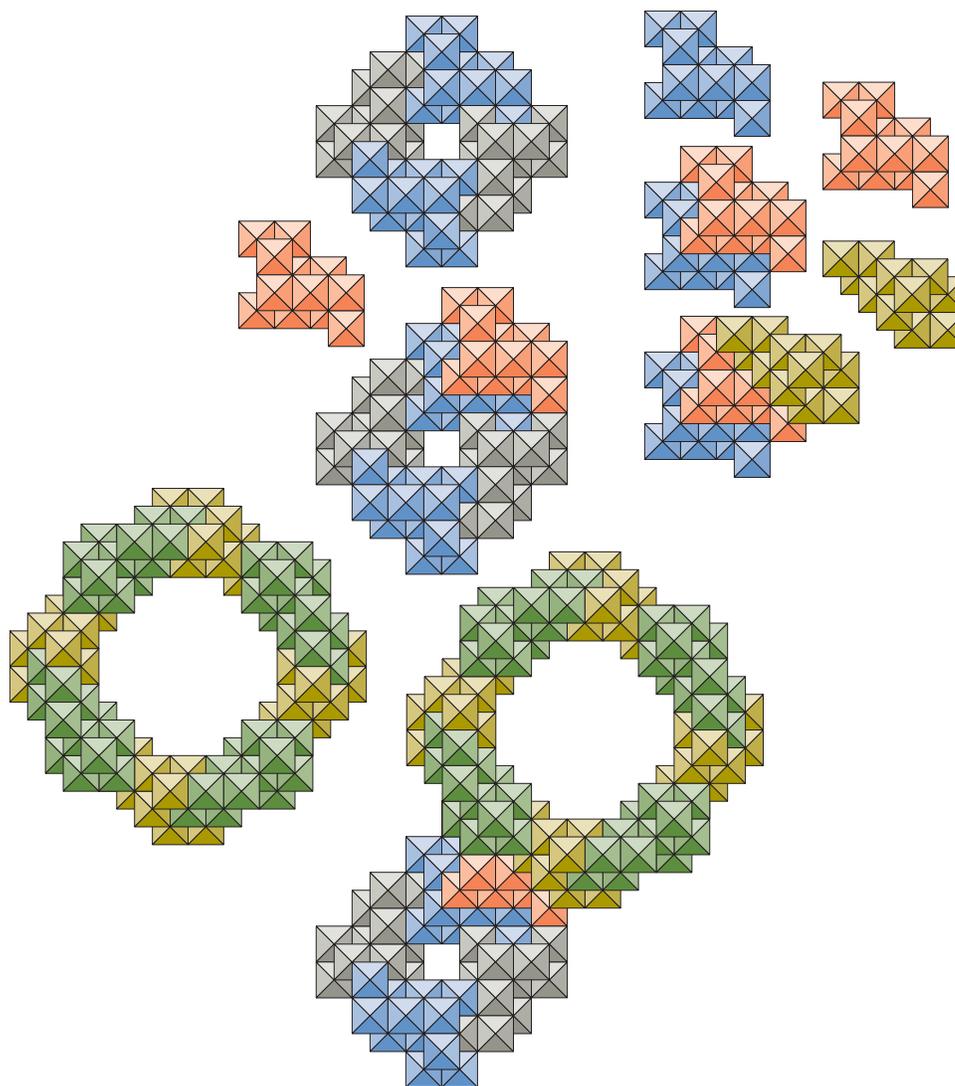


Rectangular 4helix with sheet-joined 4helix

The figure shows an extended 4helix which has a rectangular form. A single 4helix is sheet joined to it. The residue which is the near terminus of the extended 4helix is colored violet.

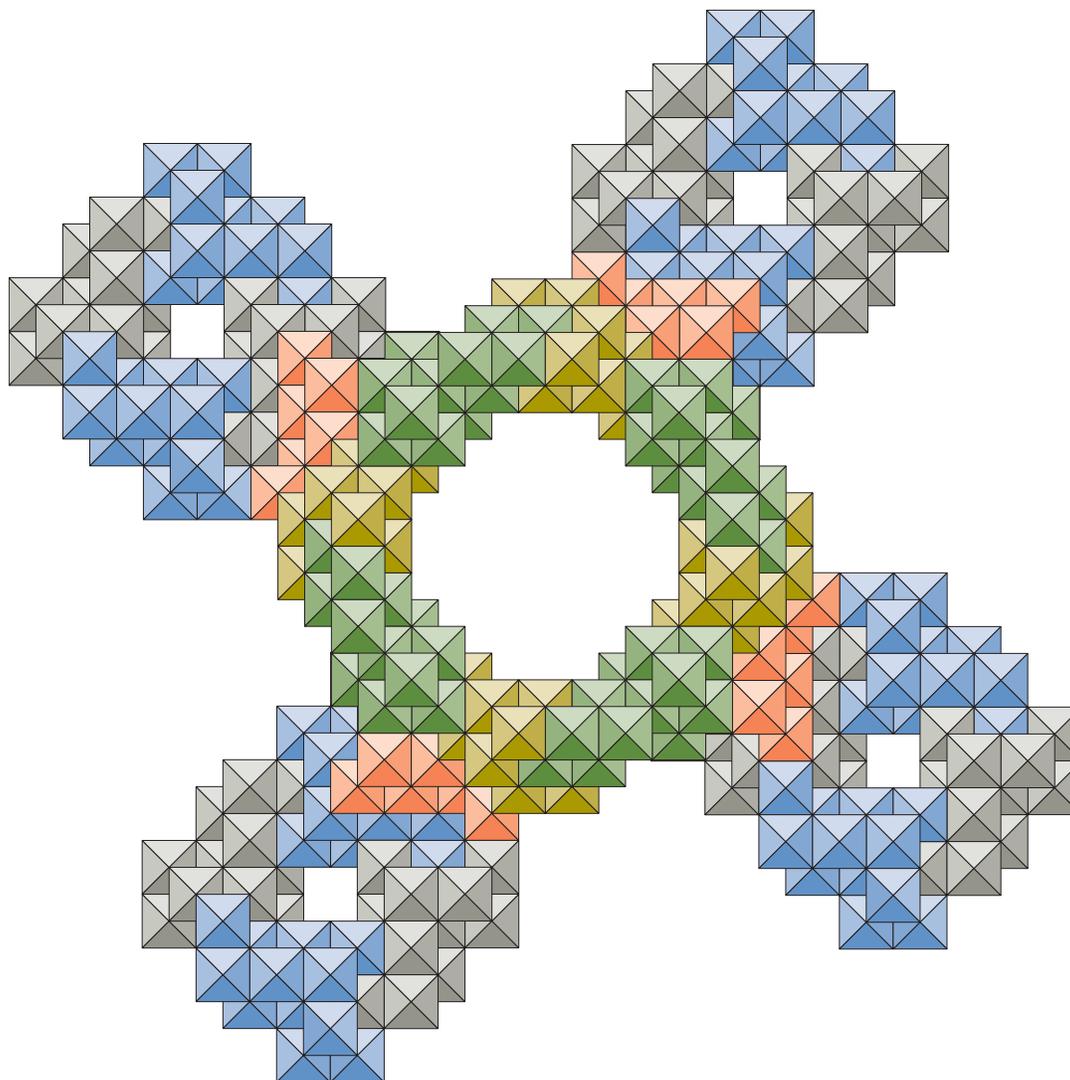
A 4helix can be joined by to a vertexial-ring by a pair of residues to form a 4-strand sheet which includes a residue of the ring, the two linking residues, and a residue of the 4helix. The ring can join four helices in this manner.

This results in the axis of the 4helix being parallel to the normal to the ring-plane. A pattern of rings and helices can be formed in this manner.

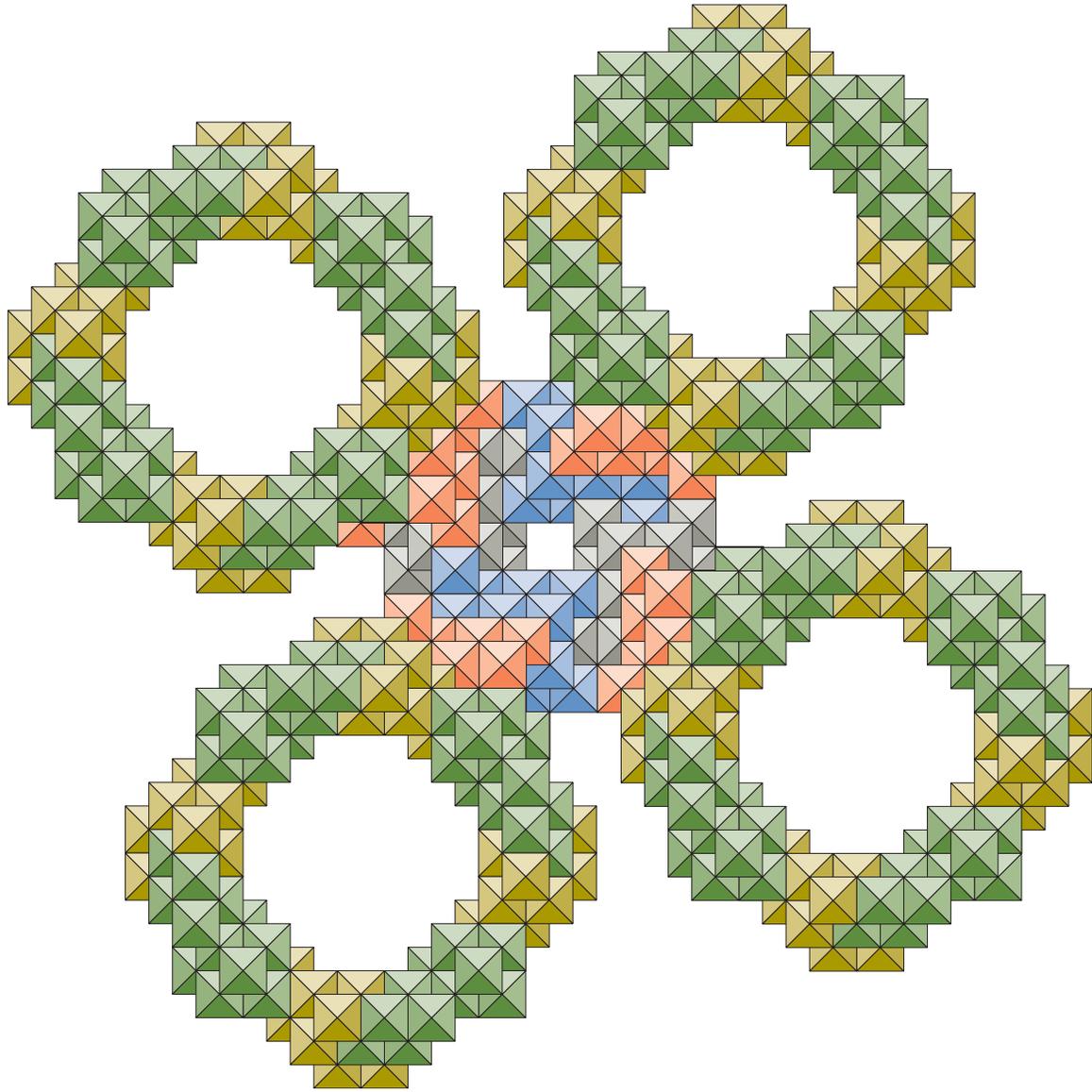


A 4helixes sheet-joined to cyclic peptide

The figure shows the joining of a 4helix to a cyclic peptide by sheet a sheet join. The assembly begins at the top with the 4helix which is composed blue and gray colored residues. A lone residue is anti-parallel sheet joined to the four helix in the next step. The ring joins to the red colored residue in a parallel sheet join to complete the assembly. In the upper right of the figure the sheet joins between the residues is shown. The blue residue is from the 4helix, the red is solitary residue, and the yellow is a residue from the ring.

**Ring with four 4helixes adjoining**

The 4helixes are identical and their near termini are colored blue and are located at the lower edge of the projected helix. The red residue enables a sheet join between the 4helix, itself, and the ring.



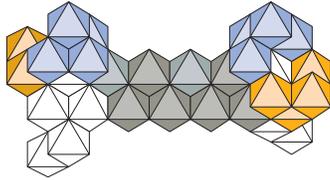
Four cyclic peptides sheet joined to a 4helix.

This figure shows a 4helix to which four rings have been sheet joined with the aid of the red colored glycine. This assembly is analogous to that shown in the previous figure.

Side chain connections of peptides

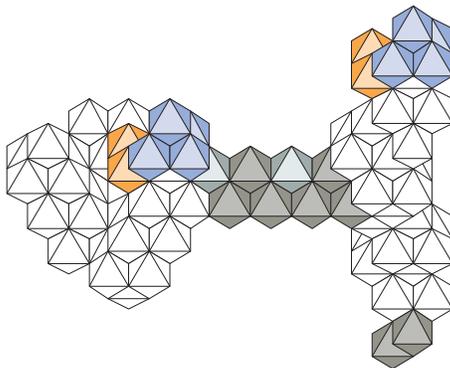
Gly-4C-gly

Two main chain units can be connected by a straight length of carbon chain which is cleftly joined to the alpha C-atom of each unit.



Pair of glycines linked by chain of four C-atoms

In the next figure the same relationship between residues and carbon chain links an alpha helix and a beta180 chain. The alpha helix is on the left and its axis is parallel to the viewing direction. The terminal NH_2O groups of the alpha helix and the beta180 chain have been colored. The C-atom at the male end of the beta180 chain has also been colored.

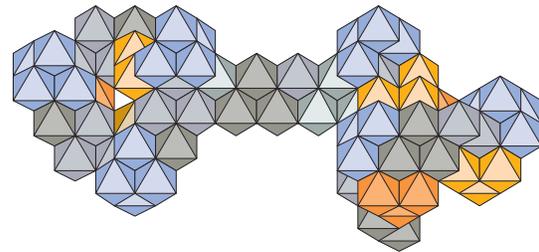


**Alpha helix linked to a beta chain
by a chain of four C-atoms**

This same linkage is shown in the figure the next page. The beta180 chain has been joined by two identical chains to form a parallel pleated sheet, the linking chain of C-atoms has been extended, and an additional turn has been added to the alpha helix. The view is a per-

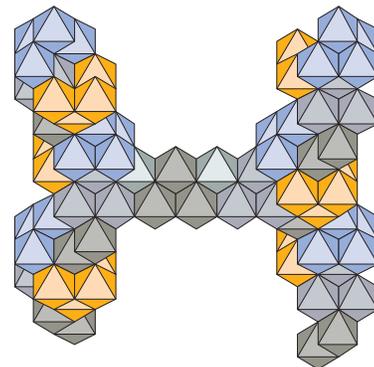
spective projection. In the second figure, the carbon chain has been extended to eight C-atoms and the alpha helix has been extended by a turn. The orientations of sheet, helix, and chain are the same as in the first figure. The axis of the alpha helix is parallel to the plane of the pleated sheet.

The join in the next figure is between two alpha helices. The helix on the left is viewed parallel to its axis, that on the right is angled to the viewing direction. The helix on the right consists of a single turn.

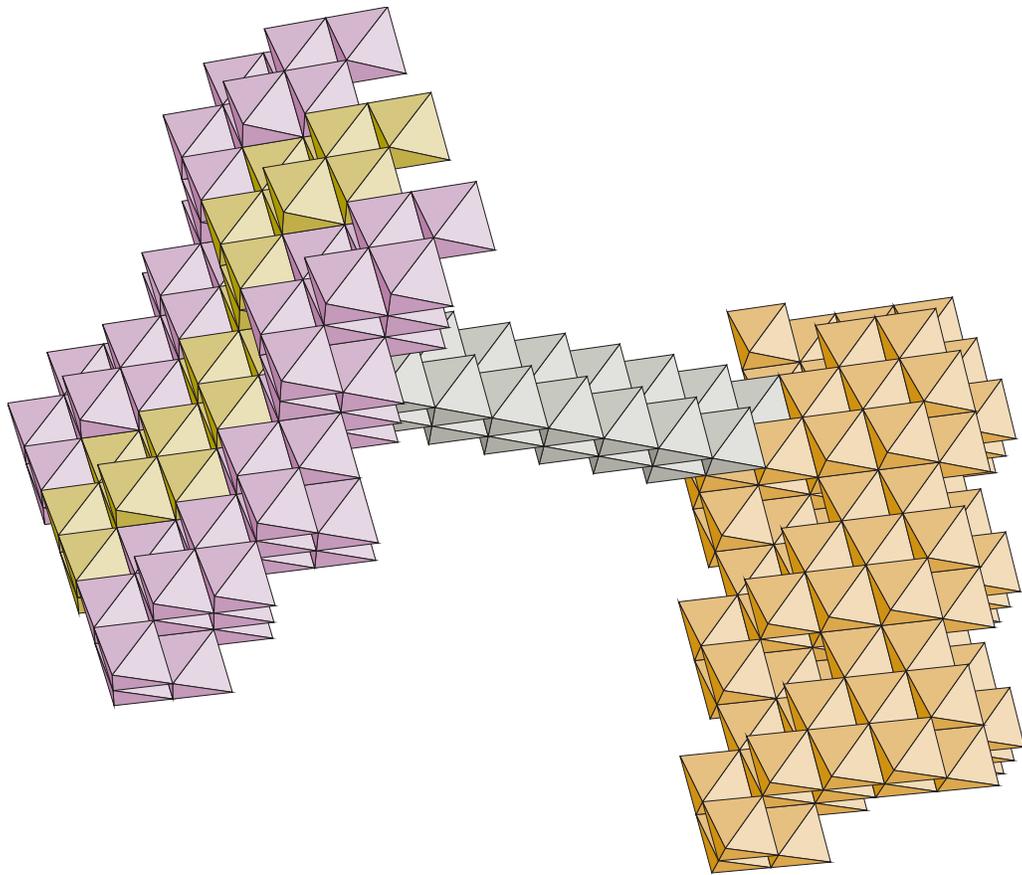


**Two alpha helices linked by a chain
of four C-atoms**

Two beta180 chains having the same carbon chain linkage is depicted here. Each chain has three units. Their axes are parallel. The two end units of each chain have the same orientation as the middle unit of the other chain.

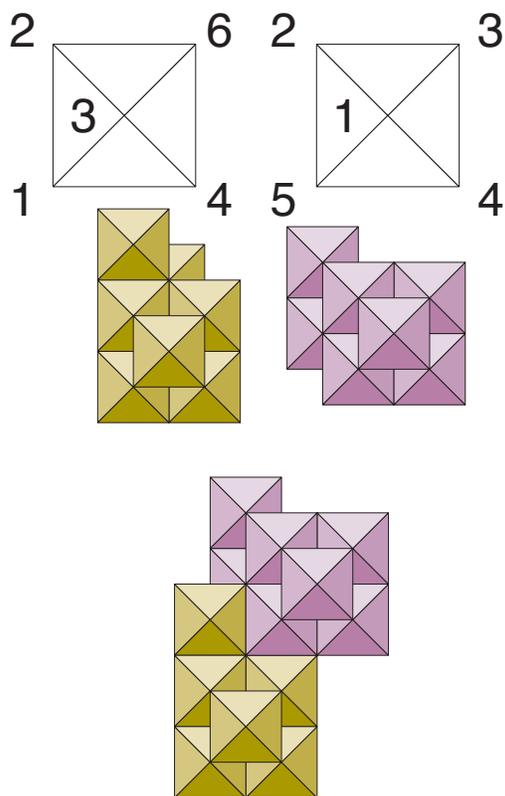


**Two beta chains linked by a chain
of four C-atoms**



Alpha helix linked to parallel pleated sheet by a chain of eight C-atoms.

Cys-cys loop in insulin.



S to S join in cys-cys loop.

The “A” chain of insulin has a cys-cys join between unit #6 and unit #11. The S-atom has four clefts. One cleft is required for joining

with the beta C-atom of the cys-unit to which it belongs. One of the three remaining clefts is required for joining with the S-atom of the other cys-unit. There are five residue to residue joins between the first cys-unit and the cys-unit to which it is joined. Each combination of C-atom to S-atom to S-atom to C-atom was tried for each combination of the six possible types of main unit joining which could link the six main chain units without interference and have the first and sixth unit cleftly joined to each of the given CSSC assemblies. Only one combination fit. The orientations of the residues and the joins between them are listed in the table.

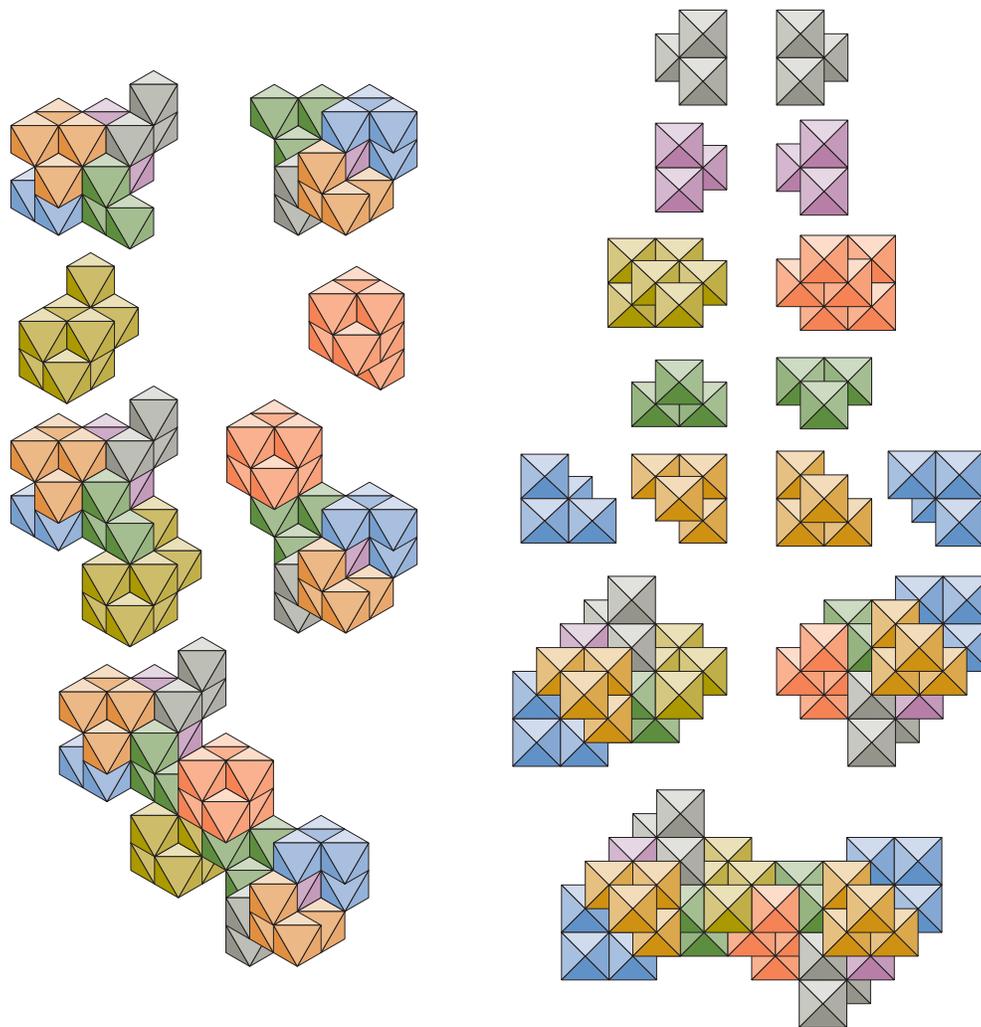
Table 20: Cys-cys loop chain joins

Unit	Orientation	Join
1	125643	
2	634152	32chain
3	265413	epsilon
4	652134	alpha
5	512364	4helix
6	526341	beta90

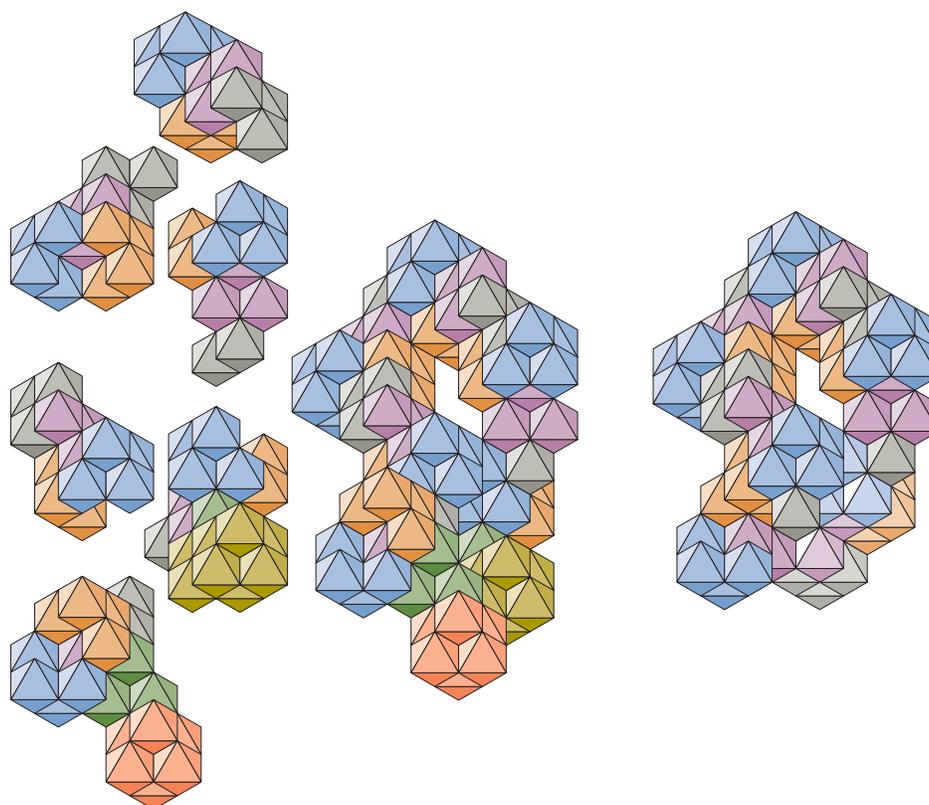
The next table shows the disposition of the clefts of the two S-atoms whose cleft join effects the “A” chain cys-cys join of insulin.

Table 21: S-atom clefts

Cleft	S-atom female end	S-atom male end
Be-S	beta C-atom	beta C-atom
Ne-Si	open	S-atom female end
Mg-Si	blocked	open
Si-S	S-atom male end	open

**Cys-cys pair 3651a**

The figure shows the atoms which constitute each of the cys-units and then shows the atoms assembled as the two cys-units. The two units are identical in conformation but are rotated 180° with respect to one another. The S-atom to S-atom joined units are at the bottom of the figure.



Cys-cys loop of insulin

At the left of the figure the residues #6 through #11 of the "A"-chain of insulin are shown unassembled. The completed assembly is shown just to the right of them. Residues #6 and #11 are cys-residues which form a cys-cys join. The S-atom of one is colored red and the S-atom of the other is colored yellow. On the right, the side chains of the cys residues have been removed to show the conformation of the main chain.

CELL

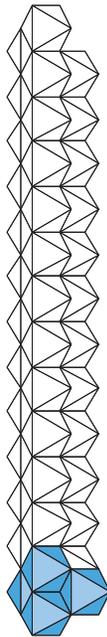
This chapter looks at structures which are important to the assembly of the biological cell. The membrane or enclosure of the cell is a lipid bilayer. Lipids are shown in the first part. Lipids are the constituents of soap films and the film junctions reveal the crystalline association of the lipids. Channels which traverse the cellular membrane are involved in molecular transport and their structures are discussed and related to the membrane structure.

Lipids

Chains of C-atoms in lipids.

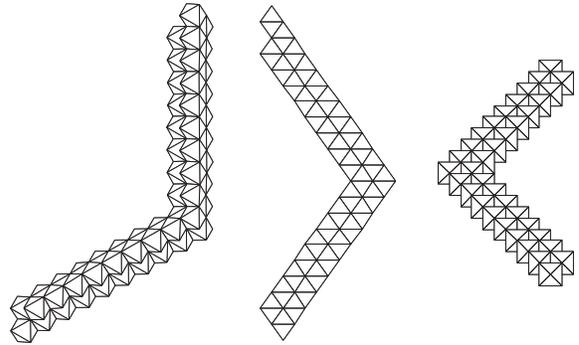
Lipid groups are characterized by chains of C-atoms. The conformation of the chains of some common lipids are indicated here.

Lauric chain



Single bend lipid

Oleic chain

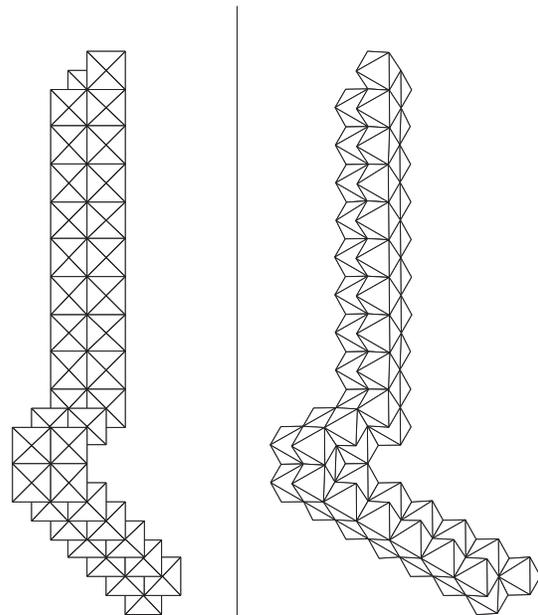


On the left, the oleic chain is oriented so that the bend angle projects as 120° , the true angle

In the middle, the oleic chain is oriented so that the projected bend angle is $180^\circ - \text{atan} \sqrt{8}$ which is about $109^\circ 28' 16''$.

On the right, the oleic chain is oriented so that the bend angle projects at 90° .

Linoleic chain



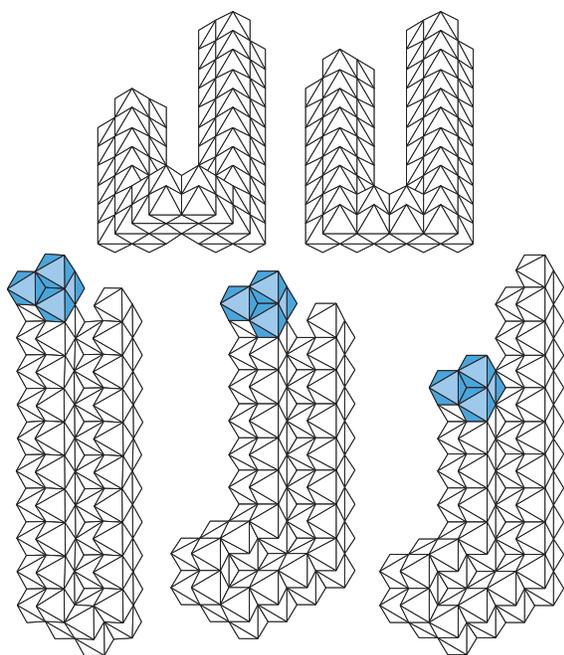
$\text{atan} \sqrt{1/2}$

On the left is a linoleic chain oriented so that the projected bend angle is 135° . This is the angle depicted in Lehninger's *Biochemistry*.¹

On the right a linoleic chain is in the correct orientation to show the true bend angle of 120° which is shown in Stryer's² *Biochemistry*. The two orientations differ by an angle of $\arctan\sqrt{2}$ which is approximately $54^\circ 44' 08''$.

Mixed bend lipid

Arachidonic acid³



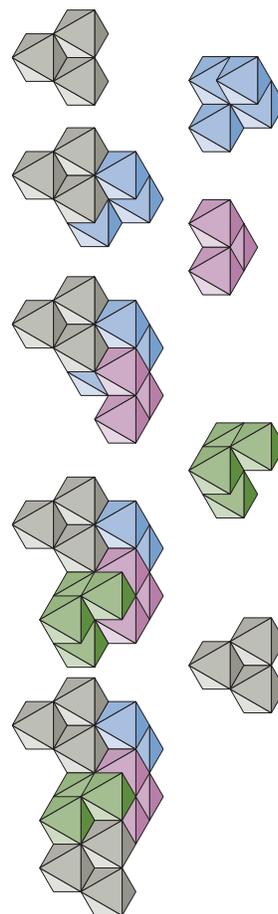
In the upper row, the two legs of each chain are not in contact. The chain on the left has an additional bend that the chain on the right does not have.

In the bottom row the two legs of each chain are in contact. The chain on the left has two

1. A. L. Lehninger, *Biochemistry*, 2d ed. p. 282.
2. Lubert Stryer, *Biochemistry*, 2d ed. p. 226 Fig.10-30.
3. Stuart J. Baum, *Introduction to Organic and Biological Chemistry*, 4th ed., MacMillan, 1987, p. 299.

bends. The middle chain and the chain on the right have three bends each. The free ends of the two legs of the chain on the right are not adjacent.

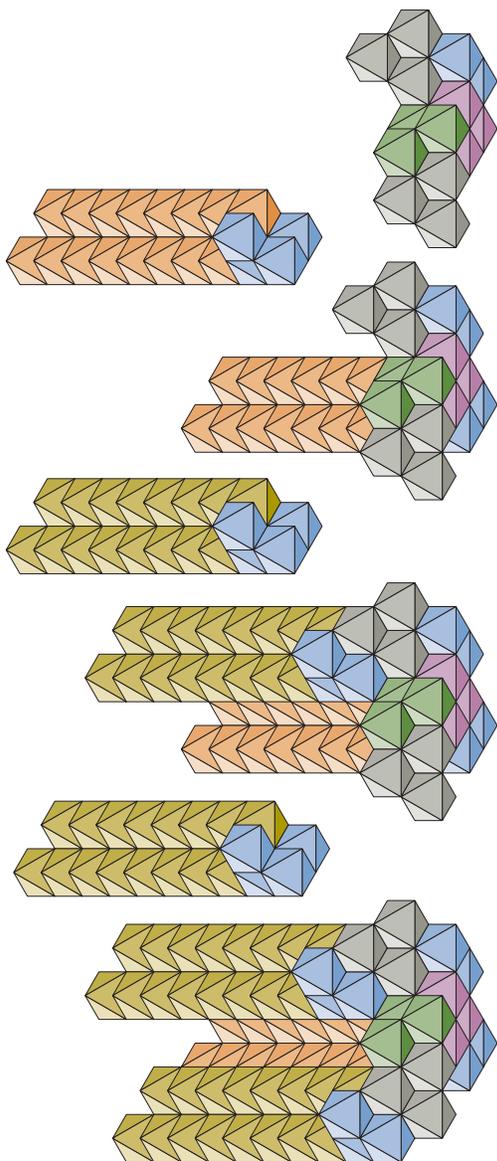
Glycerol



The arrangement of C-atoms and O-atoms of the glycerol unit must accommodate three parallel carbon chains while retaining an attachment place for an H_2PO_4 group. The assembly which is depicted in the figure provides these features. It is notable that the contacts between the C-atoms is edgial. There are no cleft-joints between C-atoms here. The C-atoms are cleftly joined to O-atoms: C-O-C-O-C. The arrangement leaves the central C-atom with one cleft for joining a carbon chain. Each of the two C-atoms at either side has two clefts for joining. One each is used to join a carbon chain. The

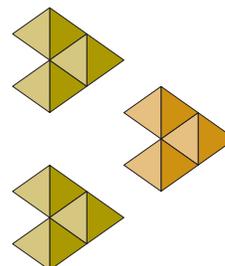
assembly depicted here begins with a C-atom at the top. The adding atoms are in the right hand column. The assembly proceeds atom by atom to the bottom.

Trilauric acid



The assembly of carbon chains to the glycerol assembly is shown in the next figure. The three chains are identical in length, composition, and orientation. Each is terminated by an O-atom which is to be cleftly joined to one of the C-atoms of the glycerol. The first chain is attached to the middle C-atom of the glycerol. The second and third chains are added to the

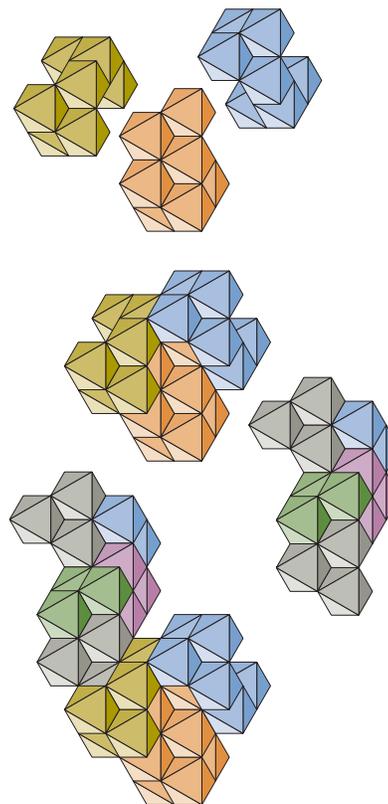
end C-atoms. The open cleft of each of the end C-atoms is seen in the final step of the assembly. The three carbon chains are parallel and are spaced as indicated in the axial view of the combined chains shown below. The viewing



direction is from the glycerol.

Phosphatidic acid

The figure shows the assembly of an H_2PO_4 group at the top. The orange S-atom represents

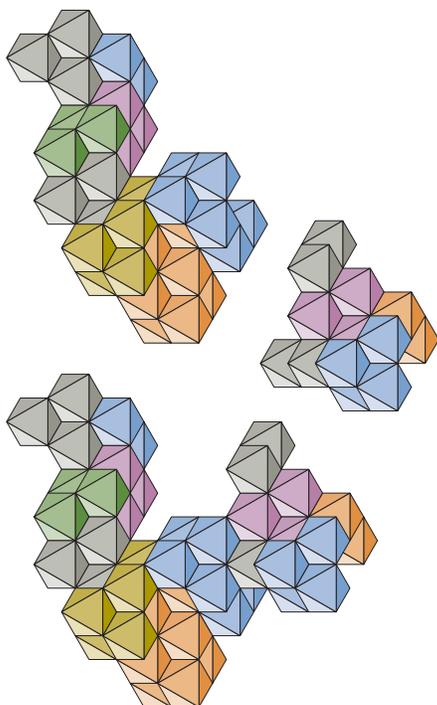


the H_2P portion and this is joined with the O_2 groups colored yellow and blue. The glycerol

group shown on the right joins with the H_2PO_4 group to make the assembly at bottom. The join to the C-atom still permits the attachment of a lipid chain in the manner shown in the trilaureic acid assembly.

Phosphatidyl serine

A serine group is added to the phosphatidic acid group in the next figure. A He-octa of the C-atom of the serine sidechain fills the void in the blue colored O₂-group of the H_2PO_4 portion of the phosphatidic acid assembly. There is more than one orientation in which the serine group can make an equivalent join.



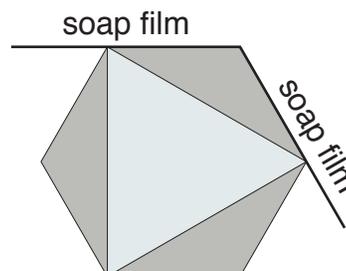
Cell walls

The walls of the cell feature lipids whose chain axes are perpendicular to the surface of the membrane. The chain is defined by the C-atoms which are arranged parallel to an edge of the octahedron. A closed form which will accommodate this octahedral orientation is the rhombic dodecahedron. This form shows up as the underlying structure of soap bubbles. Soap is composed of lipids, too. This suggests that

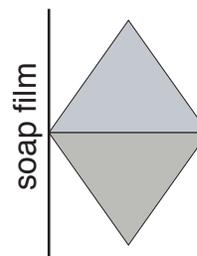
the rhombic dodecahedron is the principal structural form of the cell membrane.

Soap films¹

Joseph Plateau found that the angle between soap film planes is 120° . When two soap films are viewed so that their surfaces and the junc-



tion between them are parallel to the view direction, their relationship to a facial view of a regular octahedron is seen in the figure. Each of the films is tangent to an edge of the octahedron. The relationship of the soap film to an edgial view of a regular octahedron is such that



Soap film referenced to the edgial view of a regular octahedron.

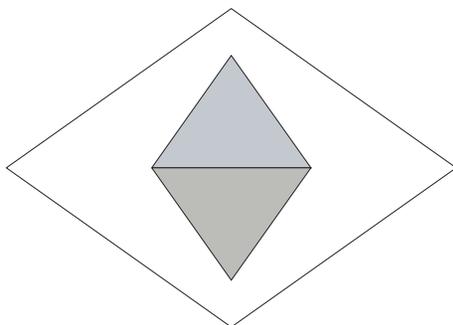
The edgial equator of the octahedron is perpendicular to the soap film plane.

it is normal to the edgial equator. There is *one* closed form of the isometric crystal system whose faces bear the same relationship to the regular octahedron—the *rhombic dodecahedron*.

1. Ian Stewart, Mathematical Recreations “Double Bubble, Toil and Trouble” *Scientific American* January 1998, pages 104 to 107. The article refers to work on soap films by Joseph A. Plateau in the 1830’s.

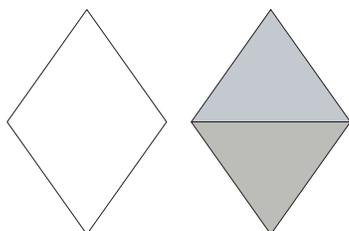
Soap films are rhombic dodecahedral planes

The angle between soap film surfaces at their junction is 120° . The angle between the faces of the rhombic dodecahedron at an edge is 120° . The surface of the face of a rhombic dodecahedron that is a crystalline assembly of regular octahedra is defined by the edges of the regular octahedra of which it is composed. The



edges of the octahedra are parallel to the major diameters of the faces. This relationship is shown in the figure where an edgial view of the octahedron is superimposed upon the rhombic face of a dodecahedron.

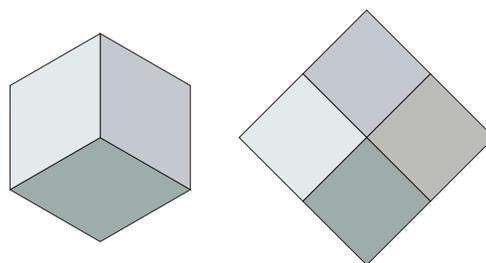
The perimeter of the face of the rhombic dodecahedron and the perimeter of the edgial view of the regular octahedron are geometrically similar. The perimeter of the dodecahedral face is shown here in the same orientation



as the edgial view of the octahedron and the two are of the same size.

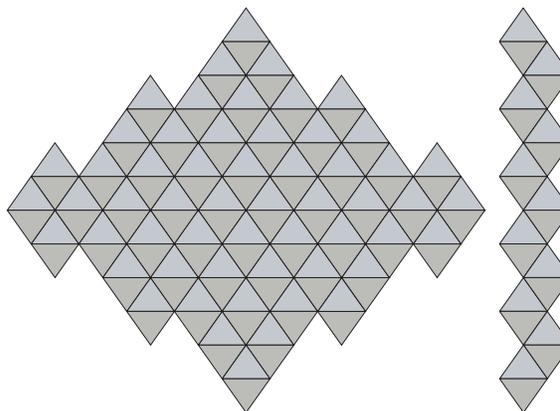
The vertexes of the dodecahedron are of two types—threefold and fourfold. The angle between the edges at a threefold vertex is $180 - \text{atan}\sqrt{8}$, or $109^\circ 28' 16''$; the angle between the edges at a fourfold vertex are $\text{atan}\sqrt{8}$ or $70^\circ 31' 43''$. These interedgial angles are shown truly in the view normal to a

rhombic dodecahedral face.



Rhombic dodecahedral assembly of regular octahedra.

A hollow rhombic dodecahedral shell can be built of regular octahedral panels. The panels

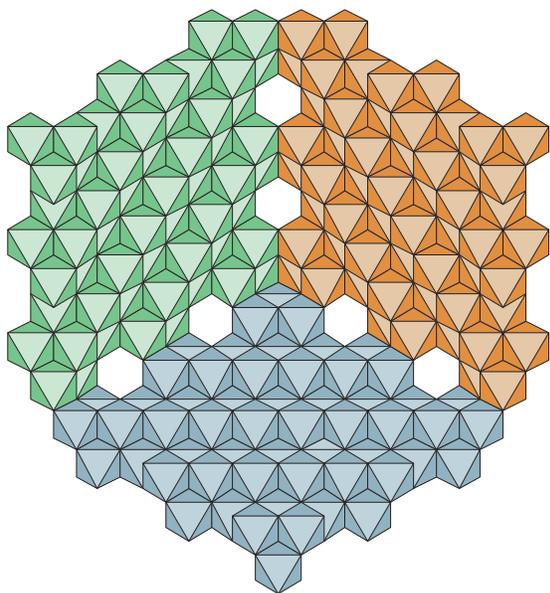


Rhombic dodecahedron: Octahedral panel
Facial view on left, edgial view on right.

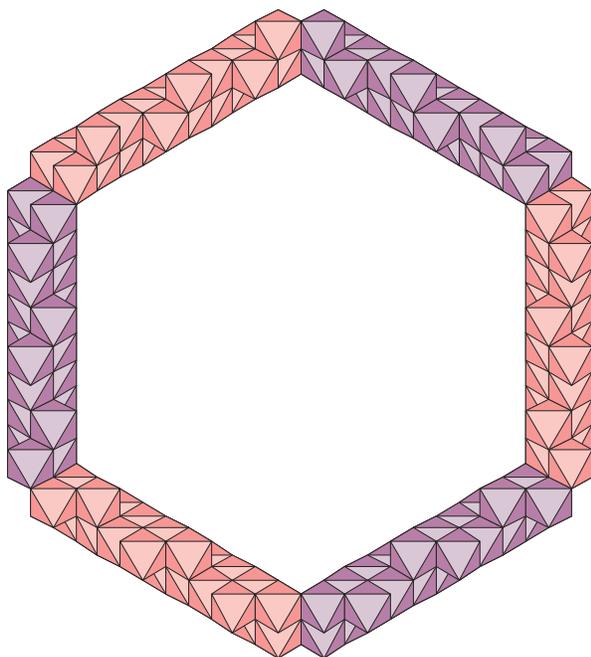
will be two edgial layers thick, the minimum for an assembly. The figure shows the panel in two views, one view is normal to the plane of the panel and the other view is parallel to the plane of the panel. One panel is used for each of the twelve rhombic dodecahedral faces.

Assembling octahedral panels to form a hollow rhombic dodecahedron

The assembly is shown using three sub-assemblies of panels. Three panels are joined at their edges so that the panels are concave toward the viewer. Each of the three panels of the sub-assembly have been colored so that they may be differentiated. They are identical.



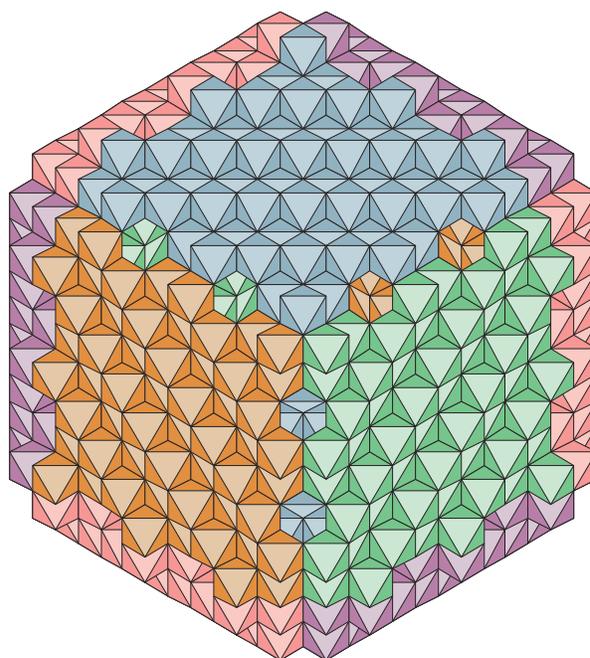
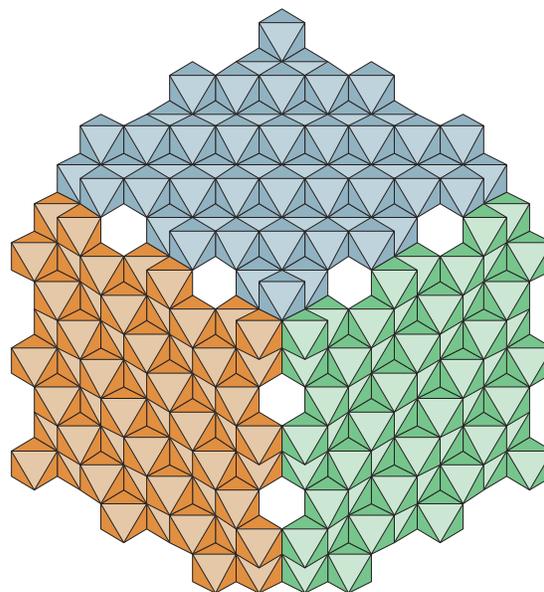
**Rhombic dodecahedral subassembly,
three panels, concave towards.**



Two panels are joined at three places where each of two octahedra of one panel share an edge with two octahedra of the other panel.

The next subassembly consists of six panels which join to one another in a manner which is identical to those of the previous sub-assembly.

bly. The panels here are viewed edgially. Together, the six panels form a regular hexagonal prism.



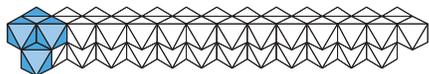
The third and final sub-assembly is identical to the first sub-assembly. It is rotated 180° to the first so that it is convex towards the viewer.

When the three subassemblies are joined so that the edges of their panels are in the same relationship as the panels at the other edges, the resulting appearance is as shown. This is a

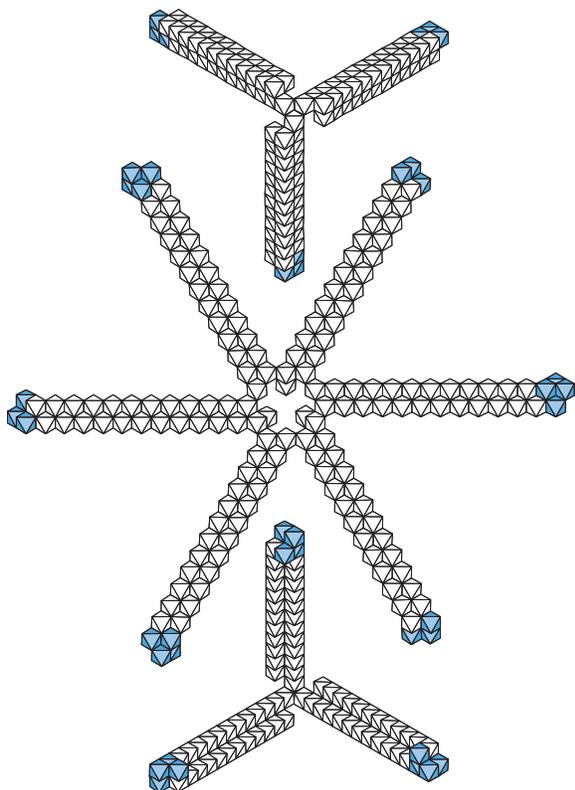
hollow rhombic dodecahedron viewed along one of its threefold axes. While the first two sub-assemblies are somewhat hidden by the third subassembly, portion of each of the panels of the other assemblies can be seen in the full assembly.

Lipid orientations relative to the rhombic dodecahedron

The lauric chain axis is a straight line paral-



lel to an edge diameter of the regular octahedra. The axis is oriented so that it is perpendicular to a plane of the rhombic dodecahedron. To show this relationship, the lauric chains are shown as they relate to each of the subassemblies using octahedral panel to form a hollow rhombic dodecahedron. One chain is depicted for each of the panels each of

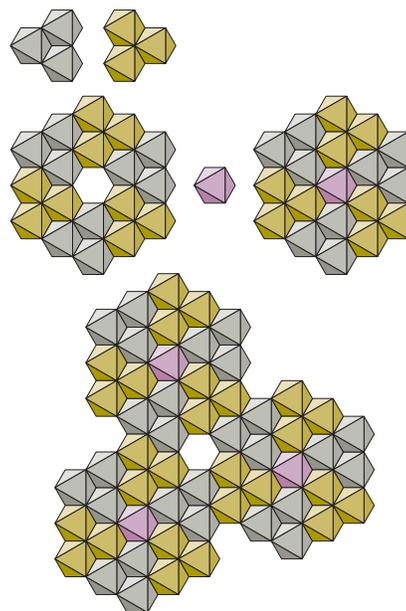


the subassemblies. The sense of each of the chains is that it commences at the exterior of the panel and proceeds away from the panel. In the top group, each of the three chains pro-

ceeds from its junction with the other two chains downward in a direction perpendicular to one of the panels of the concave threefold vertex and beneath the viewing plane. The six chains of the middle group are parallel to the viewing plane and each proceeds in a direction which is normal to one of the panels of the equatorial assembly. The chains of the bottom group proceed towards the viewer from the lower junction and each is perpendicular to one of the three panels of the convex three-vertex.

Porin

Porin is a transmembrane protein which forms channels in the outer membrane of a gram-negative bacterium.¹ Electron micrographs show a pattern which is modelable using regular octahedra. The arrangement of groups of three dark spots surrounded by whitish background fit the pattern depicted here.



The octahedra of the gray hued triplet are in the same relationship as the dark spots which

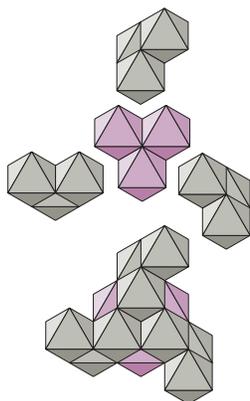
1. Lubert Stryer *Biochemistry*, 2d ed. W. H. Freeman 1981, Fig. 32-33 B <Electron micrograph of negatively stained arrays of porin channels from *E. coli*>, p. 785.

are labeled “channel” in the reference. The spacing of the gray triplets is provided by the yellow triplets to match the arrangement of the electron micrograph. The ring of gray and yellow triplets is the planar CFU which will extend the pattern over the plane. The violet octa is placed at the center of the ring to identify each of the rings in the three ring assembly at the bottom of the figure and to differentiate the ring centers from the octahedral voids which are defined by the ring assemblies.

Gap junctions

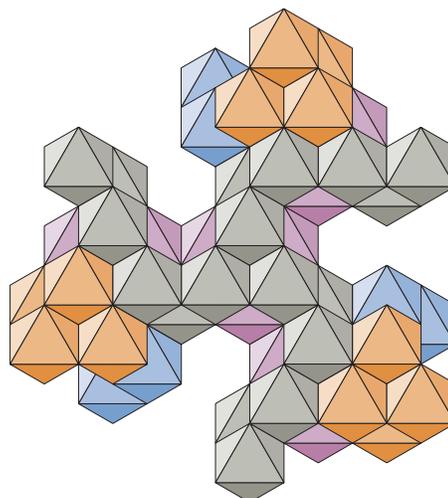
Groups which are analogous to porin form channels in the outer membranes of chloroplasts and mitochondria.¹ Gap junctions are described as having six subunits surrounding a hole of 20A. They are shown in an electron micrograph to be in an hexagonal lattice. They could be of the same form as those shown for porin.

Protein substructures composed of chains of amino acids which proceed normally to a hexagonal plane are two in number. The alpha helix and the epsilon helix. Three alpha helixes can be linked by a four C-atom assembly



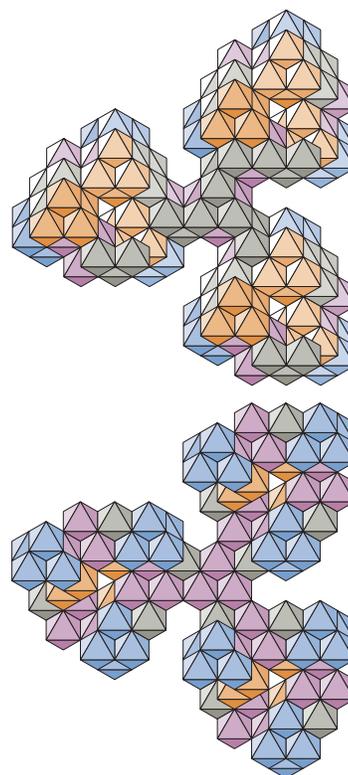
which consists of a central C-atom hub and three C-atom spokes. The C-atoms which compose the are shown above the assembled linker in the figure.

The next figure shows each of the C-atom



spokes of the linker cleftly joined to the alpha carbon of a main chain portion of an amino acid. The three aminoes together are in the three alpha helical orientations.

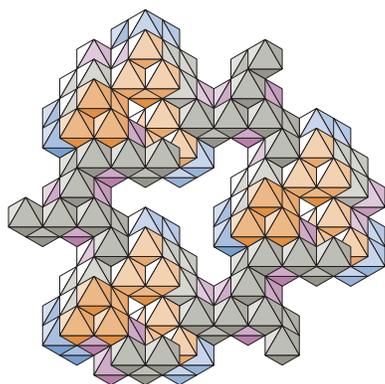
A single turn of an alpha helix has been added to each C-atom spoke of the linker in the next figure. The three helixes are in the same relationship as the three octahedra of the gray



1. Stryer, *ibid.* p.878.

triplet of the porin CFU. The male end of the alpha helix is nearest to the viewer. The obverse view places the female end of the helices nearest the viewer.

A triplet of alpha helices in which each helix is in the position of the yellow triplet of the porin CFU is shown here. The helices are



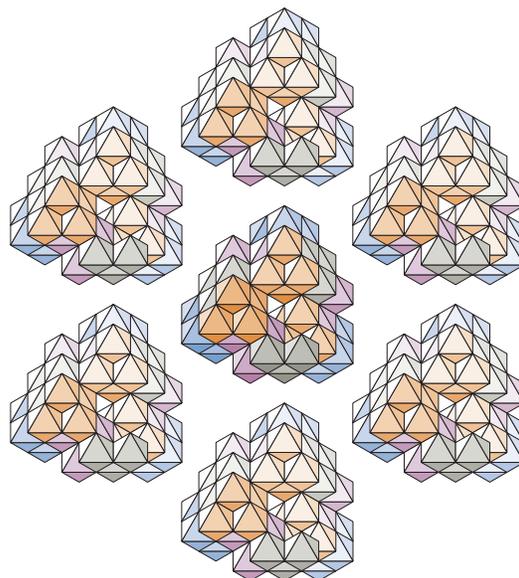
joined at the periphery by three C-atom linkers.

The two types of alpha helical triplet are then joined to form an assembly which is equivalent to the porin CFU depicted with octahedral triplets. The six helical triplets define a channel at the centroid of the assembly which is seen in the figure depicting the assembly on the next page.

Removing the yellow octahedral triplet shows the pattern which was captured in the electron micrograph. This pattern is also seen when the helical triplets which are equivalent to the yellow octahedral triplet are hidden and leave the three helical triplets which represent the gray octahedral triplets.

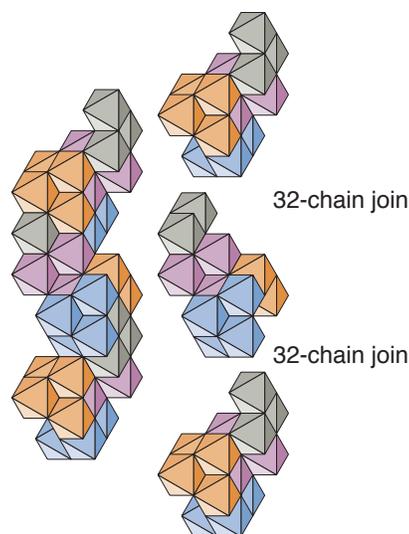
The channel formed by the six alpha helical triplets can accommodate an alpha helical turn. This is shown in the figure. For each of the six triplets, only the helix which is at the periphery of the channel is depicted. The helix in the cen-

ter is identical to the surrounding helices.

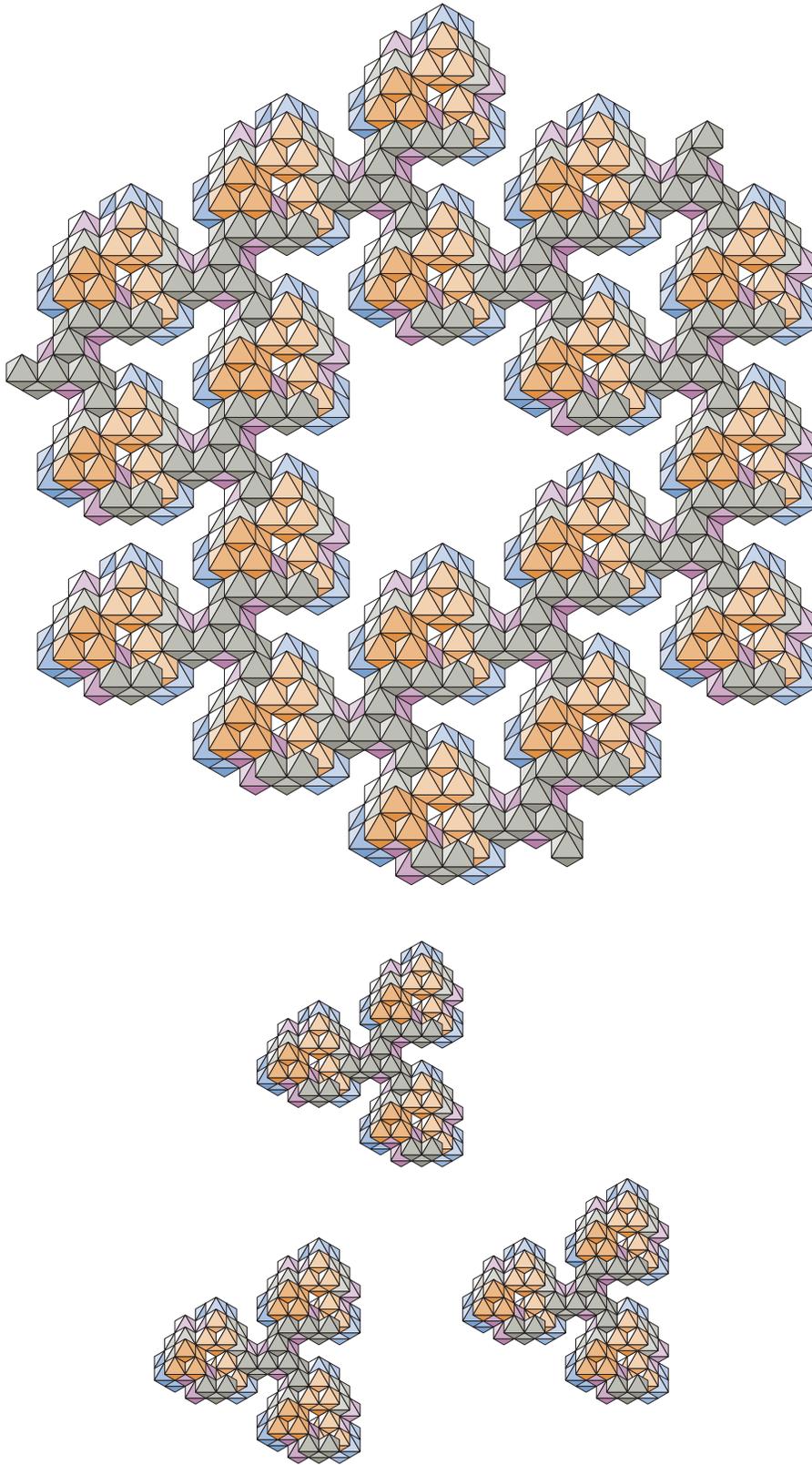


Gramicidin-A channel

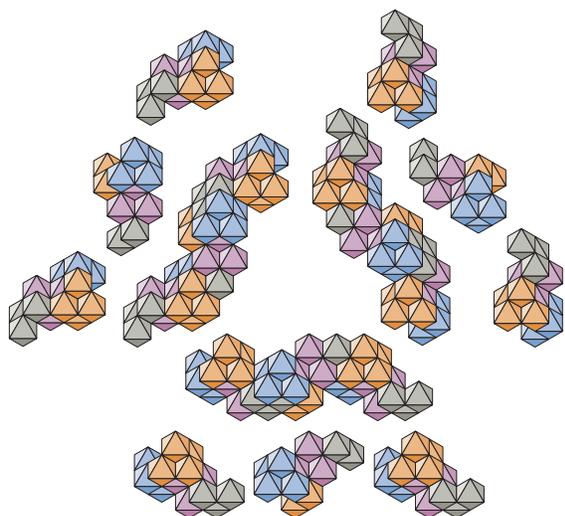
A helix can be built which could act as the gramicidin-A channel. It is an alpha helix which has been expanded by the addition of residues which link to two alpha helical aminoes to form a length of 32-chain. This expansion is shown in the next figure. The aminoes



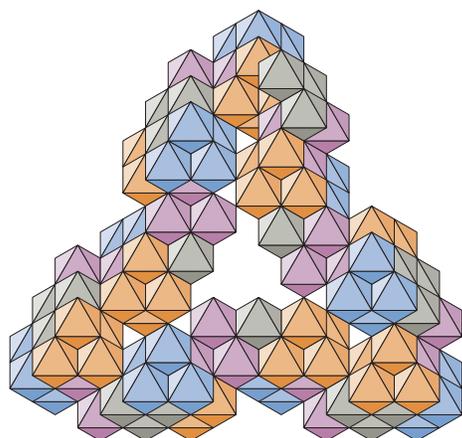
are shown in the right column. The amino at the top is in the same orientation as the amino at the bottom. The middle amino is in an orien-



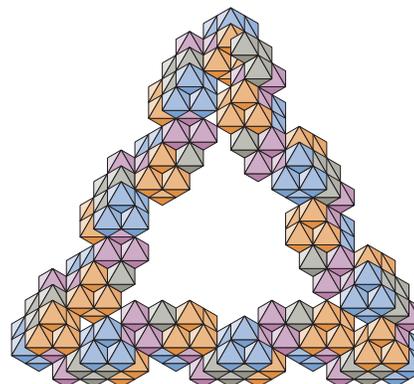
tation which permits the formation of the 32-chain on the left. The helix is built of identical chains which differ in orientation by rotation of 120 or 240 degrees. The assembly of the three legs is shown in this figure. The three



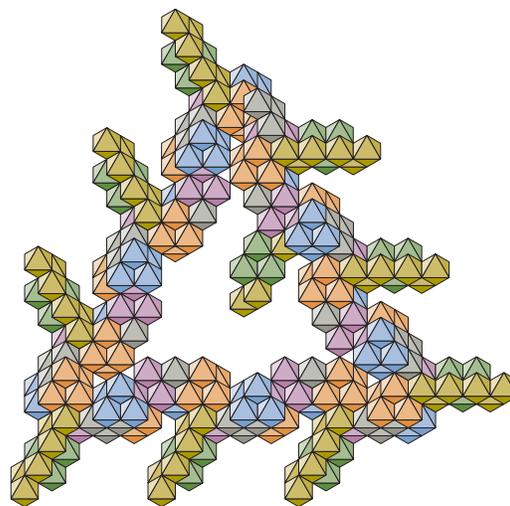
legs are oriented for joining in the alpha helical join. The assembly of the three chains is shown below.

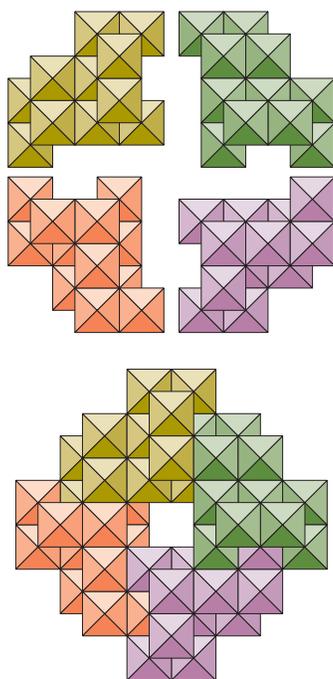


A similar assembly is made using five aminoes per chain which produces a larger channel.

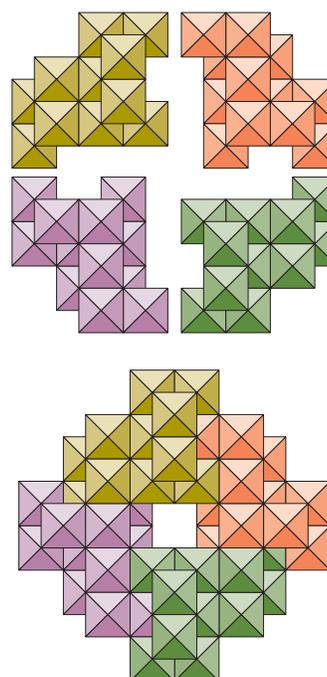


Side chains have been added in each of the external locations. The chains are identical and consist of a straight chain of three C-atoms. Each is cleftly joined to the alpha C-atom of an amino. One chain has been joined to an internal amino location. The chains are seen to be parallel to the 32-chains which make up the helix.



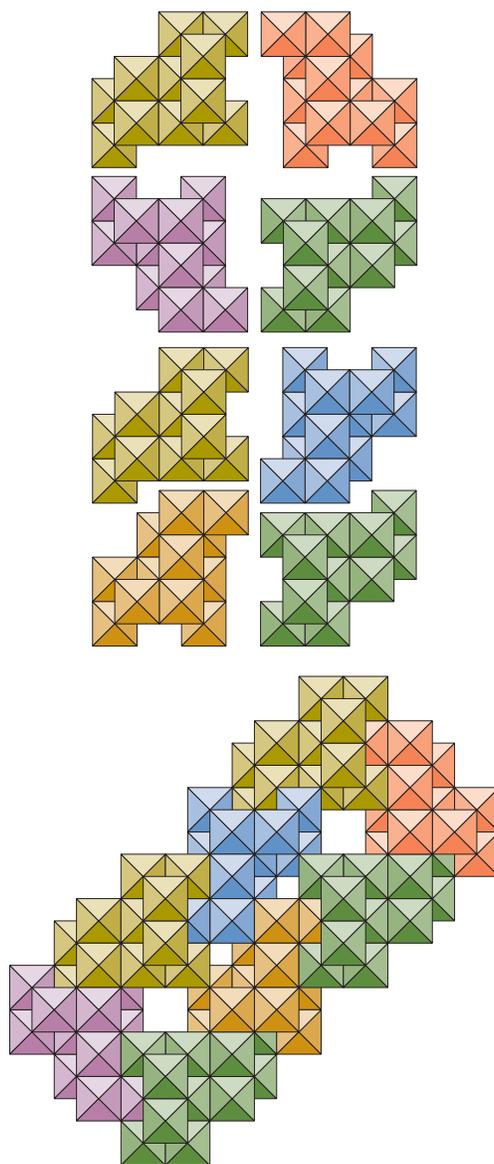
CYCLIC**Cyclic peptide LLDD****Cyclic peptide LLDD.****Cyclic peptide LLDD.**

A ring can be formed using two L-units and two D-units. The L-units differ by a rotation of a quarter turn about an axis parallel to the viewing direction. The same is true for the D-units. The L-units are colored yellow or green. The L-units are joined alpha helically. The D-units are colored red or violet. They, too, are joined alpha helically.

**Cyclic peptide LLDD.**

The same units can be used to form another ring. The L-units differ here by a half revolution. This is true for the D-units too.

Cyclic peptide LLLDLLLL

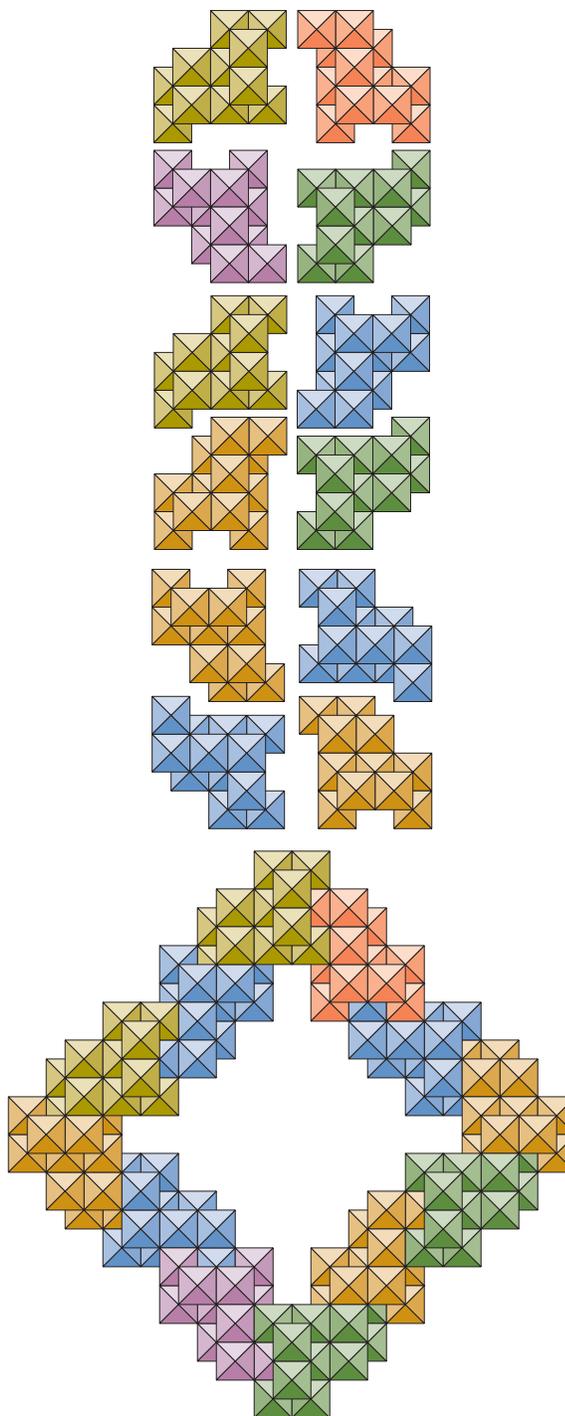


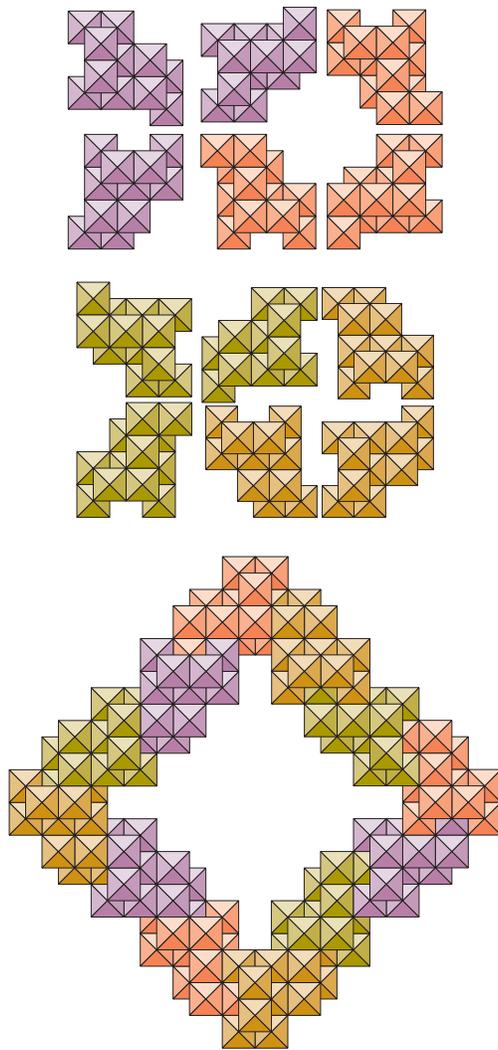
Cyclic peptide LLLDLLLL.

The ring shown in the last figure is extended by the addition of one pair of L-units between the yellow and purple units and a second pair of L-units between the red and green units. The cyclic peptide which results has the form LLLDLLLL.

Cyclic peptide LLLLLDLLLLLD.

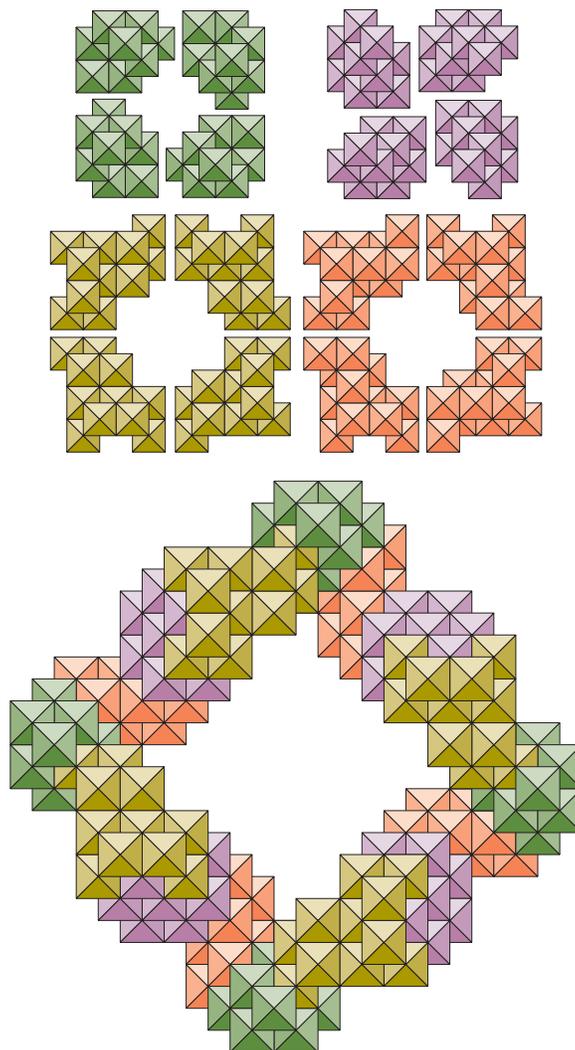
Cyclic peptide LLLLLDLLLLLD.
 The ring is extended in a direction at right angles to the previous extension in the next figure. Two L-units are inserted between the violet and yellow units and another two L-units are inserted between the red and green units. The twelve unit ring is of the form LLLLLDLLLLLD. The two units colored red and violet are the D-units.



Cyclic peptide LLDDLLDDLLDD**Cyclic peptide LLDDLLDDLLDD**

The units which form the peptide are shown in two groups of six each at the top of the figure. Those colored red or violet are D-gly and those colored yellow or orange are L-gly.

Cyclic peptide 4LDLD

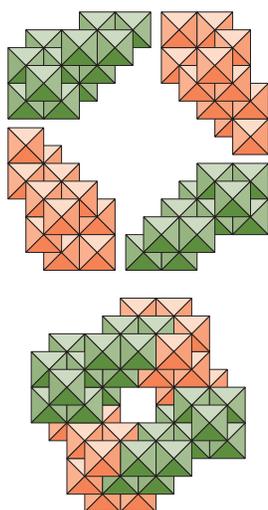


Cyclic peptide 4LDLD

The figure shows the sixteen units which constitute the cyclic peptide¹ in groups of four each at the top. Each group of four contains identical units which differ by a rotation of a quarter of a revolution about an axis parallel to the viewing direction. The units which are colored red or violet are D-units; the units colored green or yellow are L-units. The join between L-units is epsilon helical. There is a 3/2 chain join between D-units. The peptide is viewed parallel to its axis of fourfold symmetry.

1. H. N. Rydon, editor, *MTP International Review of Science*, Organic Chemistry Series Two, Volume 6, Butterworths, London, 1976, p. 243, Fig. 7.11.

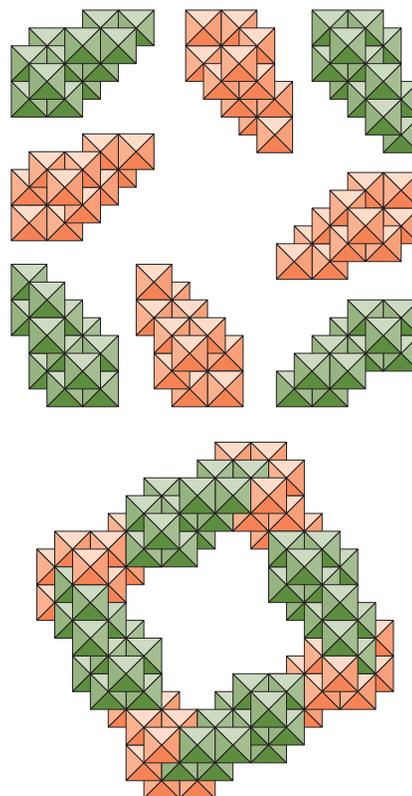
Cyclic peptide LDLD



Cyclic Peptide LDLD.

A four unit cyclic peptide with twofold symmetry about a vertical axis is shown in the next figure. There are two L-units colored green and two D-units colored red. The pattern is LDLD.

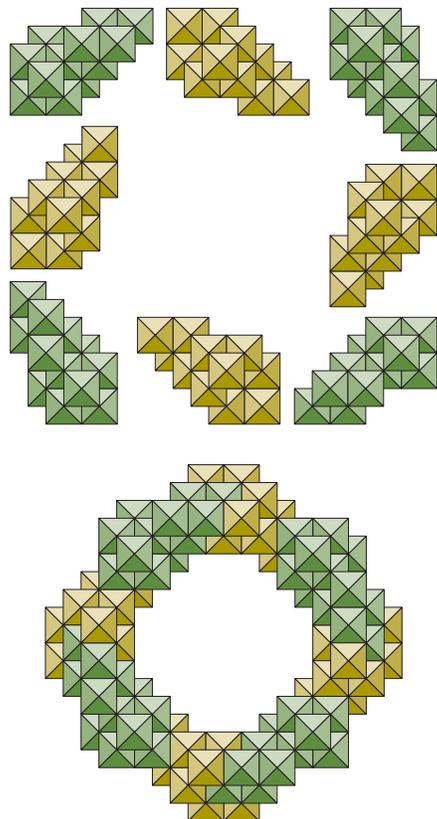
Cyclic peptide LDLDLDL



Cyclic peptide LDLDLDL.

This ring is extended by the addition of two L-units and two D-units to form a four-fold ring in the next figure. The added units are in the same orientation as those in the previous figure but differ from them by a rotation of a quarter of a revolution. The pattern is LDLDLDL. D-units are colored red and L-units are colored green.

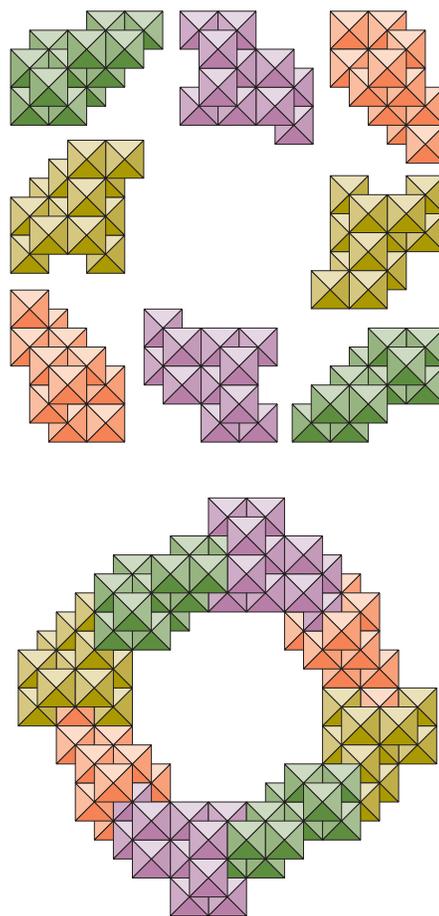
Cyclic peptide LLLLLLLL



Cyclic peptide of eight L-units.

The four L-units of the LDLD-LDL D assembly are combined with four additional L-units to provide a cyclic peptide consisting of eight L-units. The additional L-units are inverted relative to the previous L-units. They are colored yellow. The join between the male end of the green unit and the female end of the yellow unit is $\beta 32$ chain. The male end of the yellow unit is joined to the female end of the green unit in a $\beta 180$ join.

Cyclic peptide LLDDLLDD

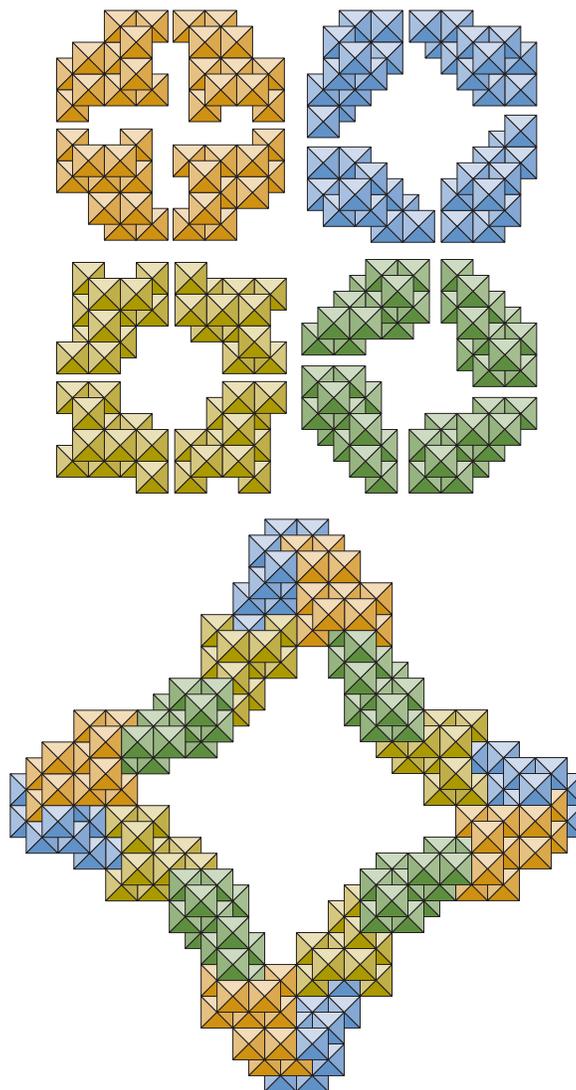


Cyclic peptide LLDDLLDD.

This ring is based on the LDLD ring shown previously. The ring has been extended by the insertion of two L-units and two D-units. The units of each pair differ by a rotation of a half revolution about an axis parallel to the viewing direction. The pattern becomes LLDDLLDD.¹ The L-units are colored yellow or green and the D-units are red or violet. The join between the L-units is $\beta 90$. The join between D-units is $\beta 90$ as well.

1. Lubert Stryer, *Biochemistry* 2d ed., W. H. Freeman, San Francisco, 1981, Fig. 36-19, p. 873.

Cyclic peptide of sixteen L units.

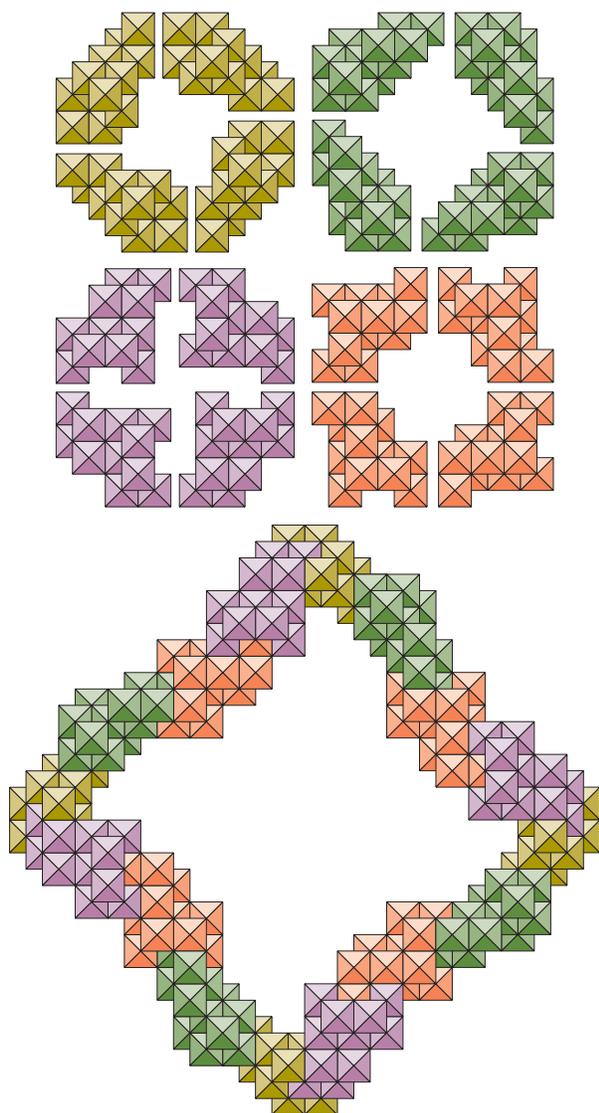


Cyclic peptide of sixteen L-units.

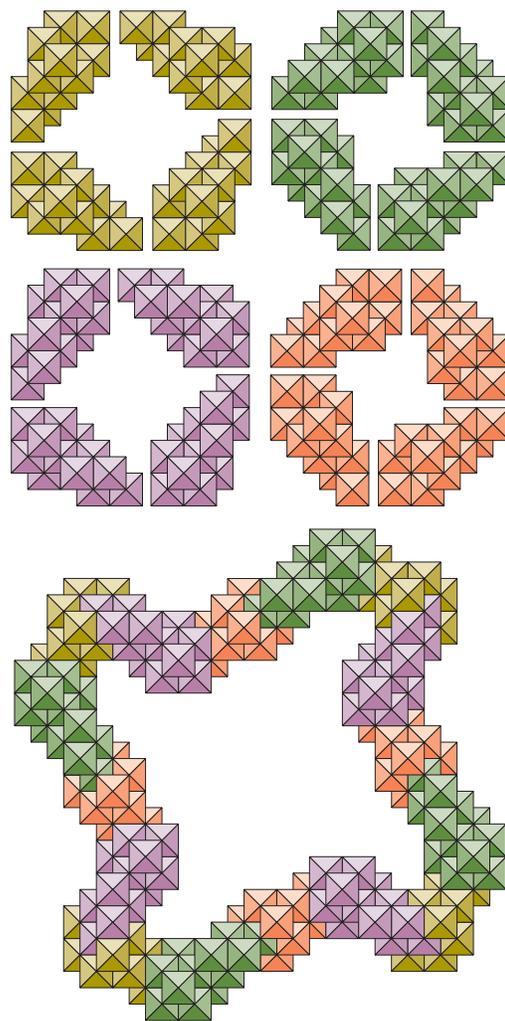
The L-units of the eight L-unit ring appear here¹ with eight additional L-units. The new units are in two sets of four. These sets differ by an inversion. Within each set, the L-units differ by a quarter turn rotation about an axis parallel to the viewing direction.

Blue and orange units are joined alpha helically. Yellow is joined with blue in a beta90 join. Green is joined with yellow in a beta90 join as well. Orange is joined with green in a beta90 join. From alpha helical join to alpha helical join the four L-units constitute a single turn of beta90 helix. The ring is composed of single turns of beta90 helix joined one to the other by an alpha helical join.

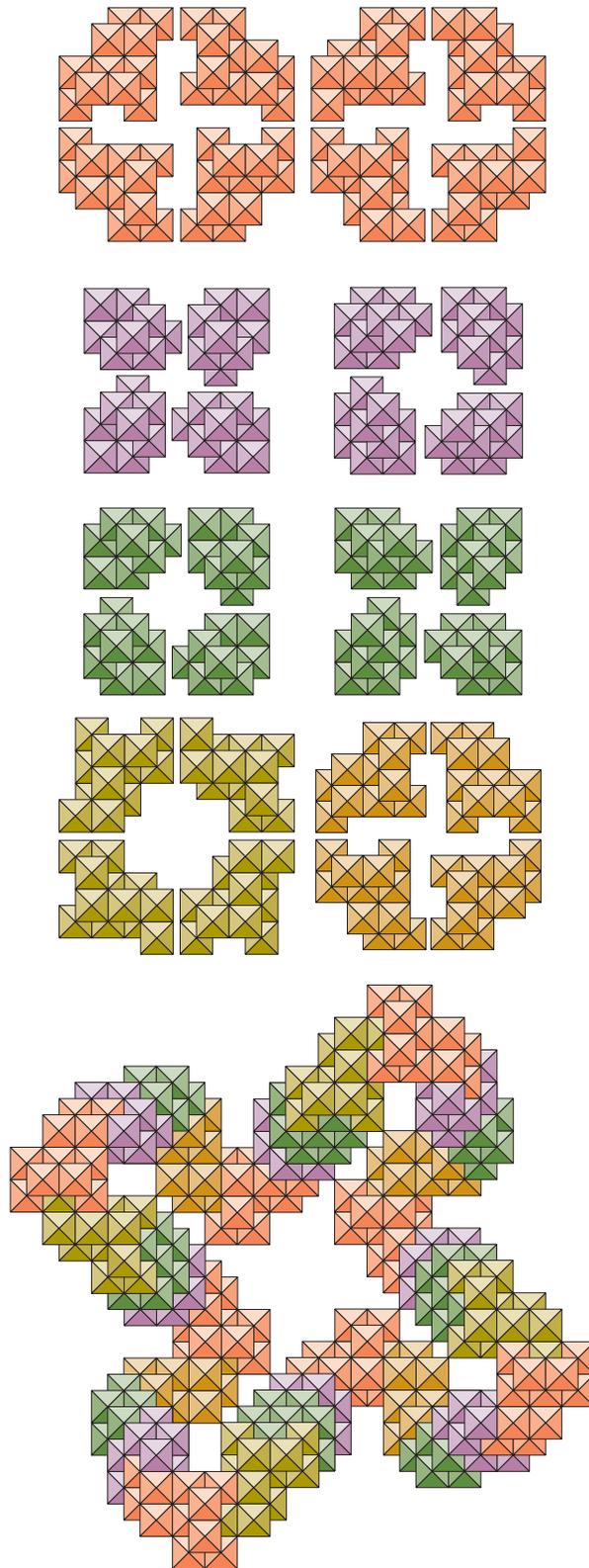
1. Rydon *ibid.* Fig 7.11(b) p. 243.

Cyclic peptide 4LLDD

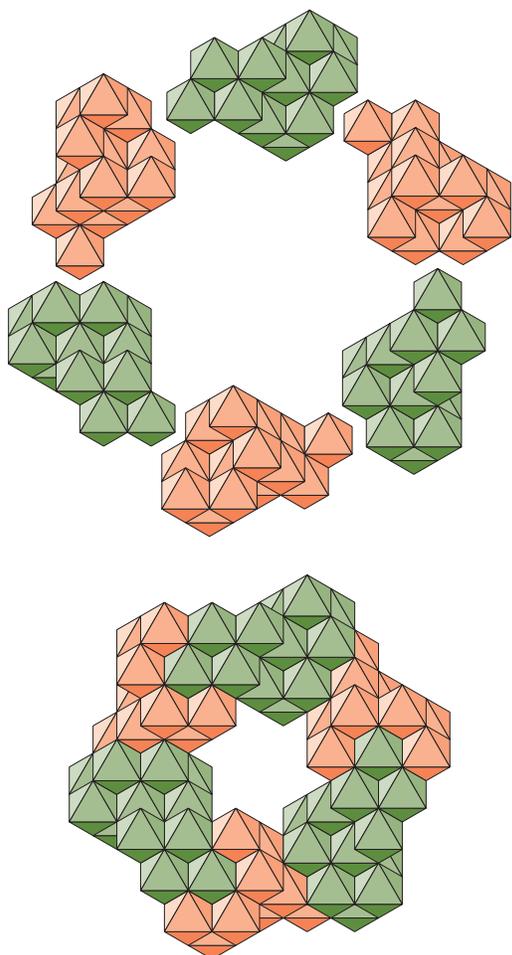
**Sixteen residue ring with vertical axis,
Type A**

Cyclic peptide 4LLDD

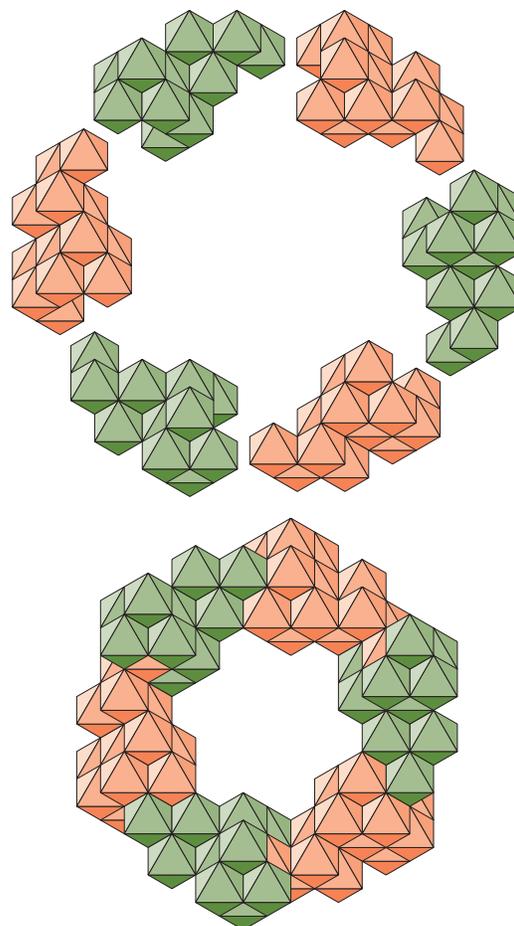
**Sixteen residue ring with vertical axis,
Type B**

Cyclic peptide 4LLD DLLDD**Cyclic peptide 4LLD DLLDD**

The thirty-two residues which form this ring are shown at the top of the figure in eight groups of four each. Red and violet colored residues are D-gly and yellow and green colored residues are L-gly.

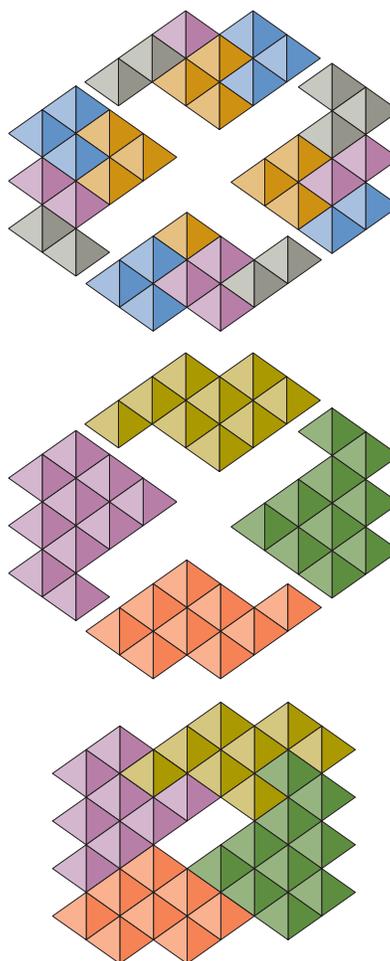
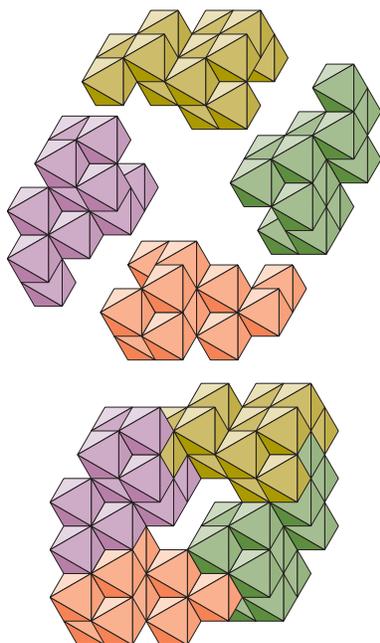
Cyclic peptide LDLDLD type A**Cyclic peptide LDLDLD type A**

The ring is made of two sets of three units each. Those colored green are L-units and those colored red are D-units. Units within a set differ by a rotation of one third of a revolution about the viewing direction. This ring is three He-octa facial diameters in thickness.

Cyclic peptide LDLDLD type B**Cyclic peptide LDLDLD type B**

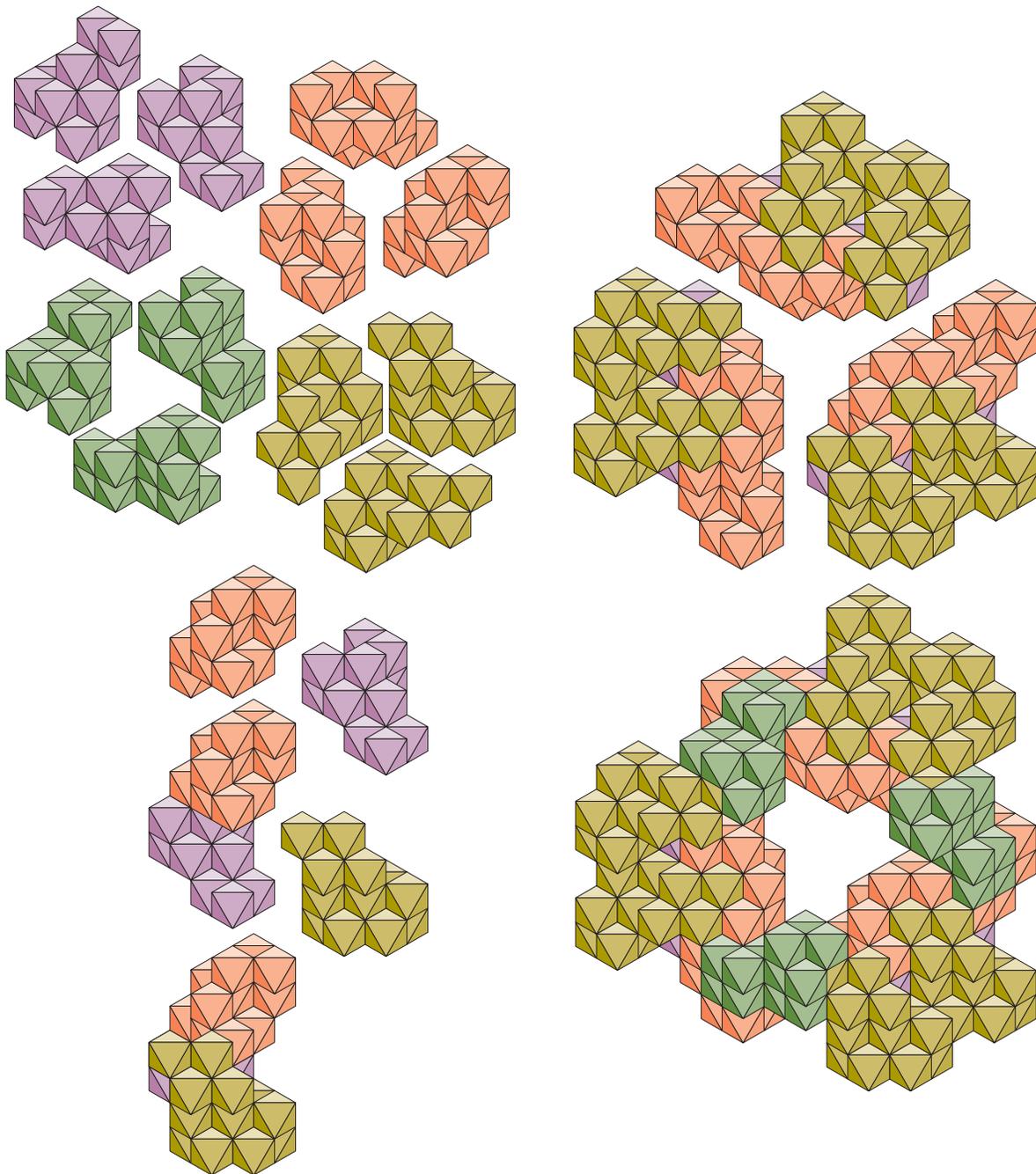
The ring is composed of six main chain units. The green colored units are L-units and the red colored units are D-units. Each set is in the orientation to produce a single turn of alpha helix. The pitch that results from the join of L-unit to D-unit is negated by the pitch which results from the join of D-unit to L-unit. This ring is four He-octa facial diameters in thickness.

Cyclic peptide LLDD



Cyclic peptide LLDD

A pair of L-units joined alpha helically can form a ring with a pair of D-units joined alpha helically. The helical axis of the D-pair is inverted relative to the helical axis of the L-pair. The L-units are colored yellow or green; the D-units are colored violet or red. In the figure on the left the view is parallel to the helical axes. On the right, the view is parallel to the axis of the ring itself. The top group shows the units with their atoms defined by color. The blue colored octas belong to O-atoms, those colored orange belong to NH₂ groups, the gray colored octas belong to the carbonyl C-atom while the violet colored octas belong to the alpha C-atom.



Three alpha helices linked by beta180 chains.

Cyclic peptide, facial axis: Three alpha helices linked by beta180 chains

A ring can be formed using three alpha helices of two turns each which are then joined in a single chain by a main chain unit. Only L-units are used here. The main chain units are shown at the top of the left column of the last figure. Below the four groups of three, the assembly of one turn of one helix is shown. An identical turn extends the helix by joining the yellow unit of one turn with red unit of the other turn. The red, violet, and yellow units form the alpha helixes; the green units are the links between the helixes. At the top of the right hand column of the figure, the three helixes are shown. Below them is the completed cyclic peptide.

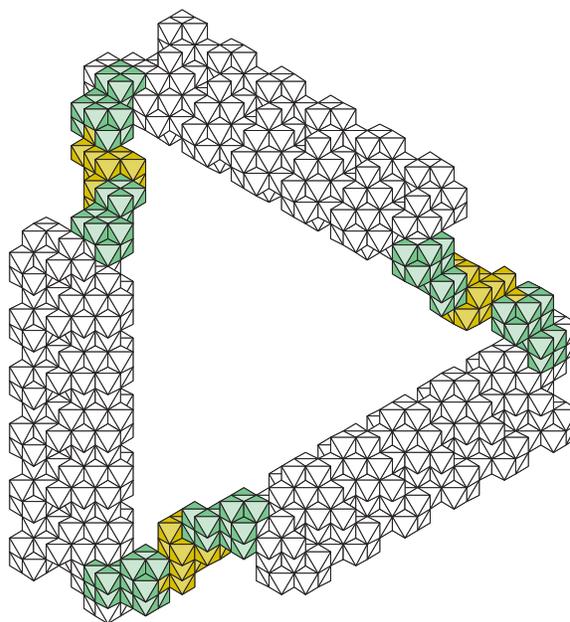
A larger ring formed by extending each of the alpha helices from two turns to six turns is viewed along the threefold axis in the next figure. The link between each pair of helixes becomes a beta180 chain of three units which are colored green or yellow in the figure. The axis of each of the helixes is inclined to the viewing plane. Each of the helixes rises toward the viewer when moving in a clockwise direction around the ring. The beta180 chain descends away from the viewer when moving around the ring in the same clockwise direction.

Each beta180 unit moves two He-octa facial diameters away from the viewer. Each alpha helical turn moves one He-octa facial diameters towards the viewer. To make the connection, the number of beta180 units must be odd. The formula for calculating the number of units is where N is the number of units in the ring, n is any integer. The number of beta180 units per link is $2 \times n - 1$, the number of units per alpha helix is $2 \text{ turns} \times (2 \times n - 1) \times 3 (\text{units/turn})$ and the number of link-helix groups in the ring is three.

$$N = 21(2n - 1)$$

Table 22: Cyclic peptides using three alpha helices

beta180 units	alpha helical turns	total units
1	2	21
3	6	63
5	10	105
7	14	147



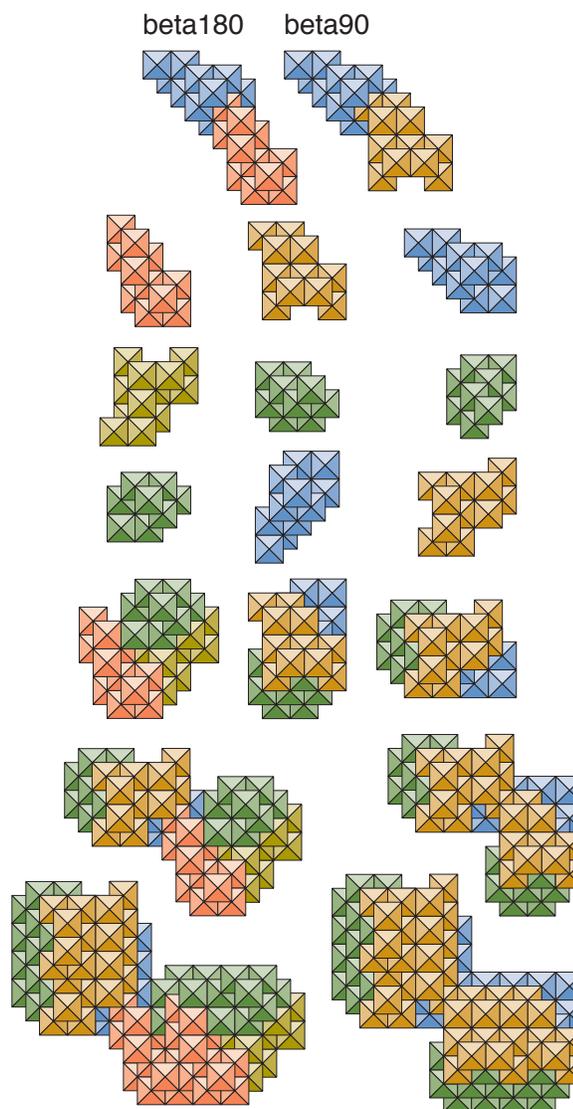
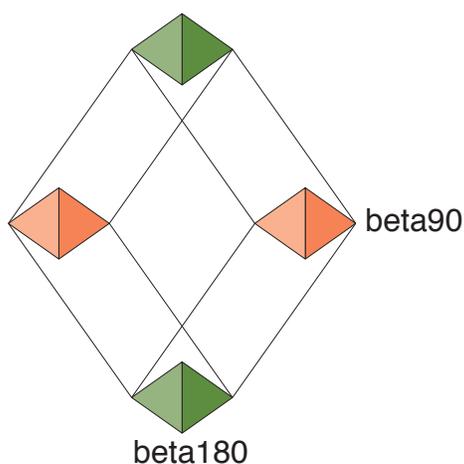
Cyclic peptide: three alpha helices

Direct joining of alpha helices

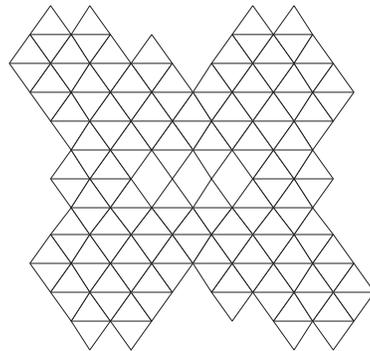
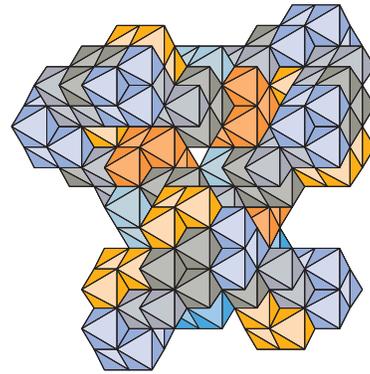
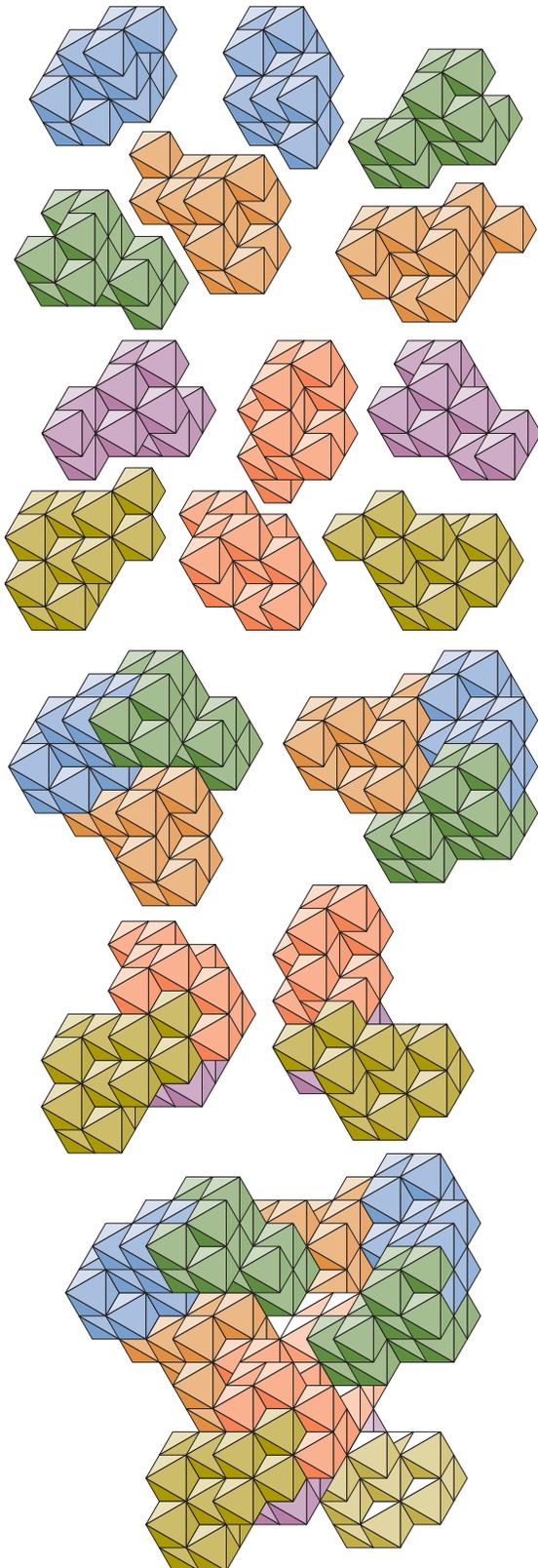
Joins between alpha helices

Alpha helices can join directly in two ways noncoaxial ways. The join between the terminal residues in these cases is either beta90 or beta180. The axes of the joined helices can lie parallel to an edgial plane of the octahedron. This is shown in the diagram below. The lines connecting the vertexes of the red and green octahedra are parallel to the axes of the alpha helices which are in oriented identically to the octahedra which compose the atoms of which the helices are made. The angle between the axes of the helices which are beta90 joined is the same angle as that between the faces of the octahedron at an edge; the angle between the axes of the helices which are beta180 joined is the same angle as that between the faces of the octahedron across a vertex.

At the top of the figure on the right are residues which are beta180 and beta90 joined. Below the two pairs, the three residues in each of the three columns combine to form a turn of alpha helix which appears below them. The turn on the right is combined with either of the two remaining turns in either a beta180 join or a beta90 join. At the bottom, each of the joined helices is extended an additional turn.



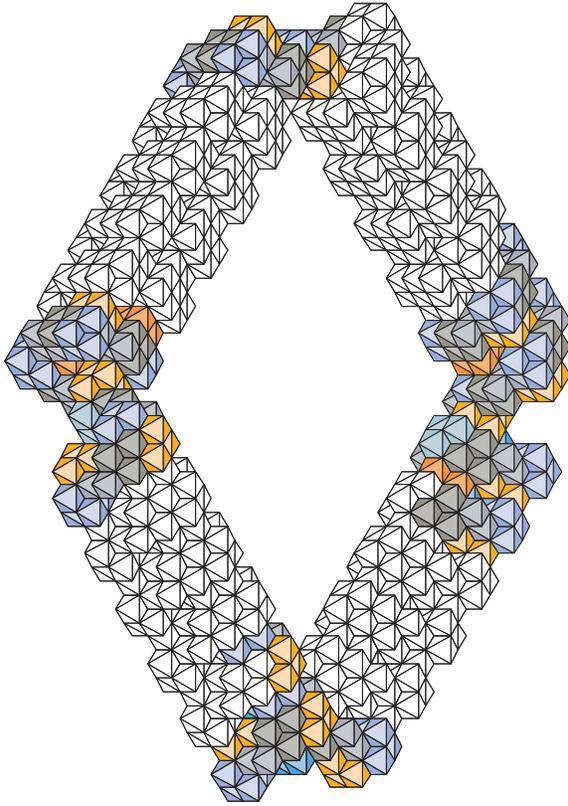
Cyclic Peptide, edgial axis: Four alpha helixes directly joined



Cyclic Peptide, edgial axised: four alpha helixes

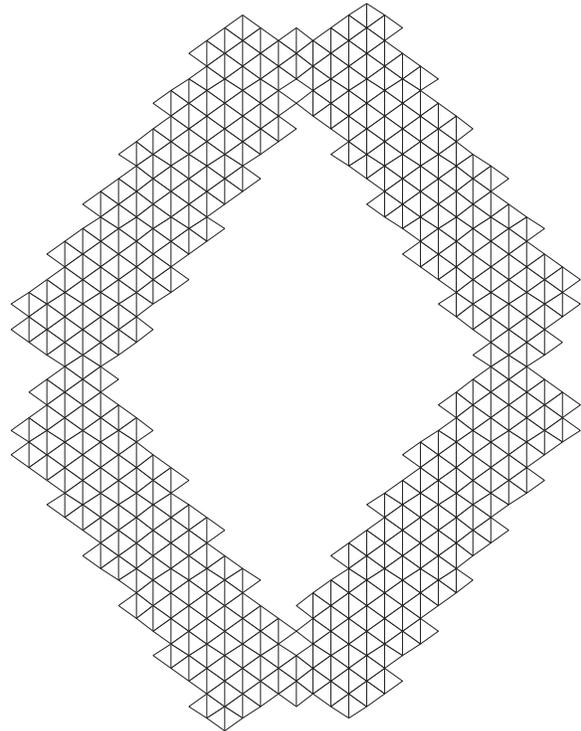
In the figure on the left, the four groups of three main chain units at the top combine to form the four single turns of alpha helix shown in the middle. These are combined to form the cyclic peptide at the bottom.

The assembly is shown at the top on the right colored so as the differentiate the atoms. Just below this figure, the assembly is viewed in a direction normal to the plane of the cyclic peptide.

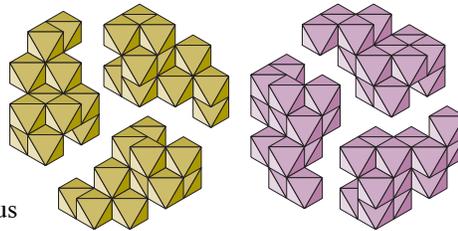


Cyclic Peptide, edgial axised: four alpha helices

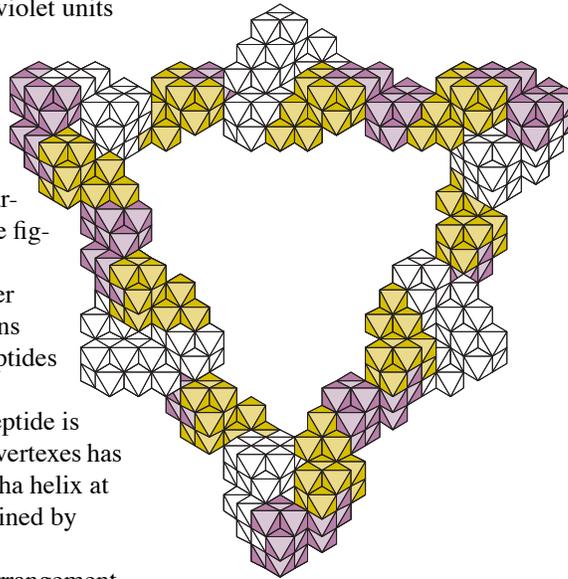
The cyclic peptide depicted here is composed of four alpha helices which are joined the same as the previous cyclic peptide but the helices have been extended several turns. In the view on the left, the atoms of the two turns of each helix which are adjacent to each of the interhelical joins have been colored. The view below is of the same cyclic peptide viewed normally to its plane.



Six alpha helix, facial axis



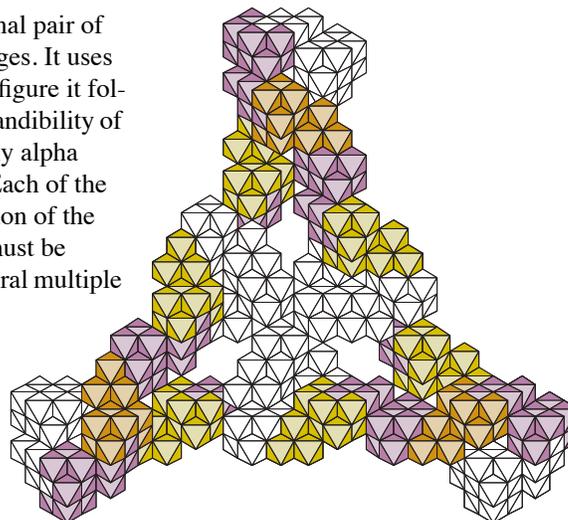
The three yellow units in the previous figure are in the orientations which can produce an alpha helix with its axis parallel to the viewing direction. The three violet units are in orientations which can produce an alpha helix which is inverted relative to that produced by the yellow units. The yellow and purple units can form 32chains whose axes are parallel to the projection plane of the figure. Units having only these orientations and which have either 32chain joins or alpha helical joins combine to produce the cyclic peptides depicted in the next four figures.

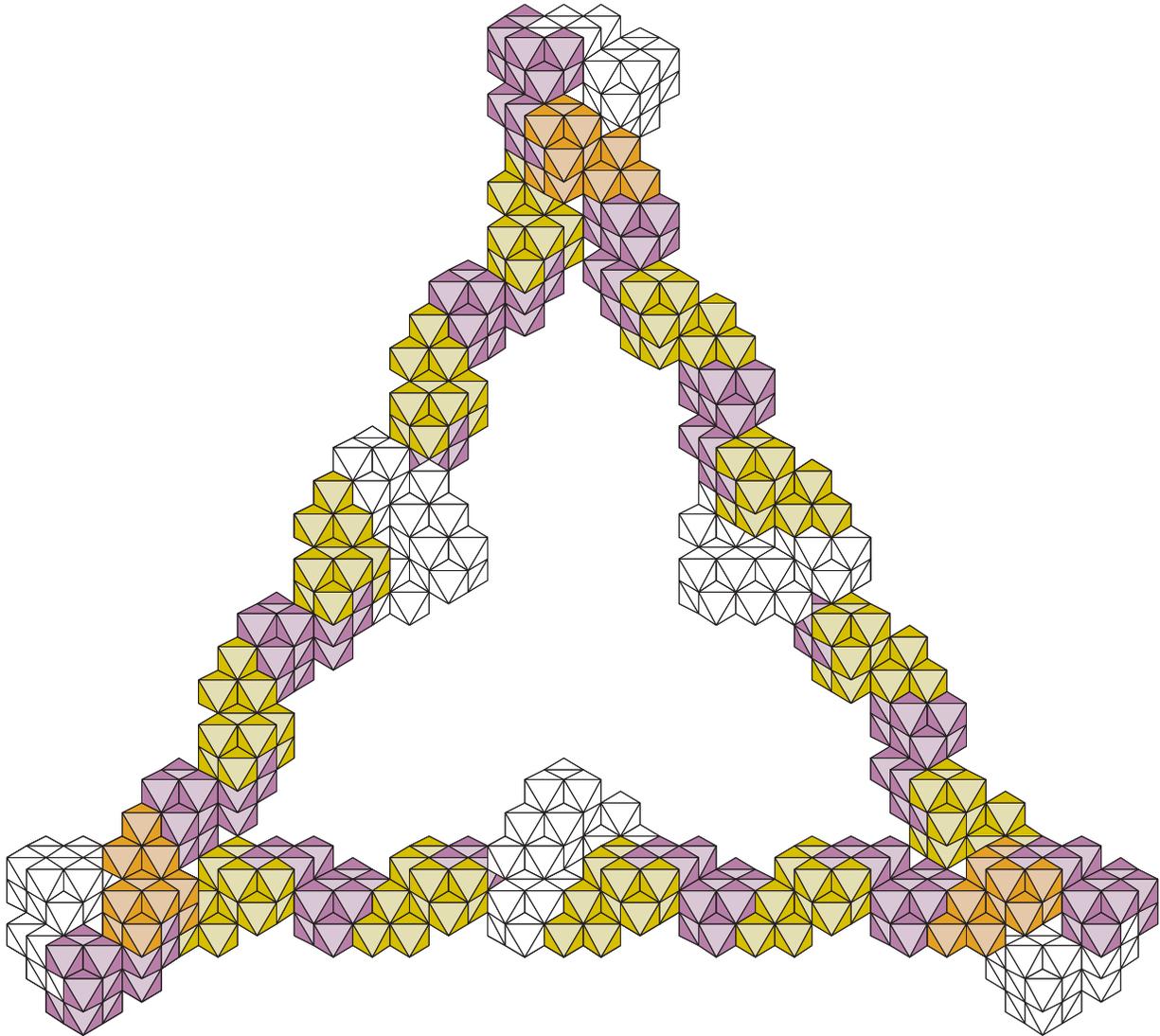


In the next figure, the cyclic peptide is triangular. Each of the triangular vertexes has an alpha helix and there is an alpha helix at each midedge. The helixes are joined by 32chains.

The next figure has the same arrangement of alpha helixes as the previous. The 32chains have been extended.

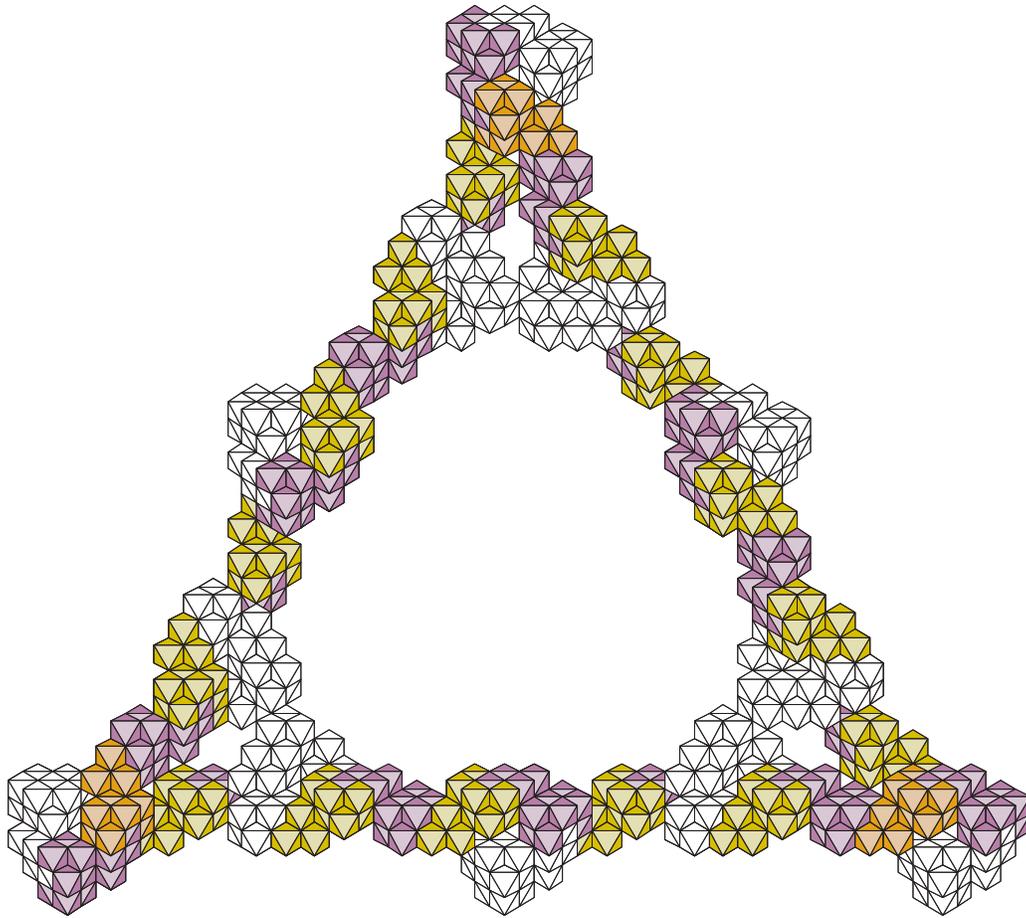
The last figure adds an additional pair of alpha helixes each of its three edges. It uses the same vertexial helixes as the figure it follows. These figures show the expandibility of the cyclic peptides which use only alpha helixes connected by 32chains. Each of the figures is extensible in the direction of the axes of the alpha helixes. Each must be extended by a full turn or an integral multiple thereof.





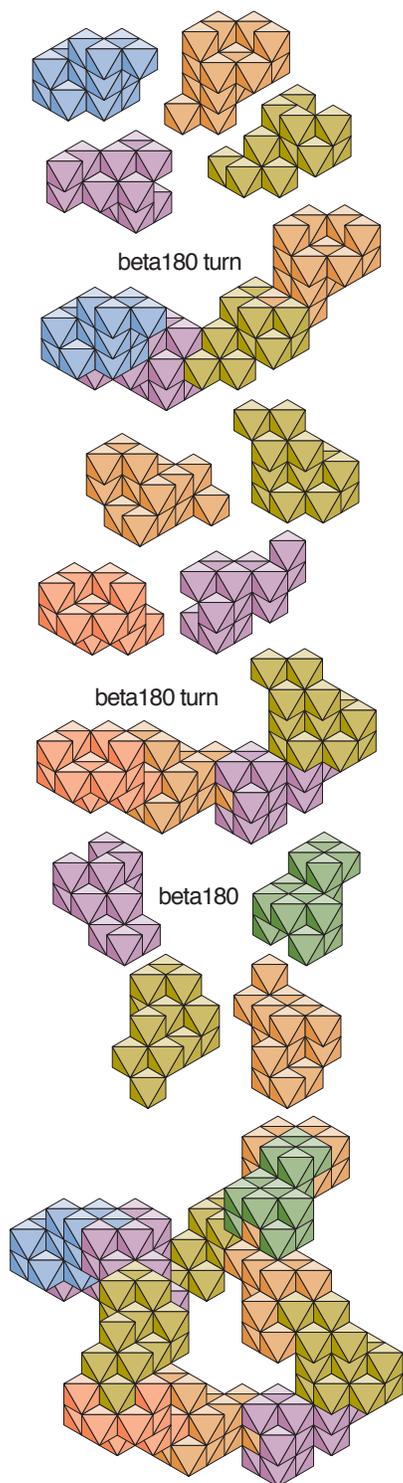
Cyclic peptide: six alpha helices

Twelve helix, facial axis



Cyclic peptide: twelve alpha helices

Cyclic peptide, sheet forming.



Cyclic peptide, sheet forming

This ring incorporates a pair of antiparallel beta180 chains whose separation is sufficient to accommodate a third beta180 chain to form a pleated sheet. At the top of the figure is a group of four units which combine to form the beta180 turn just below them. This is followed by a second group of units which form a second beta180 turn. Beneath the second turn are two groups of two units each which form the links between the two turns. The combined assembly is at the bottom of the figure.

See "Cyclic peptide sheet joined with beta chain" on page 327

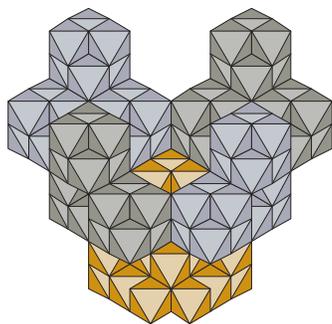
HEME

In order to model the heme group, the structure suggested by the chemical symbols of the chemistry texts must be interpreted into a structural association of octahedral atoms:

- there is a suggestion of fourfold symmetry in the arrangement of the N-atoms and the pyrrole rings which include them;
- the N-atoms are adjacent to the central Fe-atom.

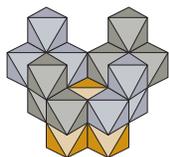
Pyrrole ring

The pyrrole ring is best realized as a C_6 -ring with one of the vertical C-atoms removed and an N-atom substituted for the horizontal C-atom opposite the vacated vertical position.



Pyrrole ring with N-atom at bottom, epn-octa detail.

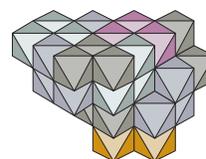
This will be represented in the following figures in He-octa detail.



Representation of pyrrole ring in He-octa detail

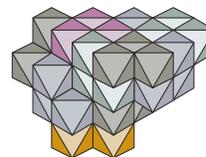
Pyrrole pair

A ring similar to the pyrrole ring could include a C-atom or an O-atom in place of the N-atom. This can join with the pyrrole ring to produce a stable assembly in which a horizontal C-atom of one ring fills the vertical C-atom vacancy of the other ring. This can happen in one of two ways. The next figure shows the pyrrole ring in the same orientation as the previous figure and a similar ring joined with it in the described manner. The added ring is



Pyrrole ring pair, left join

rotated 180° about an axis parallel to one of the vertexial diameters of the He-octa. It is slightly to the *left* of the pyrrole ring. In the next figure, the two rings have the same orientations but the added ring is slightly to the *right* of the pyrrole ring.

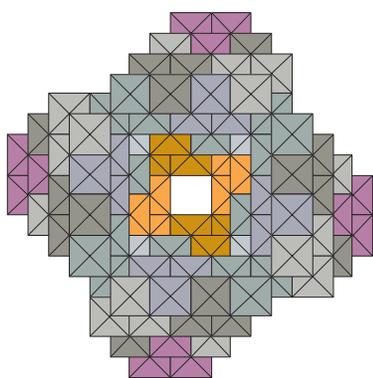


Pyrrole ring pair, right join

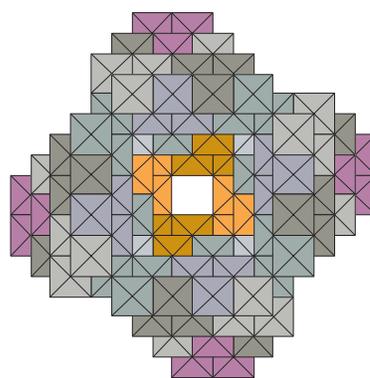
Tetrapyrrole

Four ring pairs of either hand can form a fourfold ring. The top left figure is the ring formed by leftly joined pairs. The view is parallel to the fourfold axis. The top right figure shows the ring formed by rightly joined pairs. The two ring assemblies have similar features. The bottom side is vertexially planar as can be

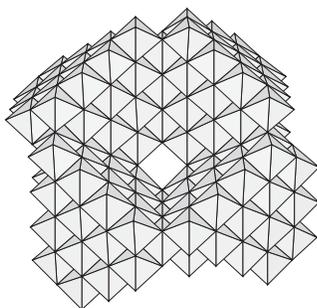
seen in the lower right figure. There is a square aperture in the center of the assembly which will just accommodate an edgial equator of a He-octa. The lower left figure shows the other side of the ring which has a pyramidal concavity which is octahedral. This feature provides the utility of the assembly as a holder of atoms. The atom fits snugly in this concavity with its He-octa occupying the vertex of the pyramid.



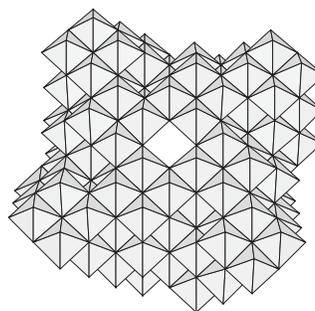
Ring formed by four pairs of leftly joined pyrrole rings.



Ring formed by four pairs of rightly joined pyrrole rings.

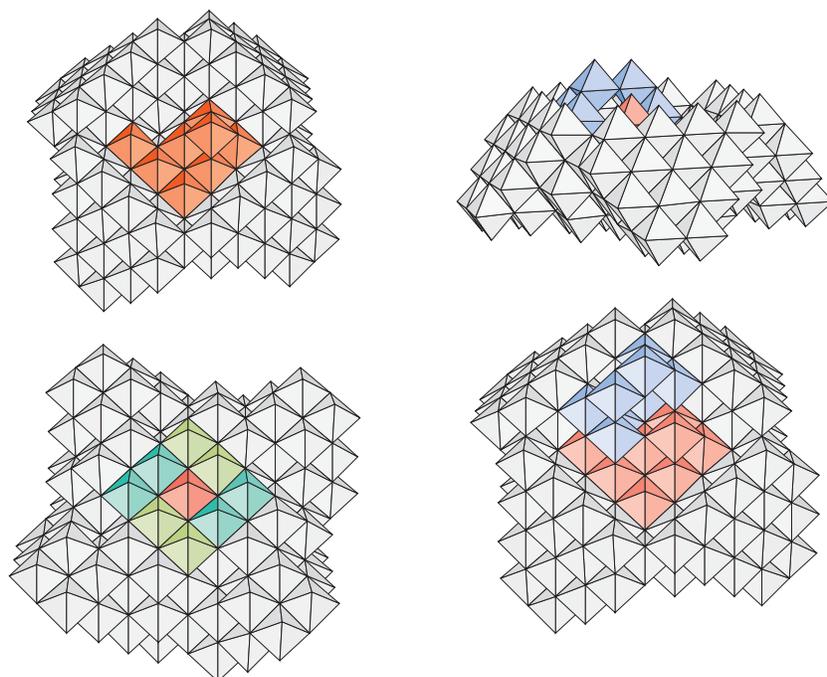


Pyrrole ring assembly, concave side.



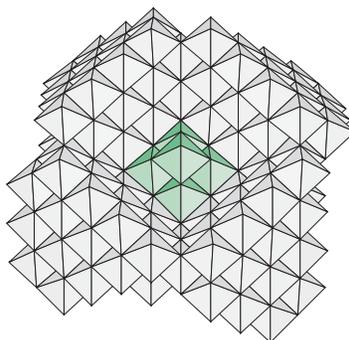
Pyrrole ring assembly, planar side

Heme and chlorophyll groups



Heme group

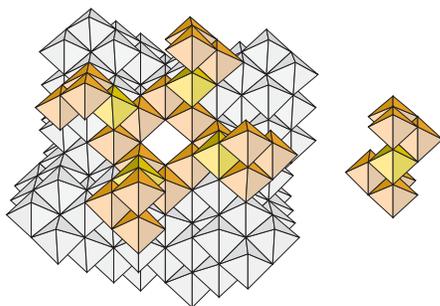
In the above figure, on the upper left there is a pyrrole ring assembly with an Fe-atom colored red occupying the concavity, as in the heme group. The obverse view just below it shows the He-octa of the Fe-atom at its center colored red. Two He-octas of each of the four N-atoms have been colored green. On the right, there are two views of the same group but with the addition of an O₂-group, as in oxy-hemoglobin. The top view shows the planar nature of the assembly. He-octas of the O₂ group protrude above the rim.



Chlorophyll group

The chlorophyll ring carries a Mg-atom which is colored green.

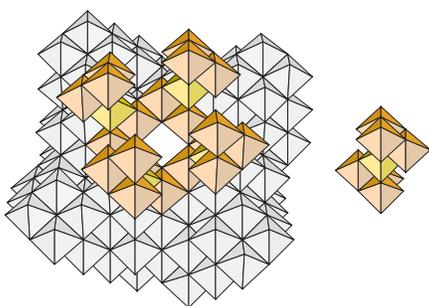
Connections to tetrapyrroles



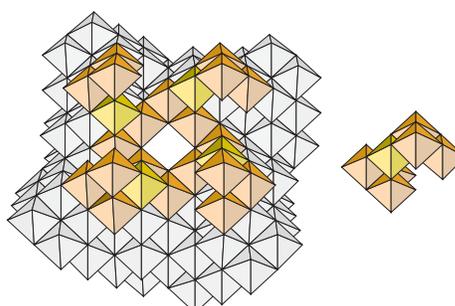
Pyrrole ring assembly: N-atom attachment at 120° clockwise

N to N connections

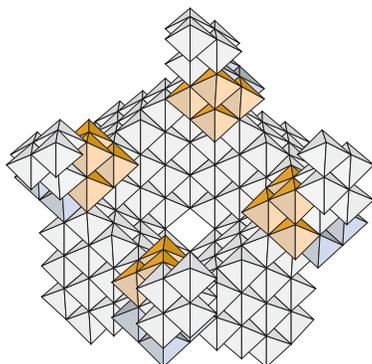
On the planar bottom, the four N-atoms are accessible for triplet-joins. This type of join can be one of three types which differ by the rotation between the pairing atoms. The next figure shows the assembly with four N-atoms joined to the N-atoms of the assembly and the inset shows the orientation between the joined pair. The next orientation between the joined N-atom pair is 120° counter-clockwise relative to the previous N-atom pair join. And the third type of N-atom pair join is 120° clockwise to the first pair join.



Pyrrole ring assembly: N-atom attachment, 0°

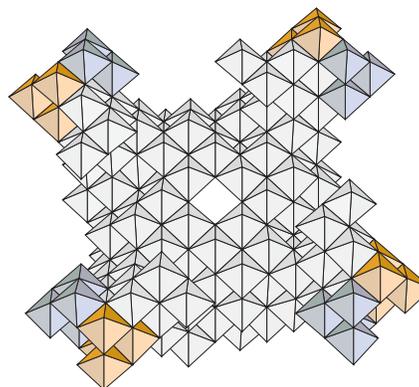


Pyrrole ring assembly: N-atom attachment at 120° counter-clockwise.



Pyrrole ring assembly: Gly attachment to C-atoms of rim

There are four places on the rim around the concavity where the NH₂-O group of a protein main chain unit can join to a C-atom of a pyrrole ring. This is shown in the next figure, with the protein units' beta chain axis normal to the plane of the ring assembly.



Pyrrole ring assembly: Gly attachments to C-atoms of planar surface.

Each of the four rings which are paired with the pyrrole rings might have a C-atom which could join cleftly with a C-atom of the protein unit. In the next figure, the C_α of the protein unit is cleftly joined to the C-atom of the ring.

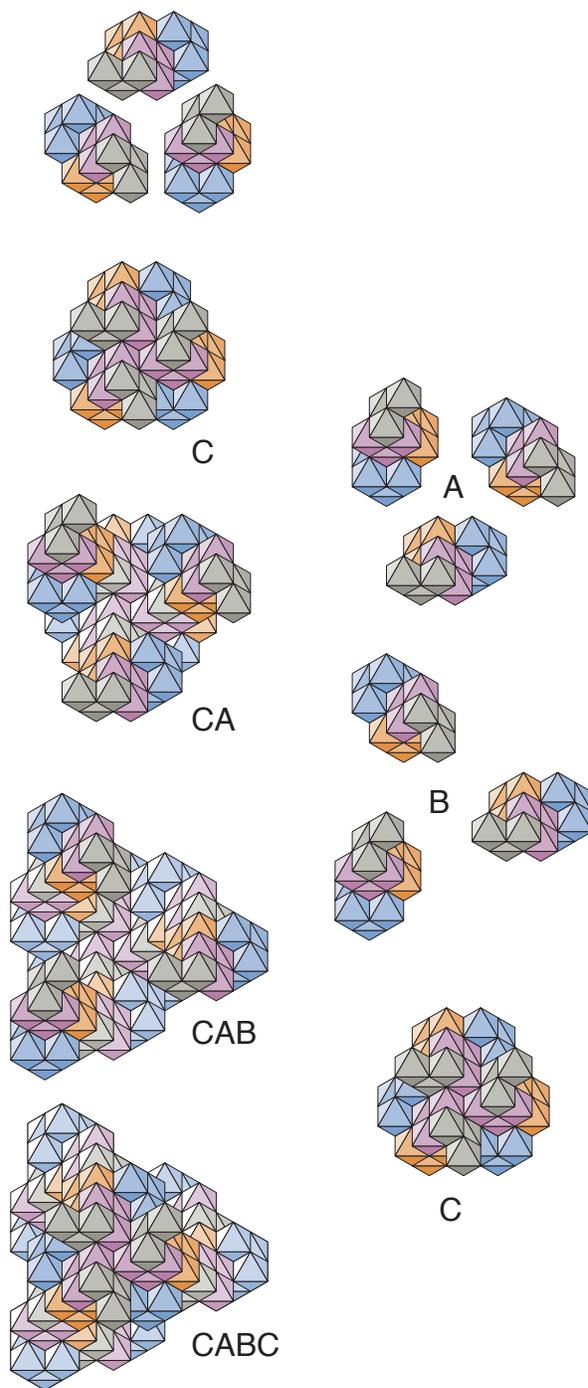
COLLAGEN

Helices composed of octahedrally crystalline atoms do not wrap around each other. They are neither wire nor rope. The epsilon helix fits well with the threefold pattern of the protein chain and the description of it being more extended than the alpha helix. The rise per residue in the so-called superhelix is given as 2.9Å and this is consistent with the dimensions derived from the data used by Pauling and Corey for the alpha helix and the pleated sheets. The rise for the alpha helix is one He-octa facial diameter; the rise for the epsilon helix is three He-octa facial diameters. The edge length is 1.1825Å the facial diameter is $\sqrt{2/3}$ times the edge length and there are three facial diameters per rise.

$$\text{rise} = 3 \times \sqrt{\frac{2}{3}} \times 1.1825 = 2.896$$

The glycine residues are aligned parallel to the helical axis. This circumstance permits the three helices to abut one another once every turn.

The figure shows the relationship between the main chain units of the three helices. No side chains are depicted. At the top, three main chain units are shown in the orientations which occur in the formation of the three helices. They differ by a rotation of one-third revolution about the viewing direction. The residues are female end away from the viewer. In the right hand column the residues are in three groups of three. Each group shows the main chain units of the three helices in the orientations and relative positions which they will have at each step of the formation of the helices. These groups are then stacked in a direction towards the viewer beginning with the C-group. The A-group is added to the stack to form three helices of two residues each and labeled CA. Then the B-group is added to form the CAB helix. A second C-group is added to form the group CABC, three epsilon helices of four main chain units each.



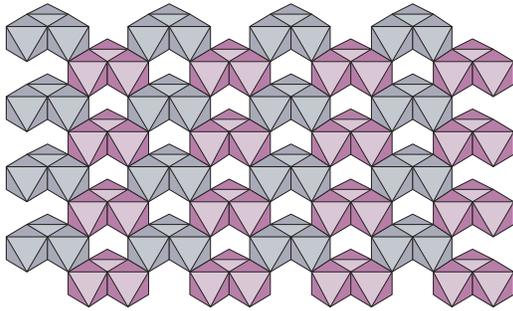
Three epsilon helices linkable by C-atom.

At the top of the figure three main chain units are linkable by a C-atom. They are shown joined in the first step of a three epsilon helical assembly. The assembly progresses by the addition of the layers shown in the right column.

IMMUNOGLOBULIN

Crystalline associations

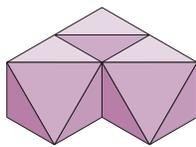
Crystal form A



Immunoglobulin: crystalline array.

Planar array of triplet octahedra in crystalline order suggested by an electron micrograph-graph of a crystal of antibody molecules.

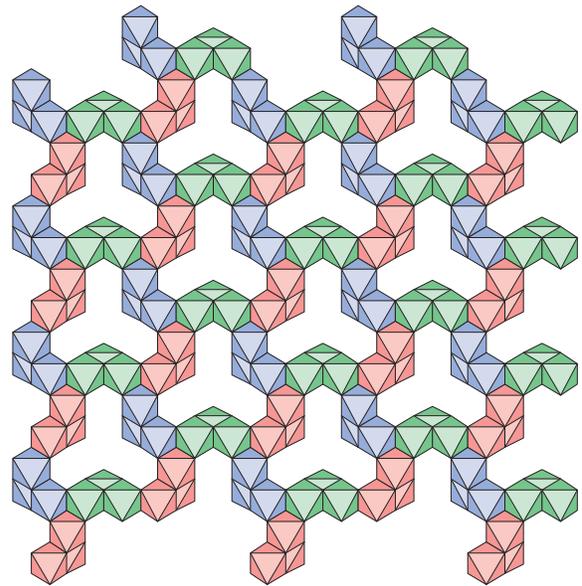
The above figure shows a planar array of octa triplets which is suggested by an electron micrograph of a crystal of antibody molecules.¹ The CFU of the above figure is shown below.



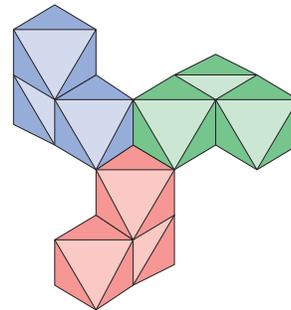
Crystal form B

A planar array of octahedral triplets in crystalline order suggested by a two dimensional

crystallization of antibodies² is shown below.



The CFU is a triplet of triplets and confirms the conformation of the immunoglobulin molecule as an octahedral triplet.



The antibody molecule

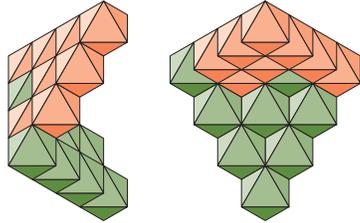
The antibody molecule is described³ as having twelve homologous domains which are divided into three groups of four each. The crystalline arrays show the molecule to be

1. Lubert Stryer *Biochemistry* 2d ed., W.H. Freeman, 1981, Fig. 33-1, attributed to <L. W. Labaw and D. R. Davies. *J. Ultrastruct. Res.* 40(1972):349.>, p. 789

2. Egidijus E. Uzgiris, Roger D. Kornberg, *Nature* v. 301, January 13, 1983, pp. 125-129

3. Alberts *et al.*, *Molecular Biology of the Cell*, Garland, 1983, p. 965

equivalent to an octahedral triplet. Schematic drawings¹ and the description of the molecule indicate that each domain could act as a facial panel for an octahedral assembly. The two domains in each of the three octahedral areas which belong to the same chain share an edge.

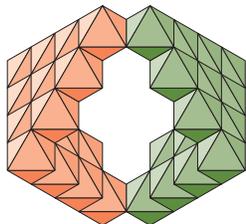


IgG molecule: Domain pairing.

The figure shows two views of an octahedral assembly which represents the pairing of two homologous domains of the IgG molecule. The red colored octahedra represent one domain and the green octahedra represent another domain. The groups are identical.

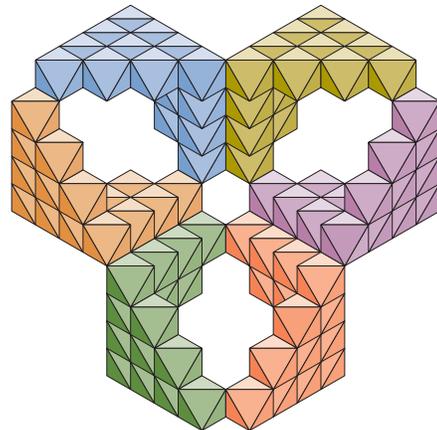
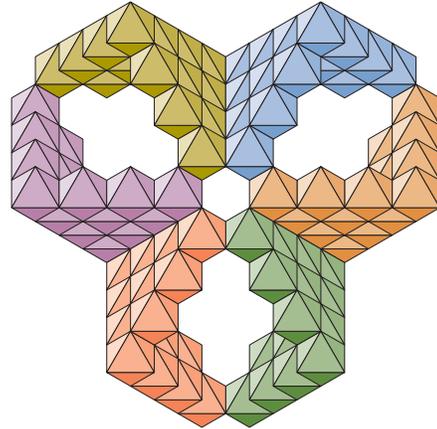
Two views a representative assembly are shown. The assembly is composed of two identical units of eight octahedra each which are colored red or green. Each group of eight octahedra represents a domain of a chain. Each is an assembly which is facially planar.

The two paired domains in each octahedral area join so that the edgial join of one pair is be



opposed tot hat of the other pair. The opposed pairs define the eight faces of the octahedron.

Four faces are defined by the faces of the octahedra in each domain. The other four faces are defined by the faces of the octahedra along the edges of the assembly. Three such assemblies join to form an octahedral triplet which is seen below in two views which differ by a half turn about an axis normal to the top of the page.



IgG molecule: octahedral structure

The figure shows two views of the IgG molecule which differ by a rotation of one half turn about an axis parallel to the edge of the page.

1. Lubert Stryer *Biochemistry* 2d ed., W. H. Freeman, 1981, Fig. 33-19 <schematic drawing of an IgG molecule>, p. 801

VIRUS

A number of viruses have icosahedral enclosures which house the molecules which encode their construction. Their octahedral structure is similar to that of the fivefold quasi-crystals. The depictions herein are based on electron micrographs and their descriptions which are available over the internet or from print sources.

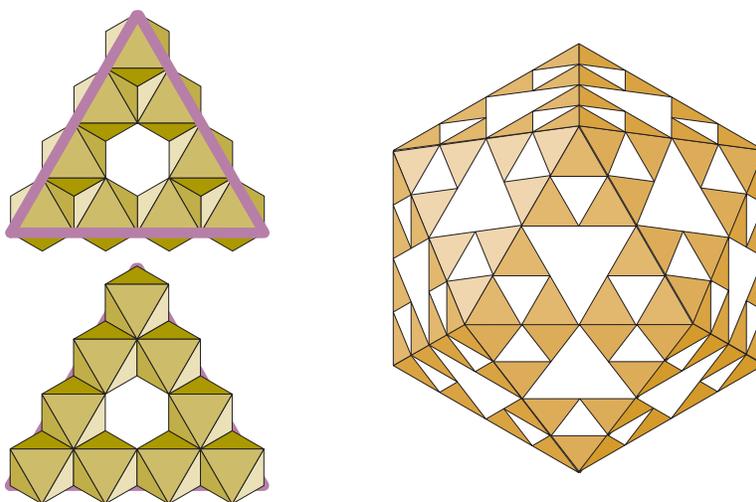
Capsid with sixty capsomers

An icosahedral facial panel can be formed by a structural assembly consisting of three triplets of identical octahedra. The top view on the

left side of the next figure shows the panel as viewed along the facial radius from the centroid of the icosahedron. The perimeter of the face of the icosahedron is superimposed upon the octahedral panel. The view beneath it is of the panel from outside and along the facial radius towards the centroid of the icosahedron. Here, the panel is superimposed upon the face of the icosahedron.

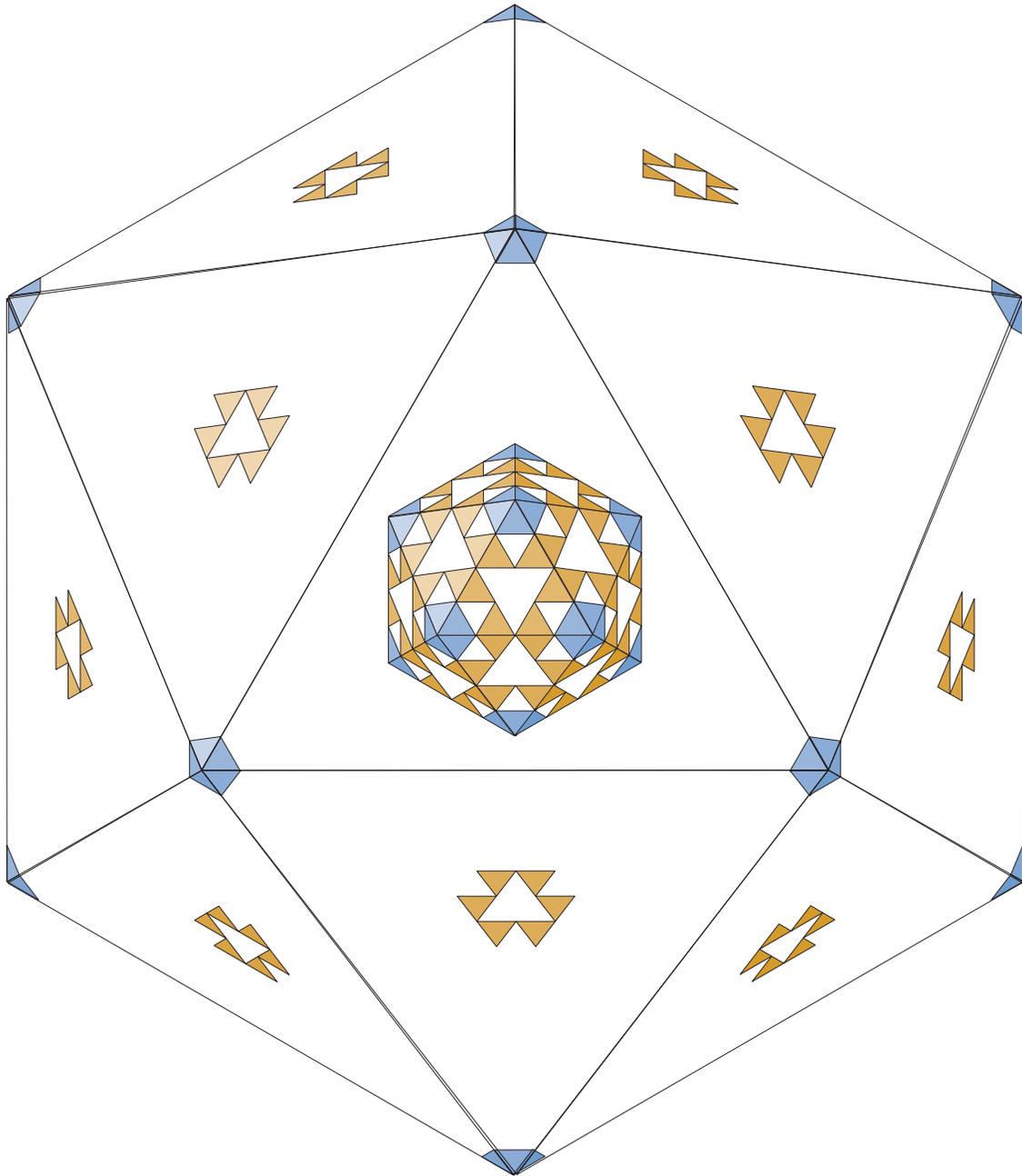
The icosahedron defined by the octahedral panels is on the right side of the figure. The view here is parallel to a facial diameter. Each of the octahedral faces which define the visible faces of the icosahedron is shown in orange.

The next six pages are devoted to illustrations of the relationship of spokes to the icosahedral enclosure.



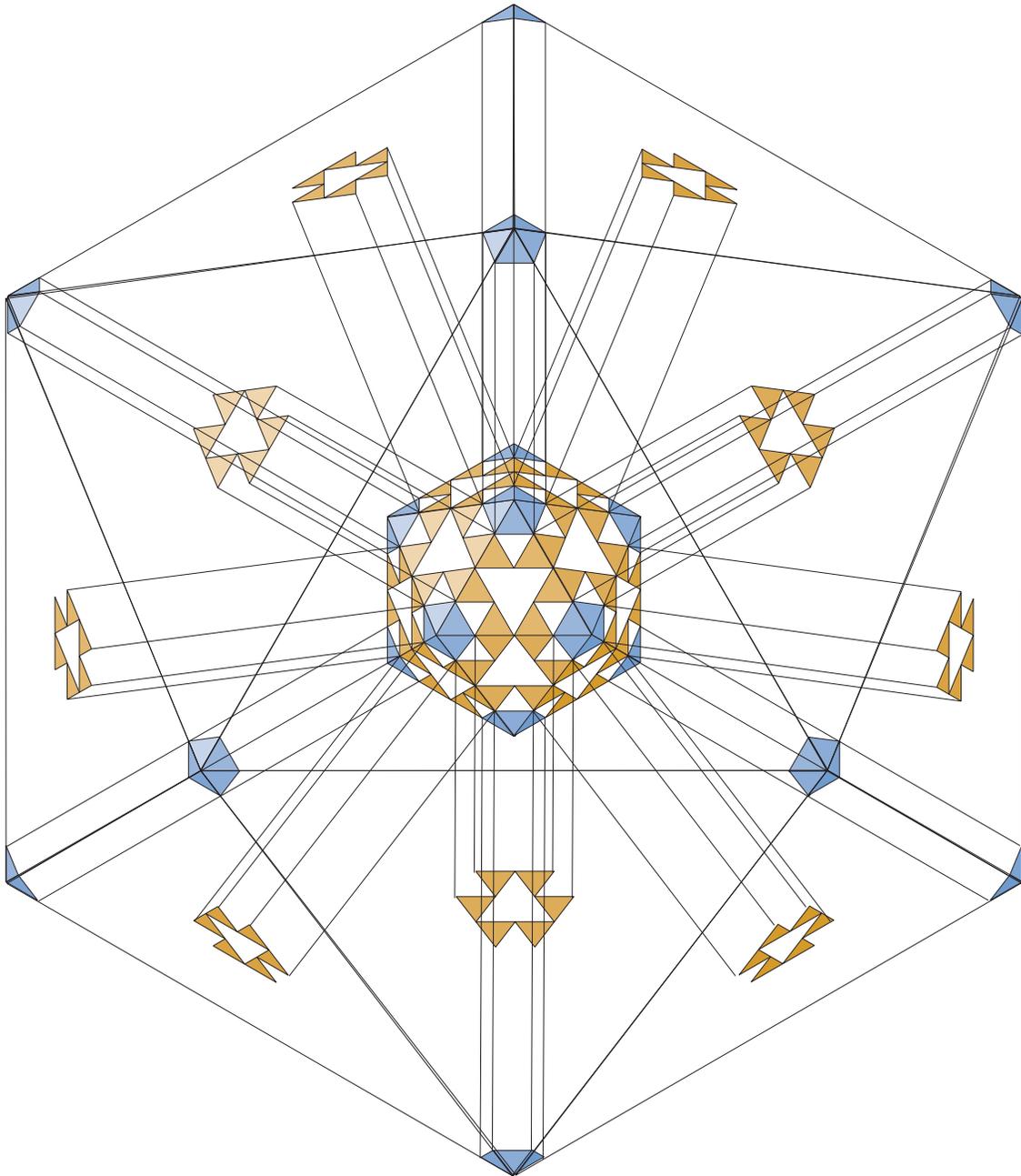
Viral capsid: sixty capsomers.

On the left, the figure shows the octahedral panel from in two views relative to the centroid of the capsid. The violet triangle represents the icosahedral face defined by the octahedral panel. The locations of the octahedra which define the icosahedral faces are shown in orange on the right.



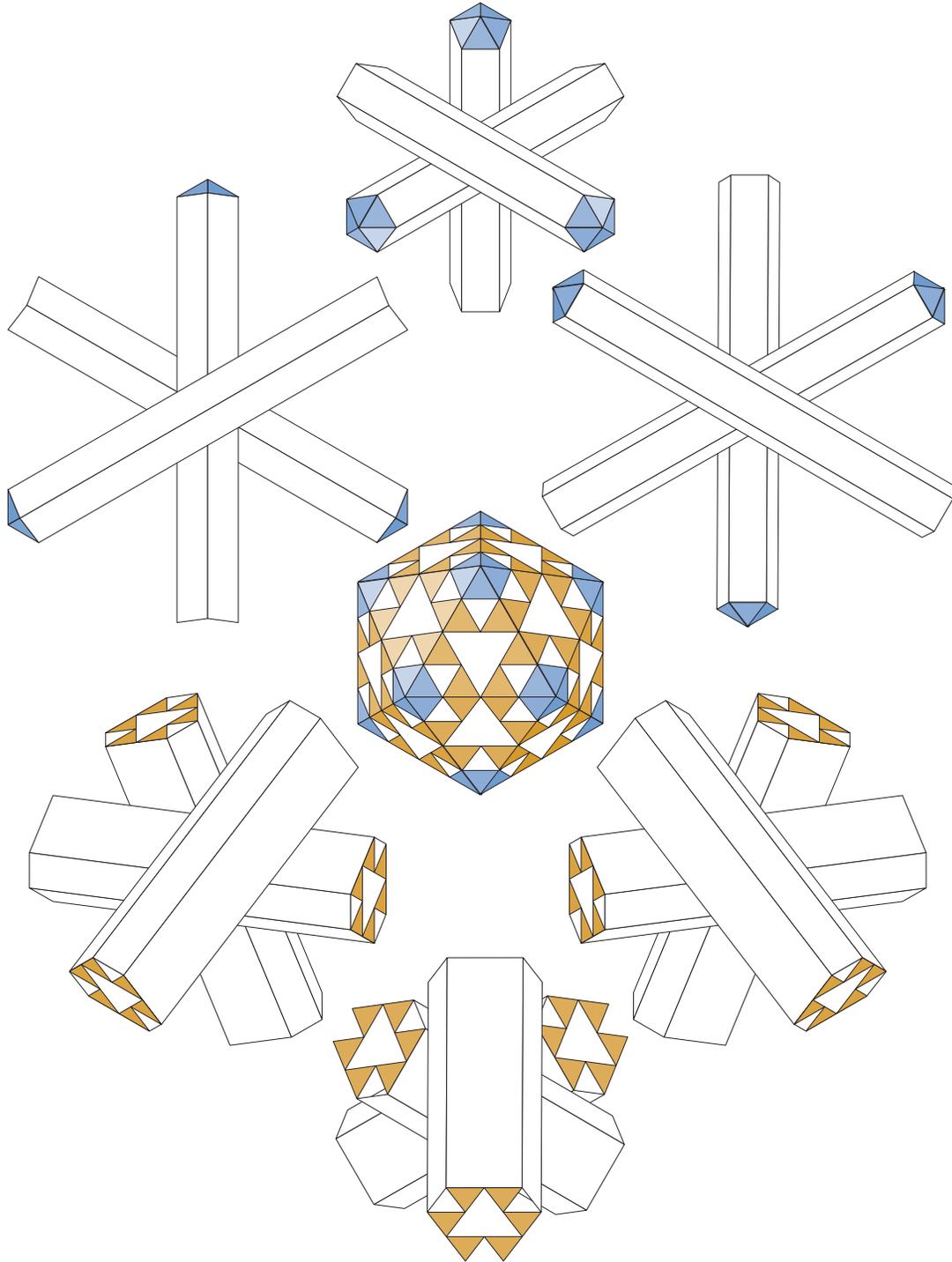
Viral capsid: Spoke distribution, figure A

The octahedra can be divided into two sets—twelve groups of five each at the icosahedral vertexes and twenty groups of six each on the icosahedral faces. Each of the groups is the foundation for a spoke assembly. This is shown in the next figure where the octahedral faces are projected radially outward upon a larger icosahedron which is concentric with the base icosahedron and of the same orientation.



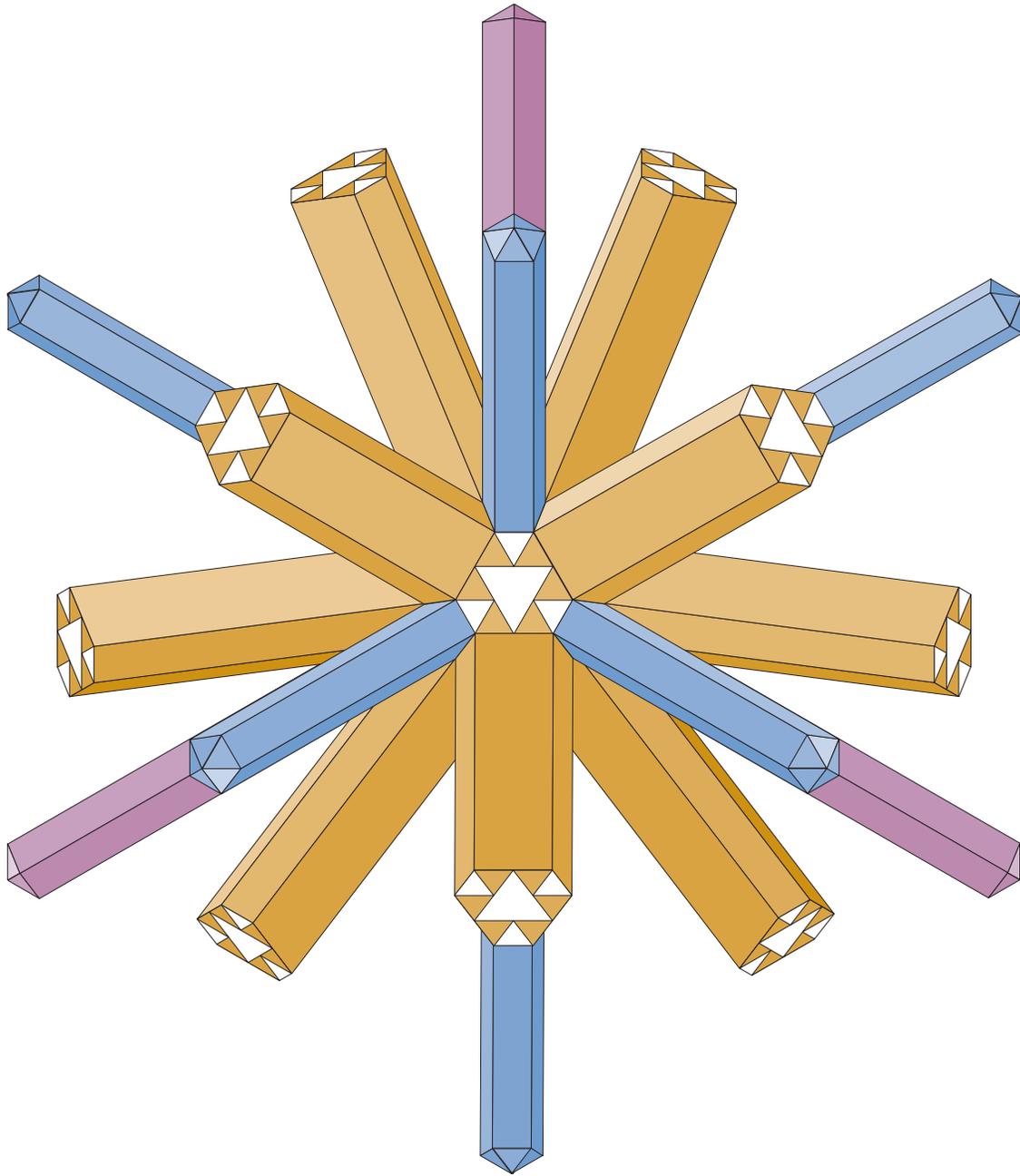
Viral capsid: Spoke distribution, figure B

The pentagonal groups are colored blue and the hexagonal groups are colored orange. The octahedral facial groups are connected by lines which represent the prism faces of spokes extending from the inner icosahedron to the outer icosahedron.



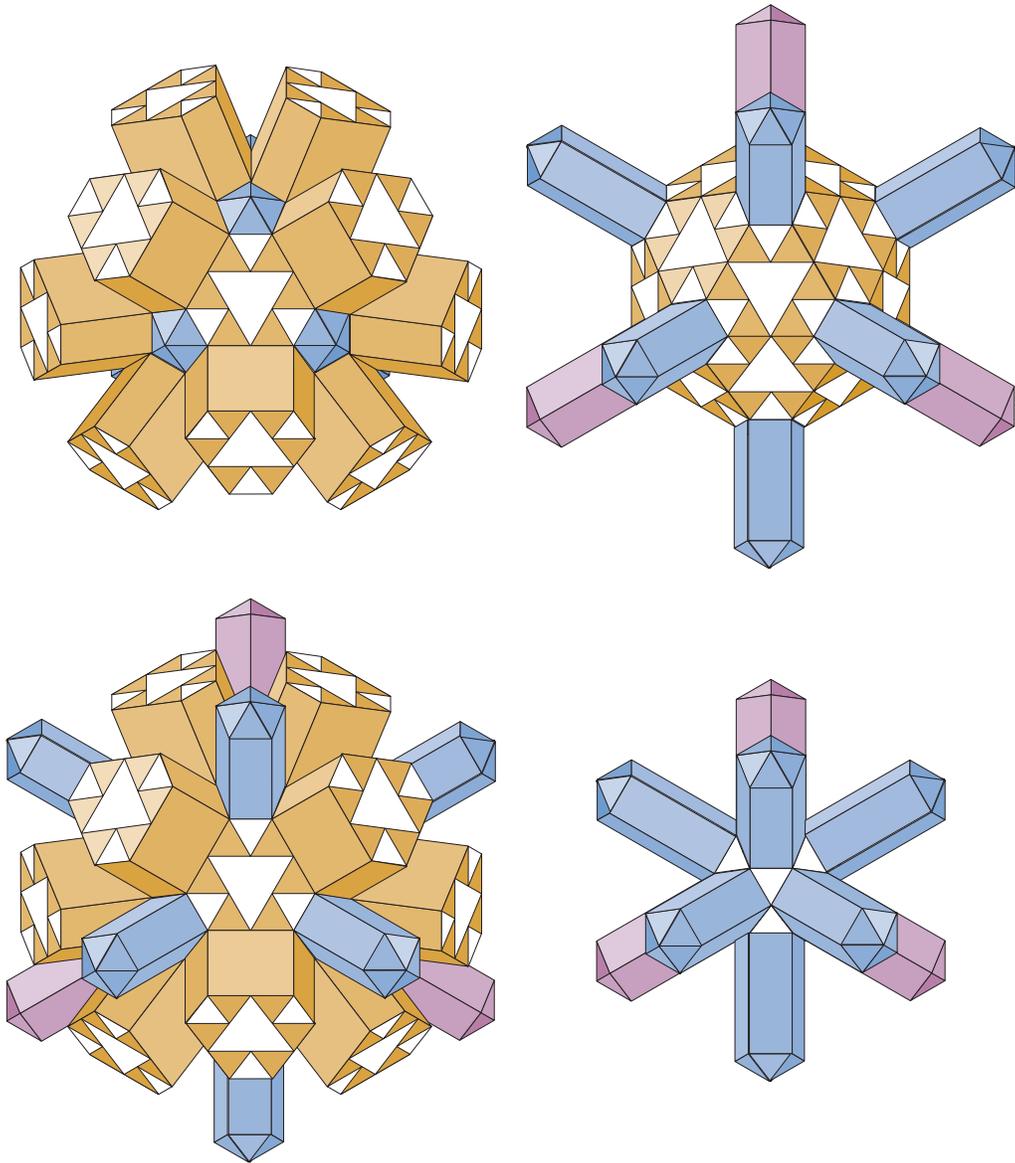
Viral capsid: Spoke distribution, figure C

The spokes which are formed are shown in groups of three, according to their projected appearance, surrounding the base icosahedron. The pentagonal spokes are identical and the hexagonal spokes are identical.



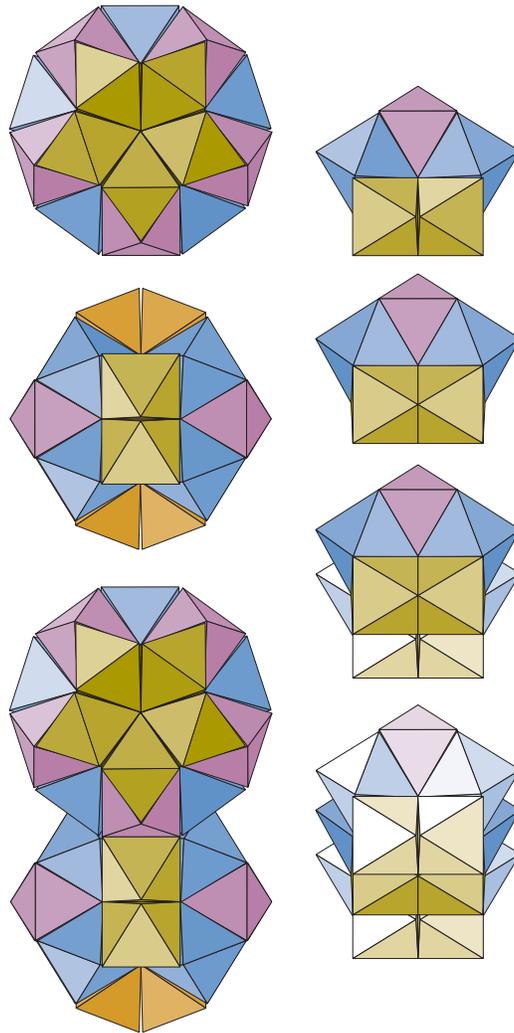
Viral capsid: Spoke distribution, figure D

The spokes are mounted on the base icosahedron and the prisms are colored.



Viral capsid: Spoke distribution, figure E

The spokes which appear in this figure are shorter. The assembly in the upper left has only hexagonal spokes. The assembly in the lower right has only pentagonal spokes. The assembly in the lower left has both hexagonal spokes and pentagonal spokes. The assembly in the upper right has the same spokes as the assembly in the lower right mounted on a smaller icosahedron.



Pentagonal spokes: Icosidodecahedral assemblies of octahedra
Rotation of octahedral units in pentagonal spokes due to joining requirement of the icosidodecahedral units.

Spoke assemblies.

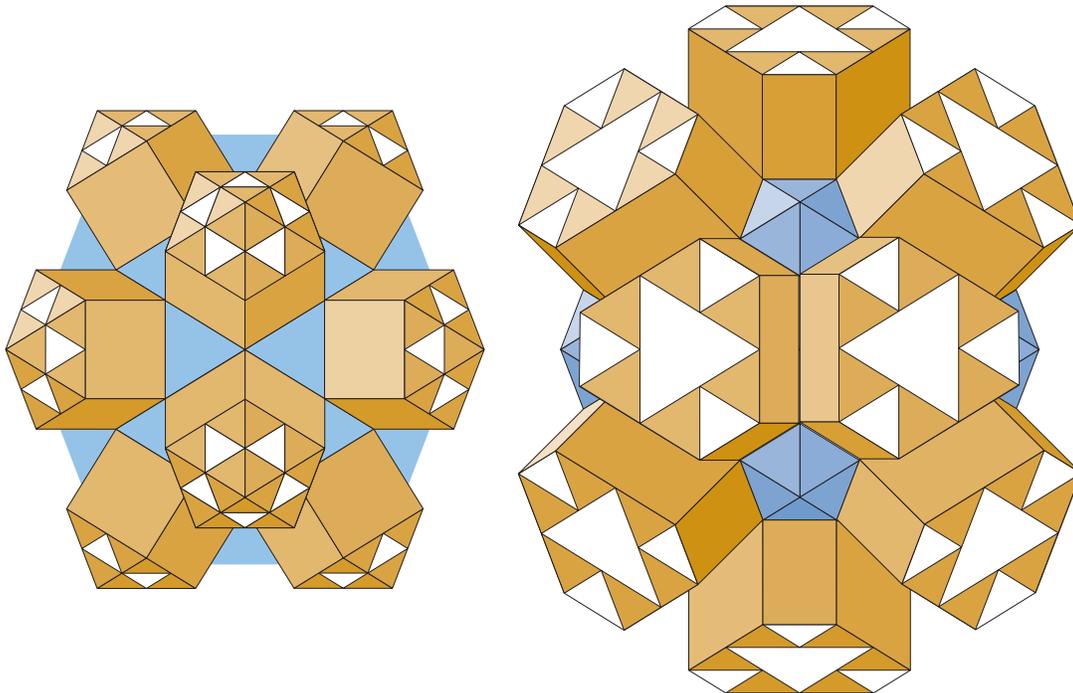
Octahedral assemblies which produce hexagonal prisms have been shown in the section on hexagonal crystals. Pentagonal prisms formed by icosidodecahedral assemblies of regular octahedra have been shown in the section on fivefold quasicrystals. These methods of assembling prisms could produce the spokes of viral capsids.

Each of the icosahedral assemblies of regular octahedra which form fivefold spokes is rotated by one-tenth of a revolution about the join axis relative to the two assemblies adjoining it. This is shown in the next figure. The top assembly and the one below it are oriented for joining along a pentagonal axis. The joined pair is shown at the bottom.

Another method of pentagonal spoke construction using regular octahedra is depicted here. The top two units are identical assemblies of five regular octahedra. Each is inverted relative to the other. They are shown joined in

the third view of the column. An additional five octahedra unit has been added in the bottom view of the figure. Alternate units in this type of assembly are identically oriented. Adjacent units are inverted relative to one another.

The five octahedra unit has two sides. Each of the octahedra provides a face of a regular icosahedron on one side. The octahedra are edgially joined by the edges of these faces. The only point of contact between the octahedra on the obverse side of the assembly is at the central vertex. The unit is not structurally stable on its own. When two opposed units are joined, the resulting assembly is structurally stable. Each octahedron on one assembly shares an edge with an octahedron of the opposed assembly. Since there is no rotation of the joined assemblies about the join axis, the octahedra are in columns parallel to the fivefold axis.



Icosahedral spokes, edgial view.

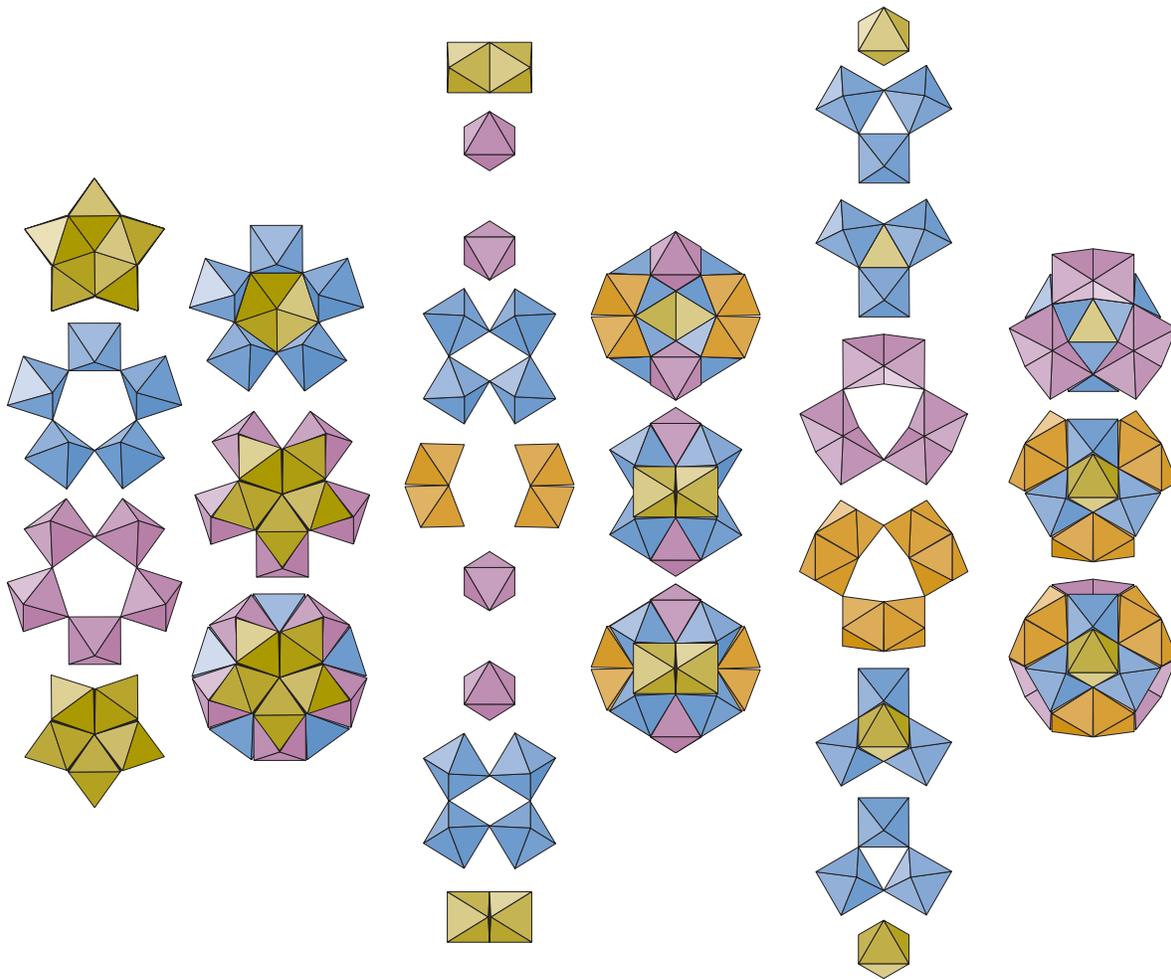
The top assembly shows the arrangement of the pentagonal spokes in a view which is parallel to an icosahedral edgial diameter. The bottom assembly shows hexagonal spokes in the same viewing direction.

Capsid with twenty capsomers

An icosahedral assembly of twenty octahedra is shown in three different views in the figure at the bottom of the page. The view on the left is parallel to a vertexial diameter of the icosahedron. The view in the middle is parallel to an edgial diameter of the icosahedron. The view on the right is parallel to a facial diameter of the icosahedron.

Within each view, the octahedra are colored

according to the layer they occupy. The octahedra within each colored group differ by a rotation about the viewing direction. In the lefthand column of each view, the octahedral groups are shown in the order of joining from farthest to nearest. In the righthand column of each view, the assembled units which form the bottom are shown first, then the assembled units which form the top, and the complete assembly.

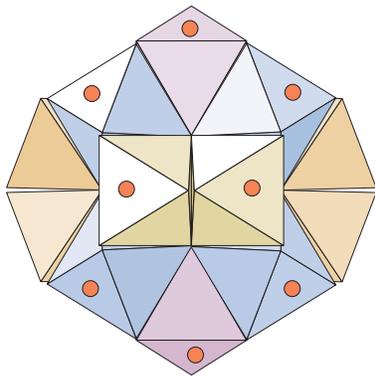
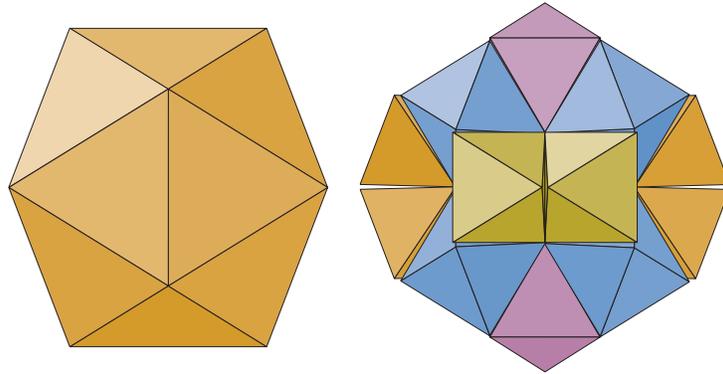


Icosahedral assembly of twenty octahedra: three views

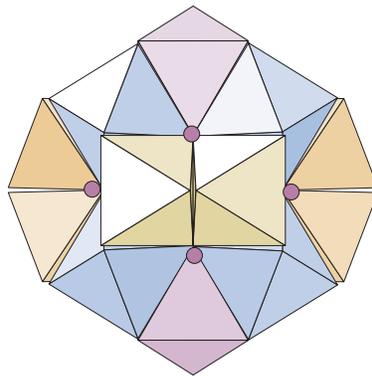
The three figures show the assembly of an icosahedral group of twenty regular octahedra from three different viewing directions. On the left the view is parallel to a vertexial diameter of the icosahedron, the middle view is parallel to an edgial diameter, the view on the right is parallel to a facial diameter.

Relating peaks to octahedral capsid

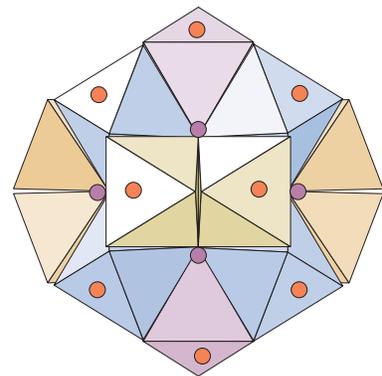
Relation of electron micrograph peaks to an icosahedral assembly of octahedra



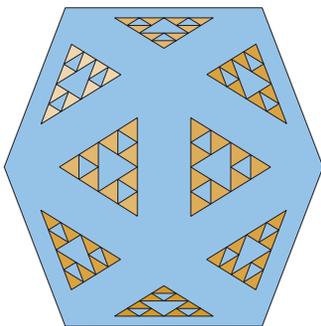
Hex spokes only



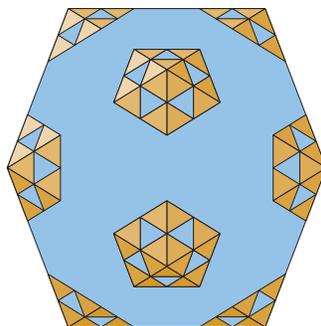
Pent spokes only



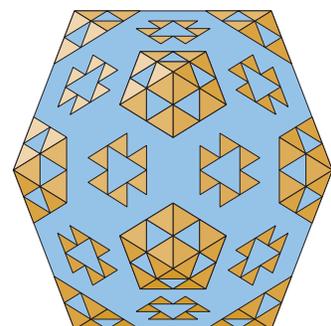
Hex & pent spokes



Red clover mottle virus
Murine minute virus.

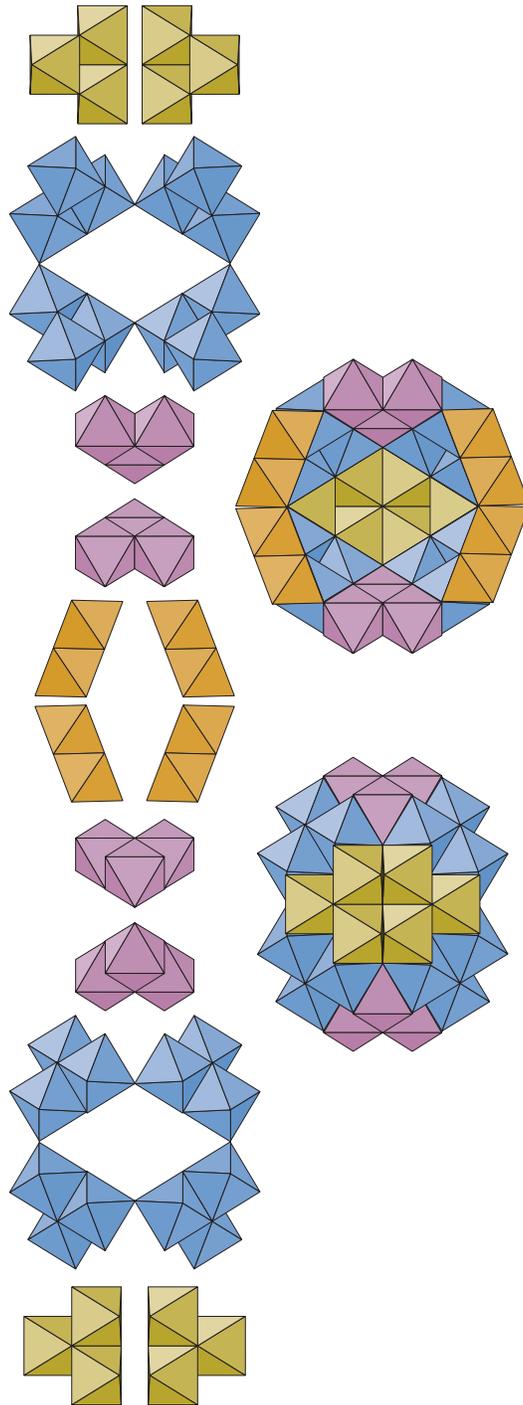


Bacteriophage G4
Bacteriophage ϕ X174
Bean pod mottle virus
Cowpea mosaic virus
Mengo encephalomyocarditis virus
Satellite panicum mosaic virus



Cowpea chlorotic mottle virus
Turnip yellow mosaic virus

Icosahedral assembly of triplets

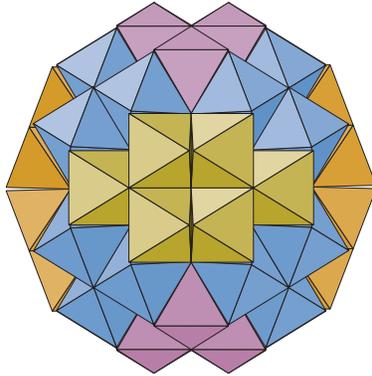


Icosahedral assembly of octahedral triplets.

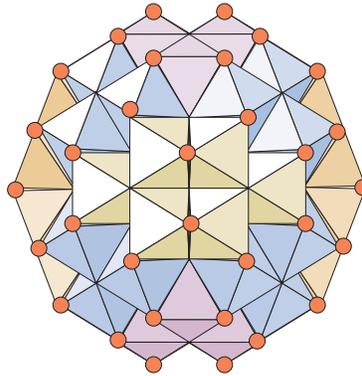
The triplets are arranged in groups according to layer. They are assembled into two groups in the right hand column. The completed assembly is in the next figure.

Relating peaks to capsid of triplets

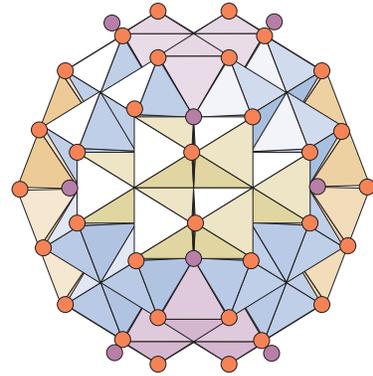
Relation of electron micrograph peaks to an icosahedral assembly of octahedral triplets



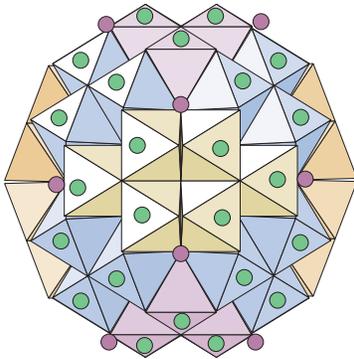
Icosahedral assembly of octahedral triplets, edgial view.



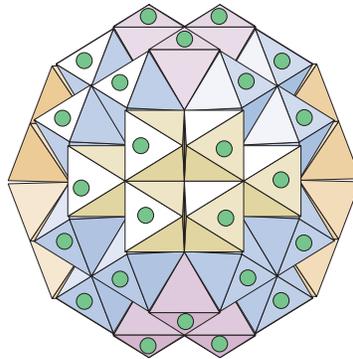
Peaks at icosahedral edge.
 Nodamura virus
 Black beetle virus
 Flock house virus



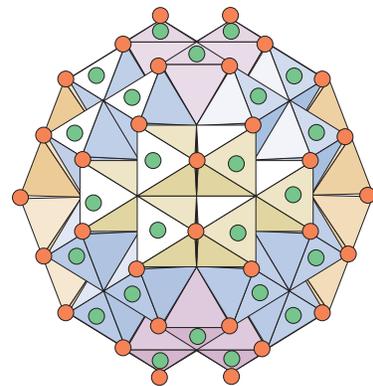
Peaks at icosahedral edge and vertex.
 Tobacco necrosis virus



Peaks at icosahedral vertex and outer face of octahedron
 Hong Kong virus.
 Echovirus 1

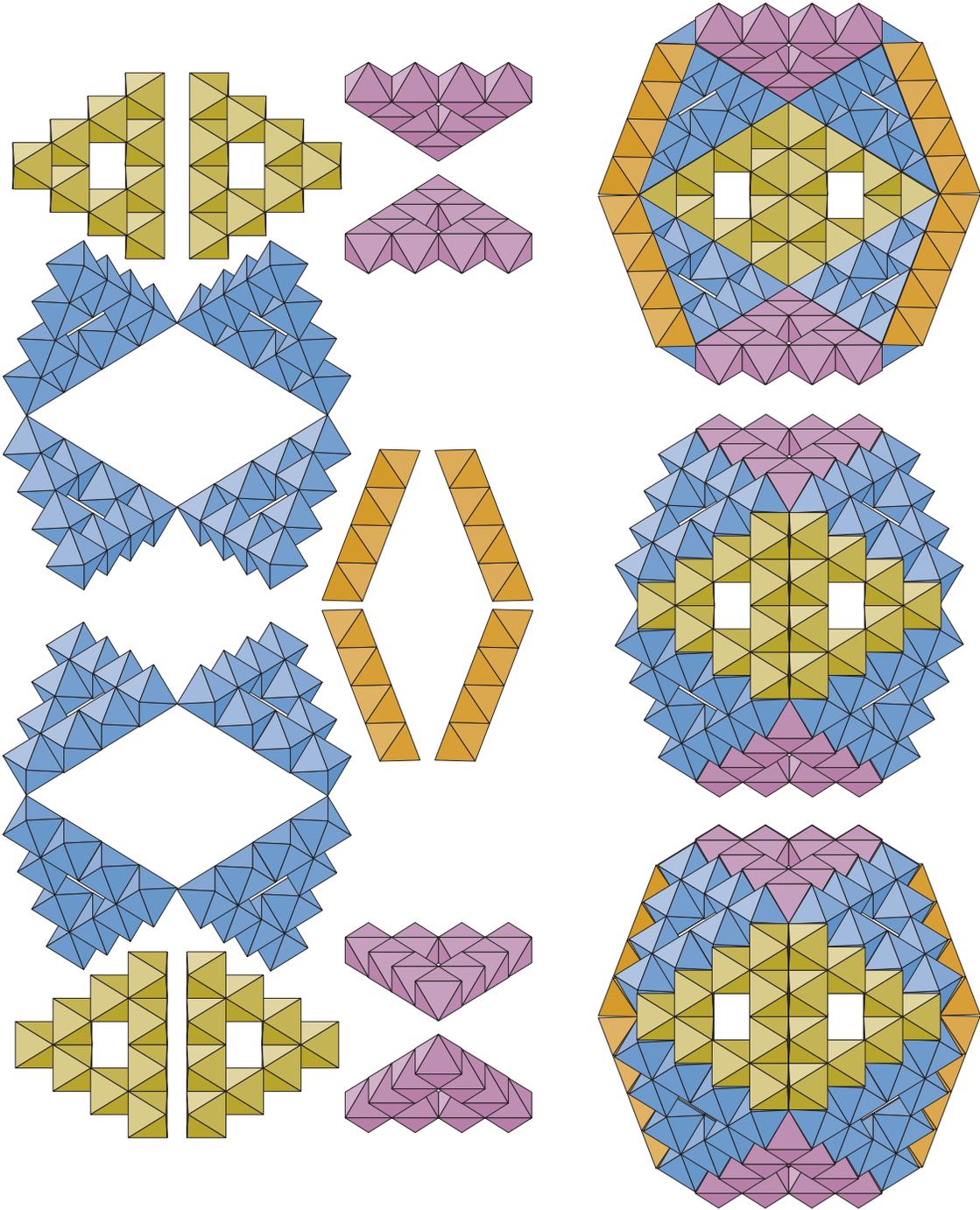


Peaks at outer face of octahedron
 Nudaurelia w Capensis virus
 Alfalfa mosaic virus
 Foot and mouth disease virus
 Human rhinovirus 16
 Theiler's murine encephalomyelitis virus (DA strain)

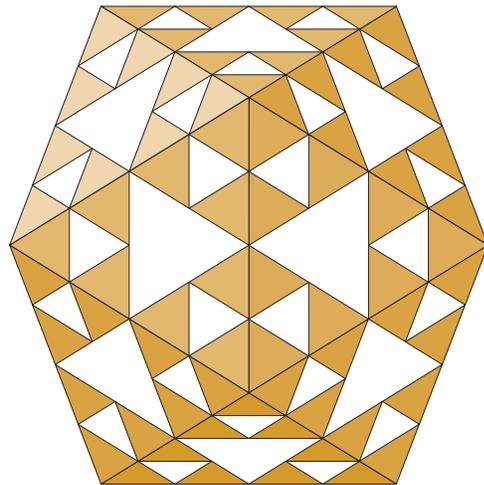
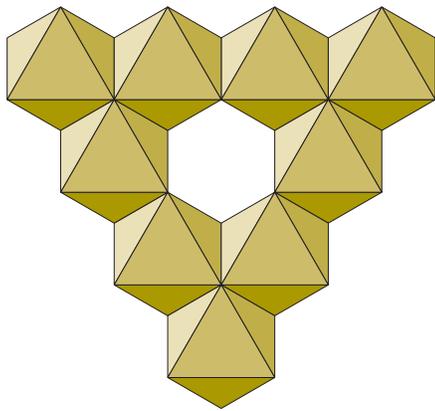


Peaks at icosahedral edge and outer face of octahedron.
 Hepatitis B virus.

Icosahedral assembly of tri-triplets



Icosahedral assembly of octahedral panels consisting of three triplets.

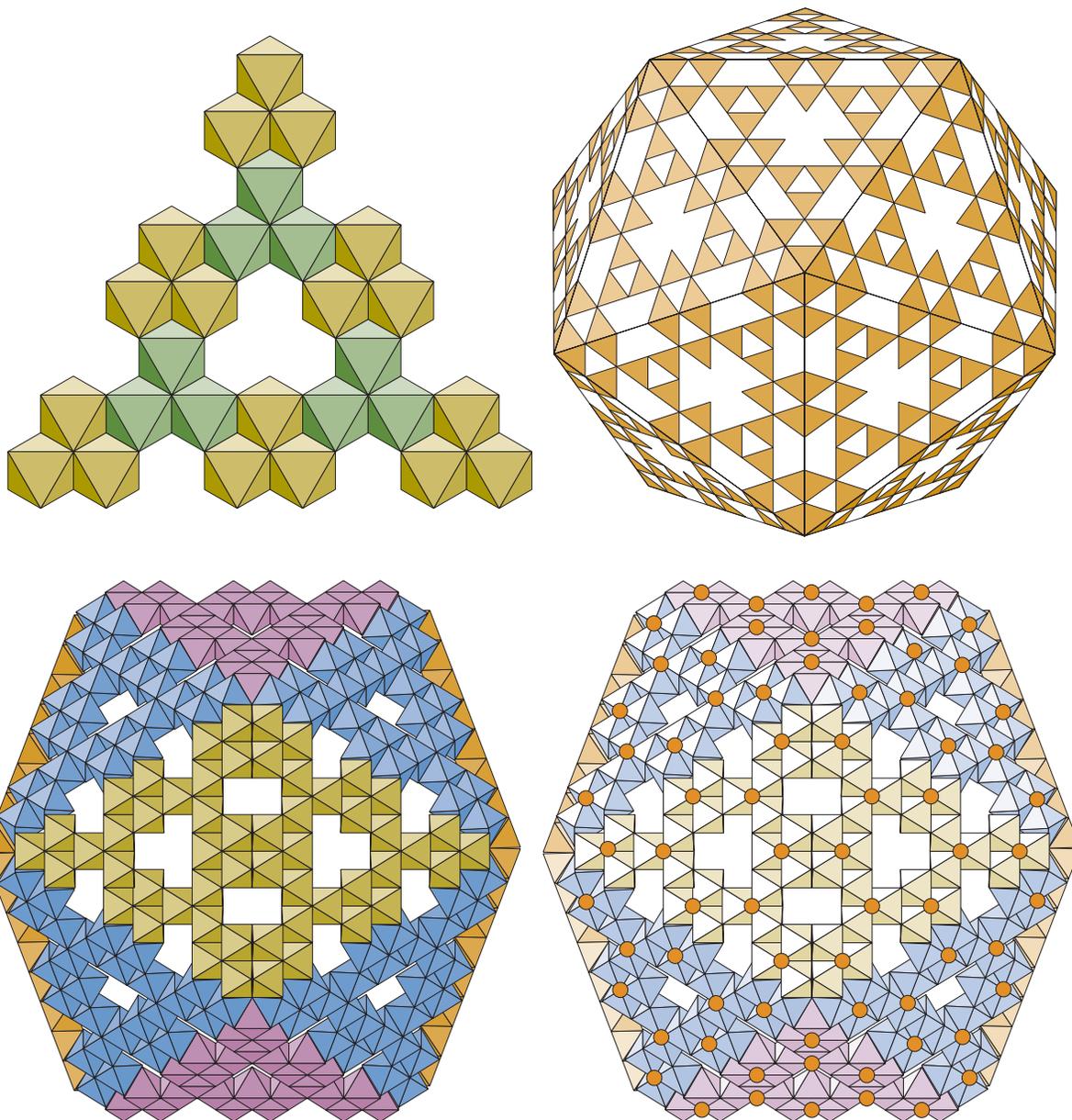


Viral capsid with three triplet facial panels

Relating peaks to nine-triplet capsid

Viral capsid with 180 capsomers

The facial panel of the inner capsid of the rotavirus is shown in the figure. The view is toward the centroid of the icosahedron. This is the minimal structural representation of the capsomer arrangement which is derived from electron microscopy. Each of the capsomers is shown as a triplet of octahedra. The yellow colored triplets at the edges of the panel are linked by the green colored triplets.

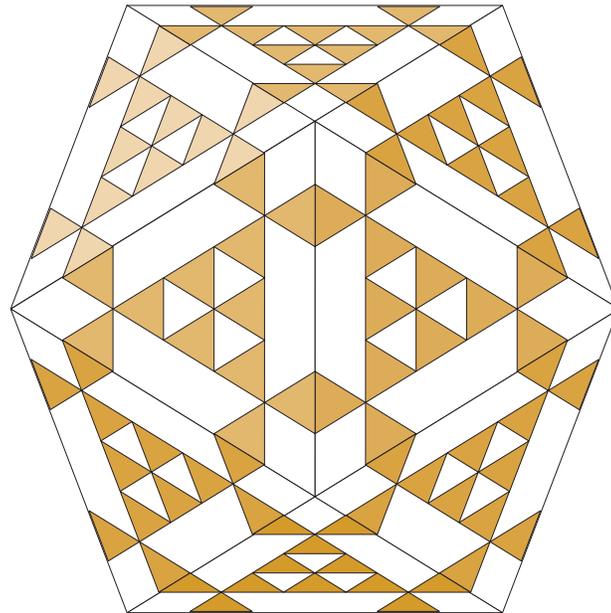
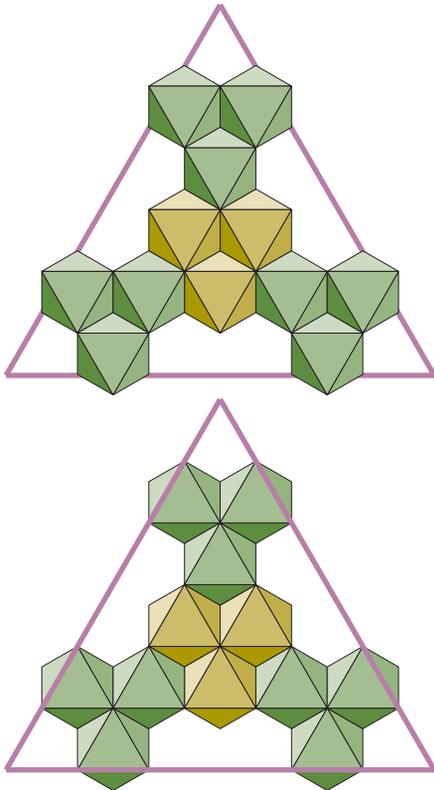
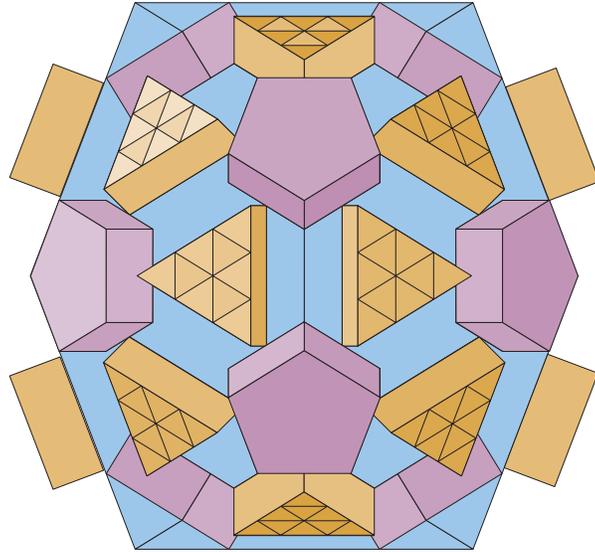


Icosahedral assembly composed of 9-triplet panels.

Bacteriophage GA peaks.

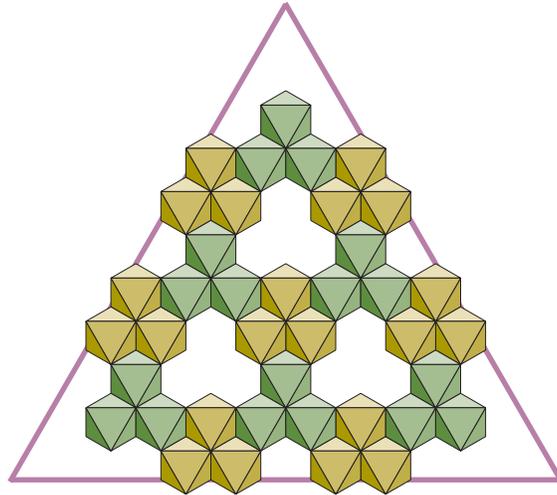
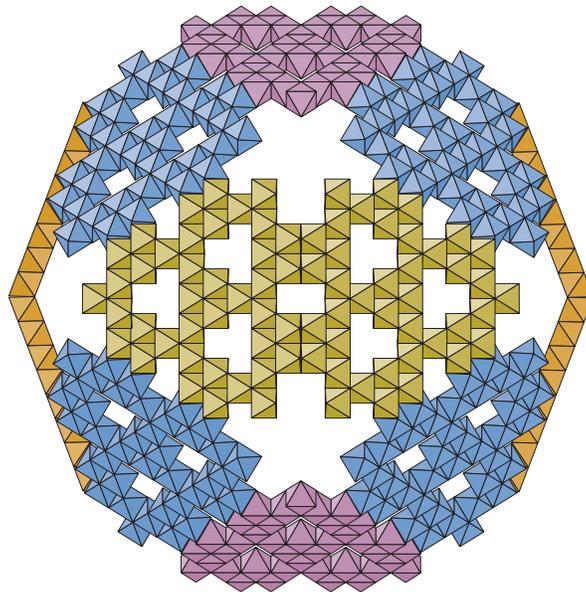
Capsid of 240 capsomers

Physalis mottle virus type capsid.
 Cowpea chlorotic mottle virus
 Cucumber mosaic virus
 Turnip yellow mosaic virus



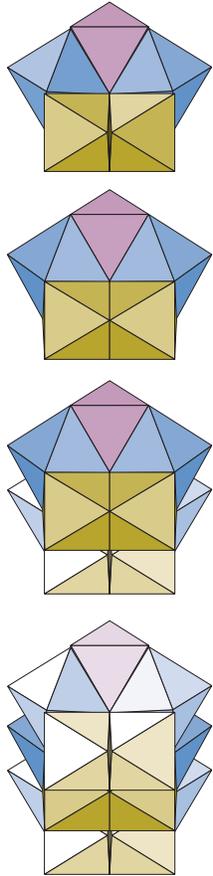
Viral capsid with 240 capsomers

A capsid consisting of 240 capsomers can be modeled using twelve octahedra per facial panel. The octahedra are structurally connected as four triplets.

Capsid of 780 capsomers**Icosahedral panel of thirteen octahedral triplets.****Viral capsid with 780 capsomers**

NANOTUBE

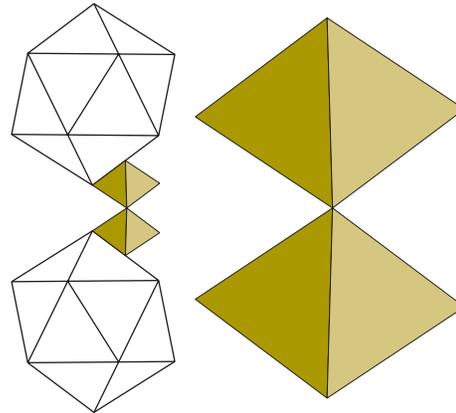
Tubular assemblies whose structure is not octahedrally crystalline occur in viruses and quasicrystals. In fivefold tubes, the relationship of an octahedron in one pentagonal ring with the octahedron to which it is joined in an adjacent ring is shown in the figure on the right.



Stacking of icosahedrally pentagonal rings along icosahedral vertexial diameters.

The stacking of pentagonal rings is shown in the figure above. The top two rings are identical except for an inversion which permits joining. The two rings are joined in the third assembly. An additional ring has been added to make the three ring assembly at the bottom.

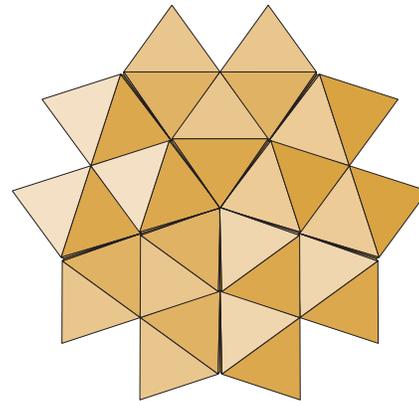
Each of the rings is composed of simple octahedra. The same type of ring can be made using a C-atom in place of the simple octahe-



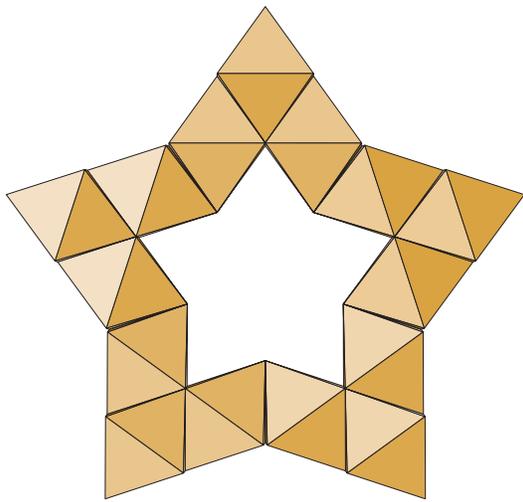
edgial angle 3.2764 deg.

Edgial join between two octahedra of adjacent icosahedral assemblies.

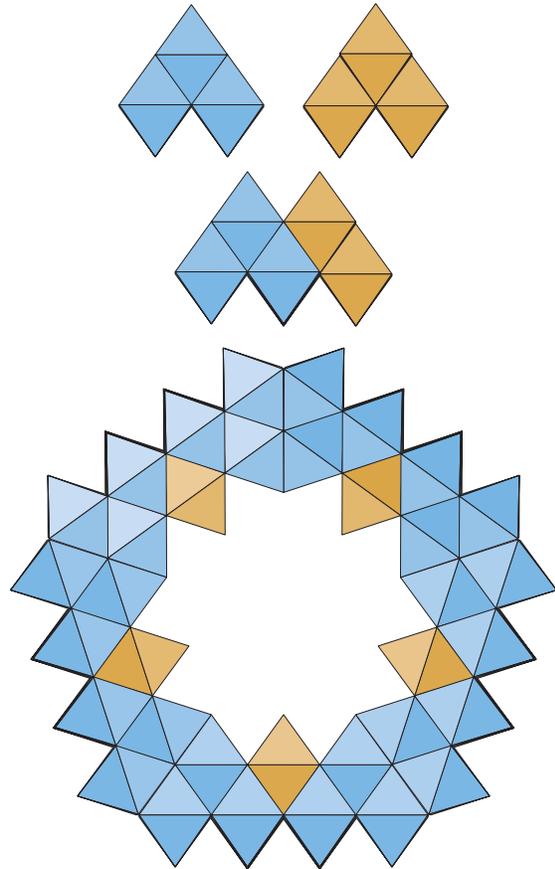
dron. The next figure shows the ring of C-atoms which have been joined so that each atom is joined to its neighbors by two He-octa edges.



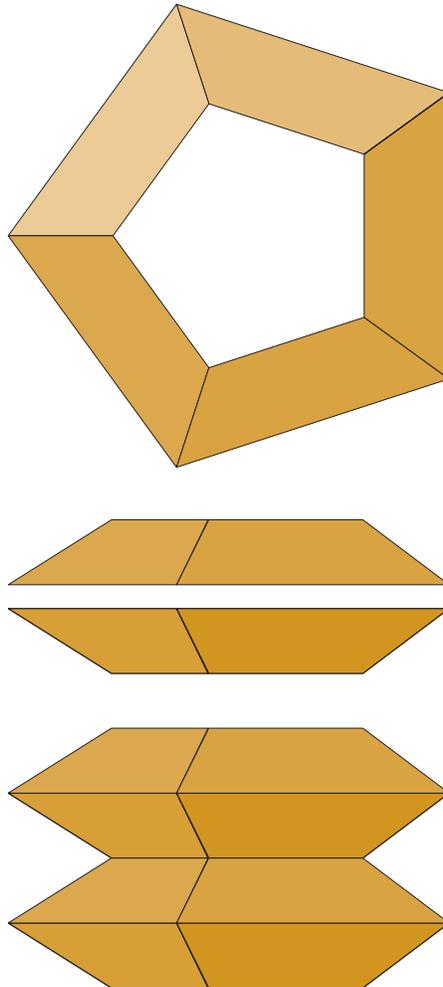
Five C-atoms joined by two edges, icosahedrally convex view.



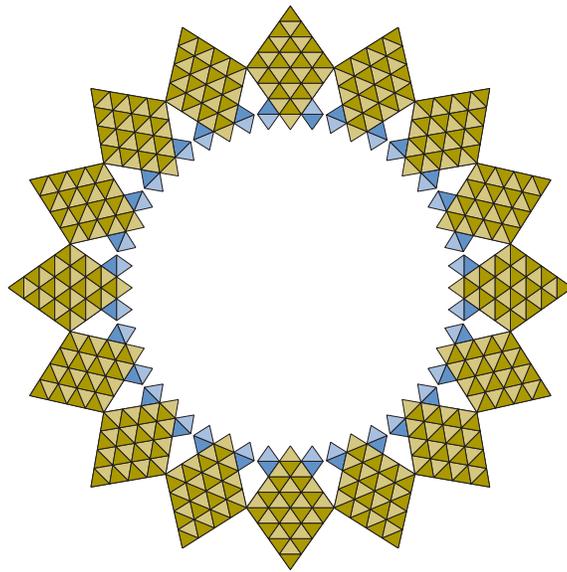
Five C-atoms joined by one edge, icosahedrally convex view.



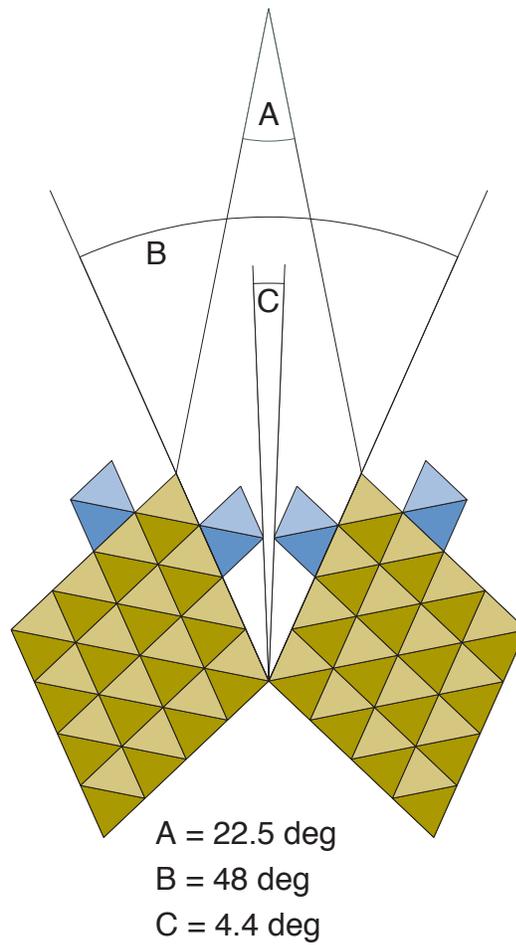
Five C₃-chains joined by two edges., icosahedrally concave view.

Pentagonal tube of panels**Pentagonal tube consisting of identical panels**

Each of the panels is, in plan view, a truncation of an icosahedral face.

Ring of sixteen edge joined octahedra

Geometry of stabilization of 16-ring.
The 1-octas in blue reduce the angle of clearance between adjacent 4-octas from 48° to 4.4° .



SUGAR

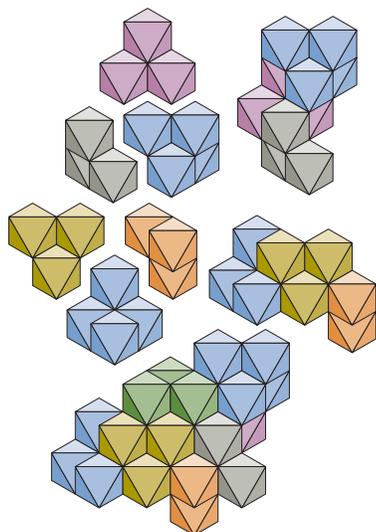
Sugar molecule

The sugar molecule depicted here consists of two units which are joined by an O-atom. Each unit is composed of two C-atoms which are cleftly and left-handedly joined and an O-atom. One C-atom acts as a hub to which the other C-atom and the O-atom are attached. The arrangement is similar to that of the L-amino main chain.

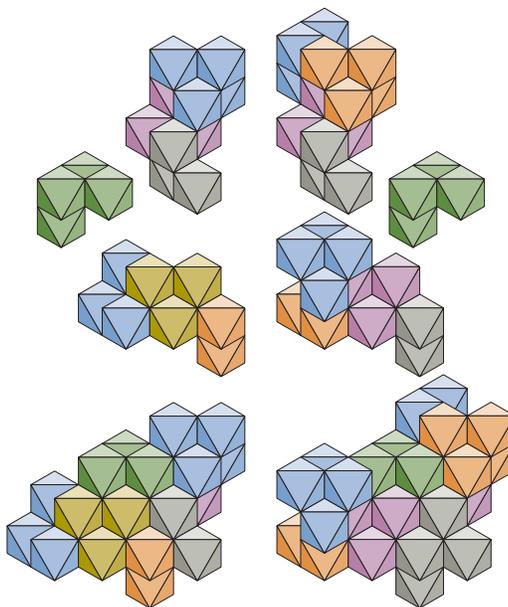
In the next figure, the units which form the

sugar molecule are shown adjacent to amino main chain units in identical orientations. The O-atom of the sugar unit has the same orientation and position as the NH_2 -group of the amino unit. The C-atoms of each unit are identically oriented and joined. The green colored O-atom which joins the sugar units is used to join the amino units. Removing the O-atoms of the joined aminos and replacing the NH_2 -units with O-atoms in the same orientations results in the sugar molecule.

The sugar molecules have four atoms with



Sugar molecule

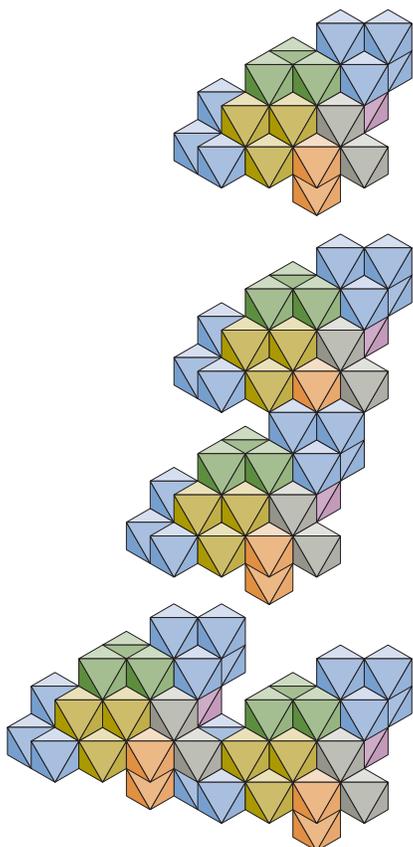


sugar

amino pair

Comparison: sugar molecule-amino pair

clefts for joining. There are the two blue colored O-atoms and the two C-atoms which are colored either orange or gray. Two sugar molecules can join C-atom to O-atom with only a translation in the viewing plane in two ways.

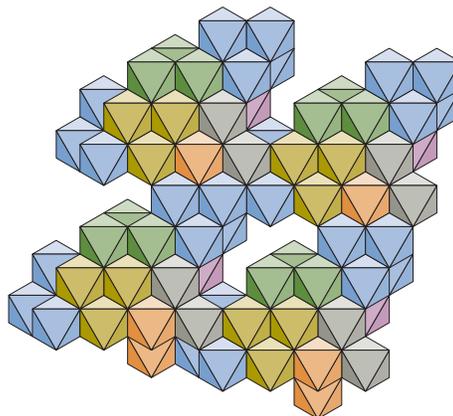


Pairing of sugar molecules

The orange colored C-atom at the bottom of the unit can join with the O-atom at the top of the unit as shown in first joined pair of the figure. The gray colored C-atom at the bottom of the unit can join with the O-atom on the left of the unit as shown in the bottom of the figure.

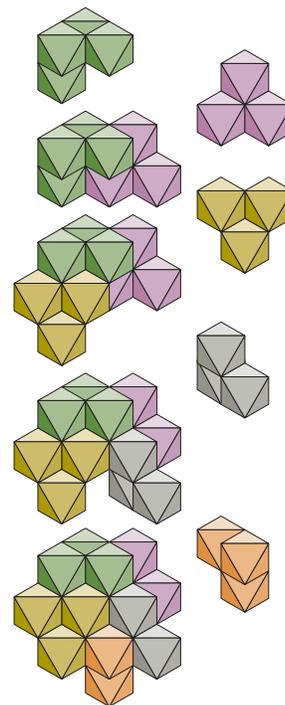
Four sugar molecules can be joined in a ring in which each is linked to one unit with one of the joins and to another unit with the second join. This can be extended by the adding identical units using the same two C-atom to O-

atom joins. The resulting planar crystal is just



two He-octa facial diameters thick, the thickness of the sugar unit.

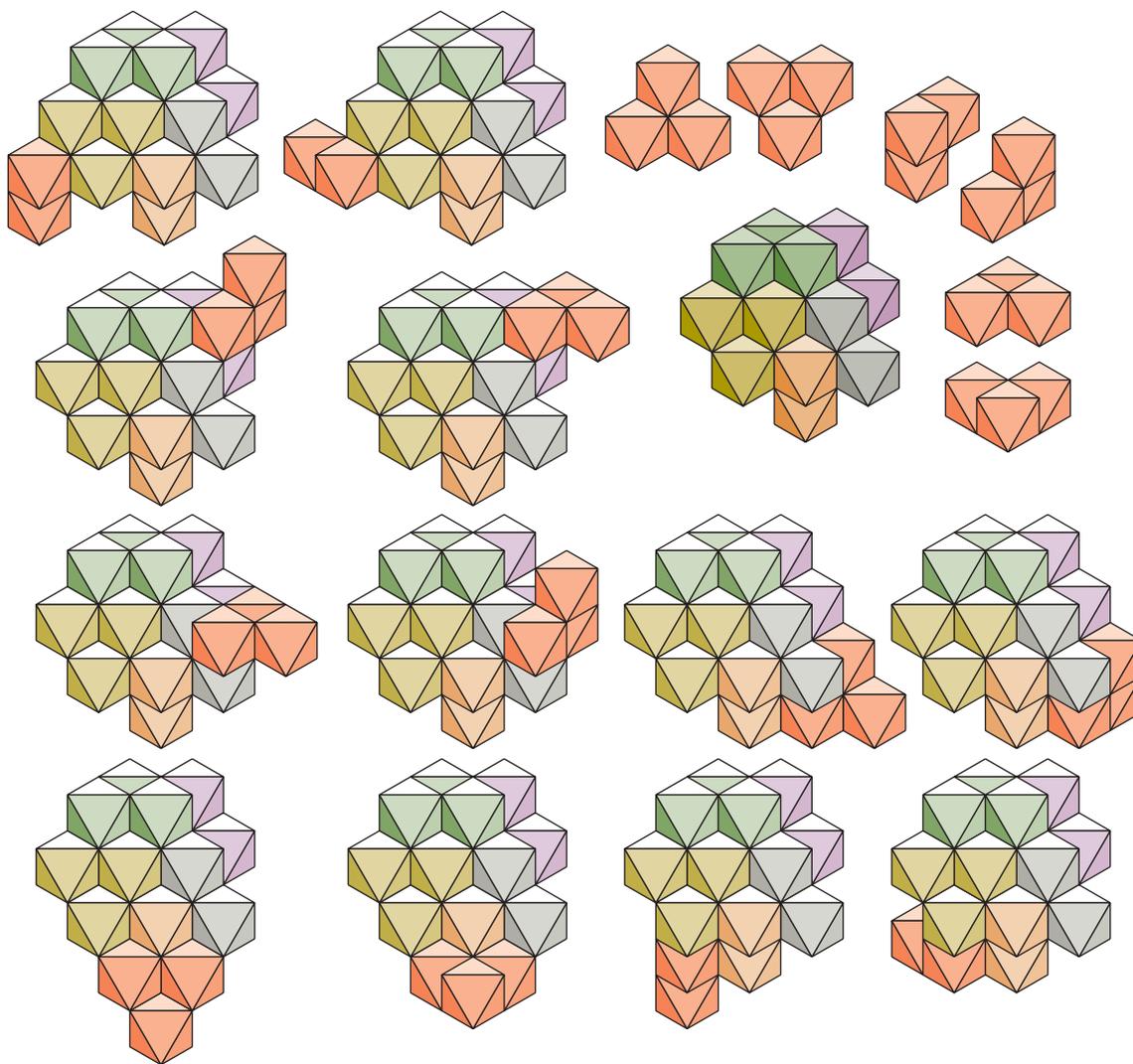
The ringness of sugars.



Sugar molecule: ring

Six C-atoms can form a ring in which each of the C-atoms is cleftly joined to each of its two neighboring C-atoms. The atoms which form the sugar molecule are not all cleftly joined. The two alpha C-atoms are colored yellow and violet. A He-octa of one shares an edge with the He-octa of the other, but they are cleftly joined to the same O-atom which is colored green. The gray C-atom is cleftly joined to the violet C-atom but its He-octas share edges with the yellow C-atom and the orange C-atom. A He-octa of the orange C-atom shares an edge with a He-octa of the violet C-atom.

Each open cleft of each C-atom can accommodate a C-atom in one of two orientations. The alpha C-atoms of the main chain unit have one open cleft each. The other C-atoms have two open clefts each. The six clefts, each with two ways of attaching a C-atom, provide twelve possible ways that a C-atom can attach to the CCOCC backbone of the sugar molecule. The figure shows the twelve possibilities. In the depiction of each the attached C-atom is colored red. Each row contains each of the possible C-atom attachments to one of the four backbone C-atoms. The top row shows the two

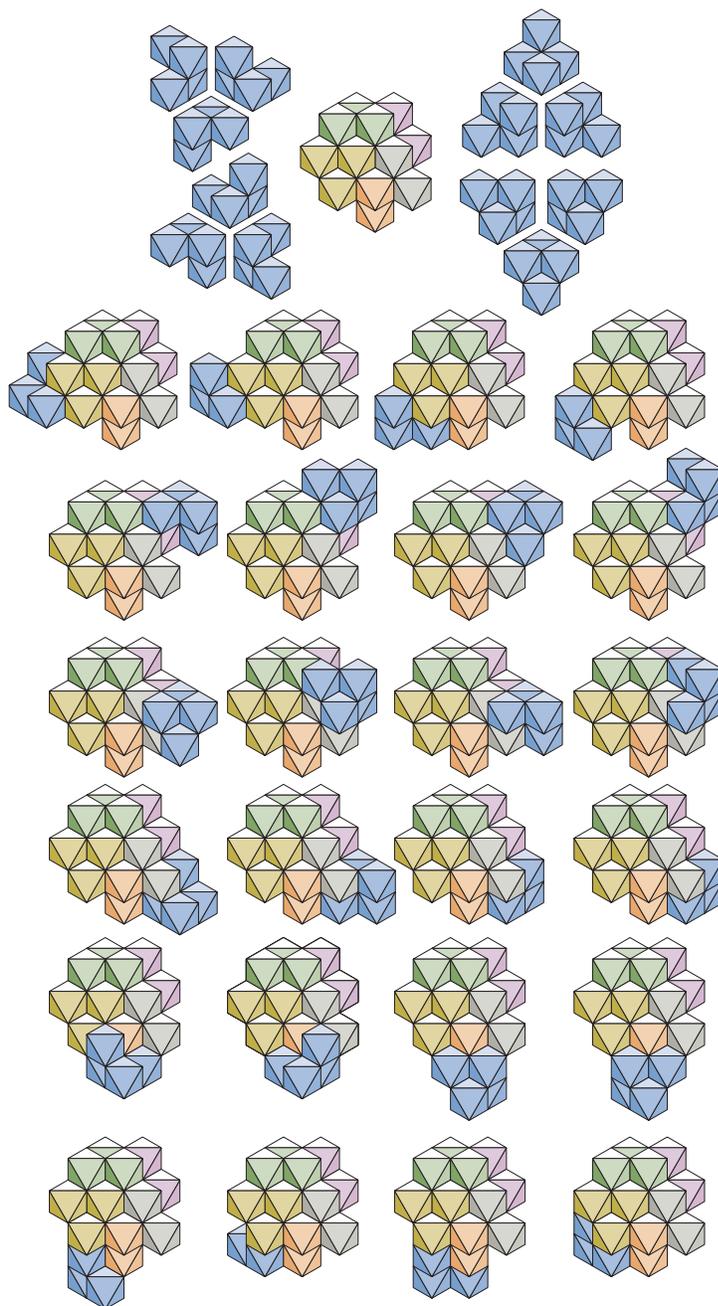


Sugar ring: C-atom attachment

possible attachments to the yellow colored alpha C-atom. The second row shows the two possible attachments to the violet colored alpha C-atom. The third row shows the four possible attachments to the gray C-atom. The bottom row shows the four possible attachments to the orange colored C-atom. The

CCOCC backbone is shown in the upper right corner with C-atoms in each of the joinable orientations.

Instead of a C-atom, an O-atom is attached to a cleft of each of the C-atoms in as many ways as possible. The twenty-four possibilities are depicted in the next figure. The CCOCC back-

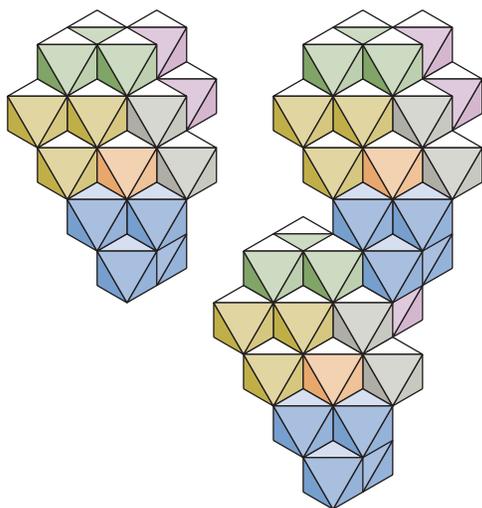


Sugar ring: O-atom attachment

bone is depicted at the top. There are four groups of three O-atoms, one for each of the twelve differentiable orientations of the O-atom.

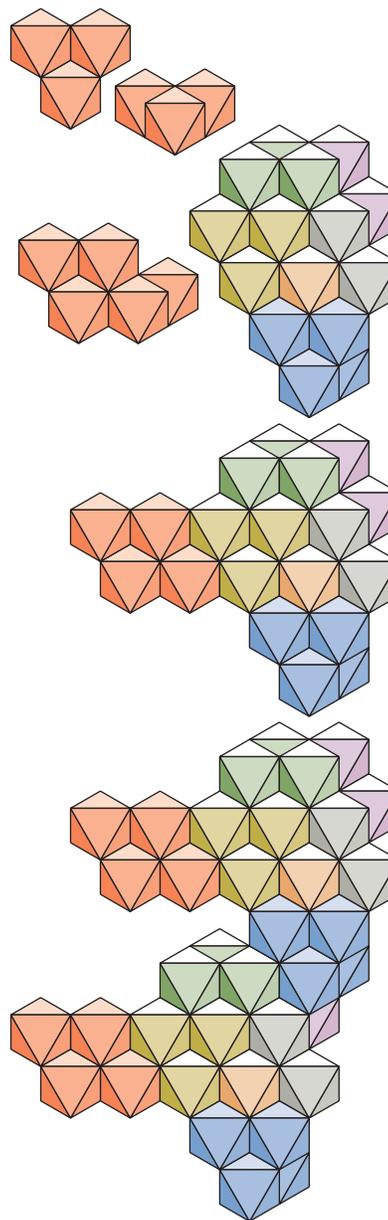
O-atom to backbone C-atom joins are shown in six rows of four. The first row shows the possible ways that the an O-atom can cleftly join to the yellow C-atom. The next row shows the O-atom joins to the violet atom. The next two rows show the joins with the gray colored atom. The two bottom rows show the joins to the orange colored C-atom.

A simple way of chaining the basic unit with an O-atom attached is shown here. The O-atom attached to the orange C-atom is cleftly joined to the violet C-atom.



Sugar ring with O-atom: chaining

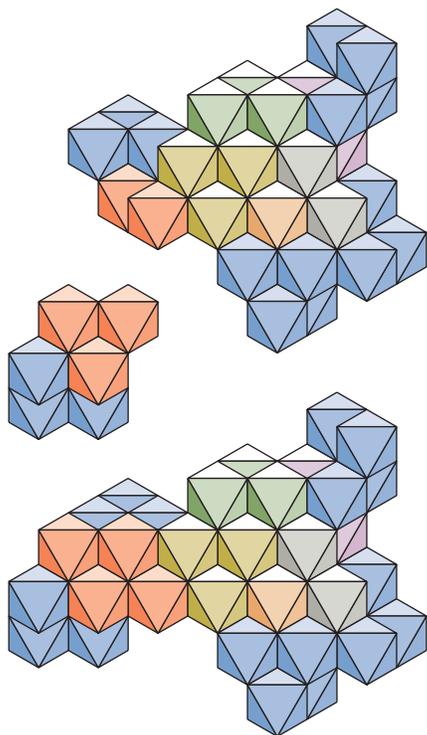
The same O-atom attachment as above is used here. Two C-atoms form a short side chain from the yellow C-atom. The added C-atoms provide a base for the O-atoms to make a hexose molecule such as glucose.



Sugar ring with O- and C-atoms: chaining

Glucose

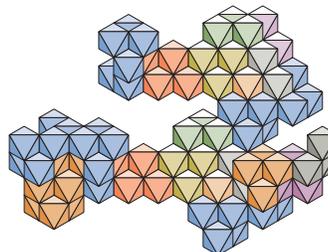
One of many possible O-atom attachments to the basic sugar form CCOCC is shown in the figure. One O-atom is attached to three C-atoms of the base unit. An additional C-atom is attached to the yellow C-atom and an O-atom to it. An additional C-atom with an O-atom attached is cleftly joined to the added C-atom. The orientation of the O-atoms and the cleft to which each is attached was made arbitrarily. There are many combinations of O-atom and C-atom attachments.



Glucose

Chondroitin 6-sulfate¹

The two CCOCC bases are joined by an O-atom between the orange C-atom of one base and the violet C-atom of the other.



Chondroitin 6-sulfate

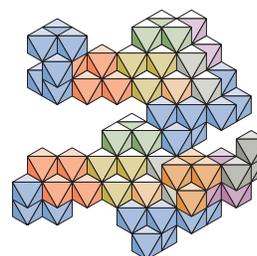
The upper unit has a CCO₂-unit added to the yellow C-atom.

The lower unit has an CCSO₄-unit attached to its yellow C-atom and an amino main chain unit attached to the gray atom by its female end.

There is more than one way of making the attachments and the ones shown are arbitrary.

Hyaluronate

This assembly is the same as the above except that the H₂SO₄ group is replaced by an O-atom.



Hyaluronate

1. Lubert Stryer, *Biochemistry*, 2d ed., W. H. Freeman, San Francisco, 1981, Fig. 9-26, p. 201.

POLAR

Introduction

The crystalline atom requires that the edges of the epn be polar so that the particles may adhere edge to edge in the manner established by the periodicity of the elements. Polarity is attributed to the phenomena of magnetism, electrostatics, and gravity.

Types of polarity

If the polarity of the epn edges were electrical or gravitational, then there should be bars with permanent electric poles and bars with permanent gravity poles which would interact only with bars of the same type. If a bar magnet is taken as a reference, then any other bar which appears to be magnetic may be tested by

bringing each of its poles near to the poles of the reference. The fact that for each of the poles the result is repulsion in one of the pairings indicates that these poles are also magnetic. There are no rods which exhibit the attractive and repulsive polar permanence and strength of the bar magnet which do not prove to be magnets. Only bars with permanent magnetic poles exist.

Magnetic polarity has the permanence and the strength to provide for the epn cohesion. The maximum weight supportable by a permanent magnet occurs when the surfaces of the magnet and load bearing armature are cylindrical so that the contact between them is linear. The edge to edge join of the epns is linear. Magnets have two kinds of poles. It follows that each edge of the epn has the kind of polarity of one of the poles of the permanent magnet.

Polarity: epn edges

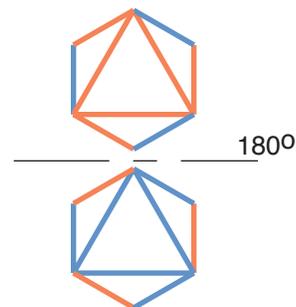
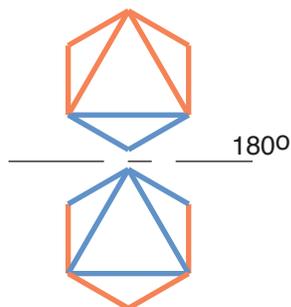
It is supposed that half of the twelve edges of the epn be one type of magnetic pole and the other half be the other type of magnetic pole. It is supposed that diametrically opposite edges have different polarities. It is supposed that the distribution of polar edges is symmetrical.

Polarity: Bowtie distribution

The edges of two faces which share a vertex but no edge are of one type of polarity. The other six edges are identically arrayed but of the opposite polar type.

Polarity: Turbo distribution

A face which is defined by edges of one type of polarity is diametrically opposed to a face which is defined by edges of the opposite polarity. Alternate edges connecting these two faces are of the same polarity. When viewed facially, the connecting edges which are of the same polarity as the near face point in either in the clockwise away direction or the counterclockwise away direction. Either choice results in an array of edges of like polarity which is identical with the array of edges of opposite polarity. But the array of one choice differs from the array of the other.



Polar orientation and the building of the atom

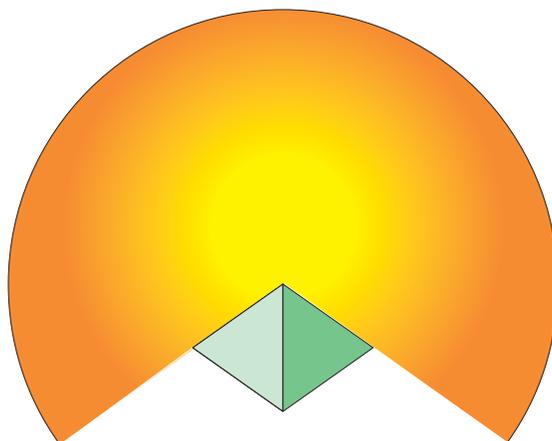
The Polar domain of the edge of the epn

The polarity of the epn edge is assumed to be directional. It is assumed that the direction is away from the center of the epn, that there is no polar interaction between one edge of an epn and any other edge of the same epn. There are crystals which are twinned so that along the twinning plane the epns must be joined face to face. This suggests that for an edge there is an outward domain, or portion of space, within which its polarity is manifest. Any pair of edges whose polar domains share some portion of the same space and which are directed towards one another are either attracted or repelled. The effect is mutual and simultaneous. Any change in the distance or respective orientations of the two edges has an immediate simultaneous effect upon each. This

is true no matter what the distance. It is true no matter how dense the population of other epn edges in the intervening space. So long as the edges are toward each other each is affected by the other.

An epn edge which is attracted by another epn edge will be caused to turn the epn so as to increase the attraction. Its equilibrium position will be at maximum attraction. If an edge is repelled by another edge, it will turn the epn so that the repulsion is zero.

A group of epns will respond to the presence of one of the two types of polarity so that each of the edges which is attracted will try to turn the epn towards the polarity while the edges which are repelled will try to turn it away. The more attracted epns will be turned more towards than the less attracted. The more repelled will turn more away. The net effect is that the group will be more attractive. Also, the accommodation the structure.



Polarity: Domain of the epn edge

The polar domain of an epn edge is bounded by the infinite extension of the planes defined by the two octahedral faces whose intersection defines the edge. The octahedrally internal angle is α ; the external angle is β .

$$\alpha = 180^\circ - \text{atan}\sqrt{8}$$

$$\beta = 180^\circ + \text{atan}\sqrt{8}$$

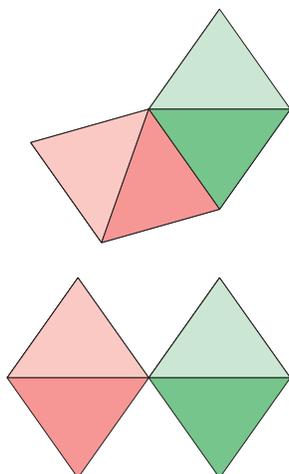
Interaction of polar edges

A pair of edges will attract each other according to the resolution of the one upon the other divided by the distance separating the two. The polar effect of one body upon another is the combined effect of each edge of the respective bodies upon each of the edges of the other body. The number of edges of each body

and their effect upon another body is expressed as an area. There is a net polarity of so many edges per unit of projected area summed over the total area. A 3 x 5 array of edges gives 15 edges

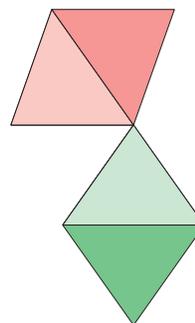
An edge of the He atom is a pair of colinear epn edges. If these two edges have opposite polarity, then the polar domain of one is the same as that of the other. An epn edge which is affected by one of these edges will be affected by the other. There are positions where the effect on one upon that edge will be negated by the effect of the other. In other locations of the domain the effect of one will be greater than the other. Unless the epn is close to the He atom, the net effect will be quite small.

epn edge pairings in atomic pairings



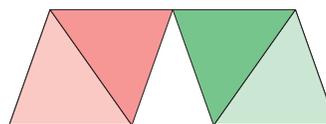
Polarity: Range of contact influence.

The polar strength limits for edge join are shown here. The top join is the weakest; the bottom join is the strongest.



Polarity: Boundary of influence.

The equator of the red epn is located on the boundary of polar influence for the rightmost edge of the green epn.



Polarity: Minimum influence.

The attraction between the upper edge of each of the epns is at a minimum since they lie on the limit of the polar domains.

Polar communication

The polar effect of one epn edge upon another epn edge is accomplished without the intercession of a messenger and requires no medium. A change in the orientation of one epn has a simultaneous and immediate effect upon every other epn, however remote. If an apparatus could be invented which could distinguish a pattern in the polar effects upon an epn or group of epns and the direction of the polar entity whose changes congrue with the effects, then a means of communicating across astronomical distances will exist. Communication between the inhabitants of the "earths" of remote solar systems will be possible with a delay which will be determined strictly by the time taken by the apparatus to detect and process the polar disturbances effected by the communicator.

Detection of the very small amplitude of the disturbances caused by the communication will require a very sensitive apparatus. The frequency of the communication will be determined by the detection technology. Randomness, amplitude magnitude, and background frequencies can be filtered. The communicants must have reached the same stage of evolution and have the same technology.

The function of life in universe

If converting a planet to a star requires humanlike life to set its surface atomically afire, then each of the stars was once an inhabited earth. Other stars of the same type as the Sun may at this moment have inhabited earths with humanlike creatures who are as knowledgeable as humans. Since the state of current knowledge requires the discovery of unstable atoms and the building of reactors, and since the destabilization of stable atoms follows from this, it is uncertain how much time is left for the inhabitants of such an earth before the proliferation of unstable atoms terminates them. The requirement of star size, planet evolution, life evolution, and knowledge evolution, and the termination of knowledge through surface ignition, are limitations on the population of possible communicators in Universe at this time.

Mass and the octahedral atom

Polarity of epn described by observer orientation

Universal unit based on epn edge

Since the epn edge is the unit of polarity as well as length, and since mass is a polar phenomenon, then every quantifiable attribute of matter is, at root, an aspect of the edge length of the epn. Thus, each and every quantity is expressible in units which are at base the edge length of the epn, or ratios of quantities which are expressible as the edge length of the epn.

Density paradox

The atoms are composed of identical epns with a definite shape in identical orientation whose edges are polarly joined. In a molecule and in a crystal composed of molecules, the epns are in crystalline order throughout. The epn occupies a volume which includes its own octahedral form plus 1/4 of the tetrahedral voids which result from the crystalline association. The combined volume is that of a rhombic dodecahedron with major facial diagonal equal to the edge length of the epn. When molecules are formed, the odd atomic numbered elements join so as to pair the odd triplets. The crystal is then formed of He octas each of which has a volume which includes the 1/4 tetrahedral volume at each face and the volume is a rhombic dodecahedron whose major facial diagonal is the edge length of the He octa. The spatial integrity of the epn shape and the He octas which are built of them is essential to permit formation of molecules and to account for the shapes of the crystals. The mass associated with the He octa is 2. If a tetral void formed by the He octas of an atom is occupied this increases the isotopic mass by 1. One quarter of this mass belongs to each adjacent He-dodec. The maximum mass for a He-dodec is 4 for the He-octa + $8 * 1/4$ for the epns in the voids. This gives a mass of 6 for the He-dodec. The volume of an atom in a crystal is at minimum the volume of its He-dodecs. The number of He dodecs in an atom is the (atomic num-

ber/2). The minimum mass per dodec is 4 and the maximum is 6. The atomic density is between 4/He-dodec and 6/He-dodec. The volume of the cfu will be larger than the sum of the atomic volumes within it. Thus the CFU density will be less than the atomic density. Yet when the value of the axial unit length is calculated on the basis of the density and the atomic weight, the size of the atoms would have to be flexible or the mass of the atoms must vary or the number per standard volume must vary. An explanation is wanting, but the periodicity and the crystal forms and the molecular structures could not exist if either the size or shape of the atoms varied.

$$1 \text{ octa} = 4 \text{ tetra}$$

$$1 \text{ rhombic dodec} = 1 \text{ octa} + 8 \times \frac{1}{4} \text{ tetra} \times \frac{1 \text{ octa}}{4 \text{ tetra}} = \frac{3}{2} \text{ octa}$$

$$1 \text{ cube} = 4 \text{ rhombic dodec}$$

$$1 \text{ cube} = 2 \text{ cubocta}$$

The field basis of General Relativity

Einstein stated that the general theory of relativity was a field theory and is not consistent with “material points which move under the influence of forces acting between them.”¹

The periodicity of the elements is a periodicity of form which derives from the shape of a regular octahedron which joins with identical regular octahedra in crystalline order, so that an edge of one octahedron is congruent with the edge of an adjoining octahedron, and between which exists a polar attraction. To the extent that the regular octahedron is a material point, and to the extent that like octahedra

move under the influence of the interaction between their polar edges, general relativity is invalid.

Millikan experiment

This experiment involves the cfu of the oil, the cfu of the x-ray, the cfu of the light, the cfu of the plate. The “electron” here is the same as the CRT “electron”, one of the cfus.

Magnetism

Easily² magnetized directions in Ni and Co crystals

Ni, FCC, [111] direction, octal facial

Co, HCP, [0001] direction, octal facial

The octal facial direction is the direction of the polar axis for the turbo distribution of polar edges.

1. Albert Einstein, *The Meaning of Relativity*, 5th edition, Princeton University Press, N. J., page 140

2. L. F. Bates, *Modern Magnetism*, 4th ed., Cambridge U. Press 1963

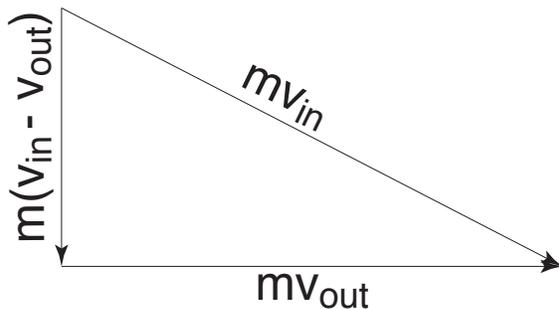
MOVING

MOMENTUM

Energy

Kinetic energy

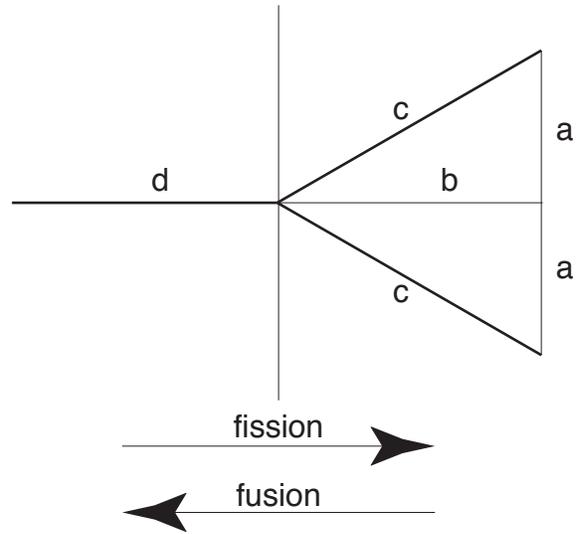
Energy has been treated as if it was a substance or independent entity. But, for a moving particle, it is no more than a condition imposed upon the transfer of momentum. The condition is that for any loss of momentum that the particle undergoes in a collision, the vectors representing the velocity of the particle going into the collision, the velocity after the collision, and the change in velocity as a result of the collision will be as the sides of a right triangle.



Momentum exchange: collision
Condition required for “energy” conservation.

Fission and Fusion

The crystalline atom is built by the association of identical epns in identical orientation. The epns are held together by the attraction between their congruent edgial poles. The periodicity of the elements indicates that the epns form triplets, and these triplets then join one by one to form the successive growth stages of an atom which are the elements. The crystalline addition of the triplets is best effected when the relative motion between the parts approaches zero. This is best effected when the parts are isolated from other atoms. The joining will always require a relative velocity of joining, and this velocity will be lost when the two are joined. The growth of atoms necessar-



Momentum exchange: Fission vs. fusion

Vector diagram showing relationship between *fission* and *fusion* for the crystalline octahedral atom.

The line segments labeled **d** or **c** are velocity vectors. Vector **d** and the two vectors labeled **c** each represent the velocity of a single particle. The vectors labeled **a** or **b** are the components of the velocity vectors labeled **c**. Vectors **b** and **d** are equal in length.

In a *fission* event where a particle with velocity **d** splits into two identical particles, each of the pieces continues with a velocity **c** which is equal to the vector sum of velocity **d**, the original velocity, and velocity **a**, the velocity acquired by their mutual repulsion. In a *fusion* event, each of the joining particles loses the component of its velocity represented by the vector **a**, and the joined pair proceed with the velocity **d** which is equal to the component of the velocity that each had in the direction of vector **d**, which is vector **b**.

ily entails a reduction in the number of thermal entities and the loss of the momentum which existed between their parts. The crystalline form of the parts is not altered by their joining, nor are they rearranged. The join is one of addition. The term “fusion” is associated with melting and is contrary in sense to the crystalline addition of parts.

The maximum attraction or repulsion that can exist between a pair of epn edges is that of congruent contact where the respective epns are in identical orientation. The most attractive association is separated from the most repul-

sive association by a simple rotation of one of the epns relative to the other so as to replace the attractive edge with one of opposite polarity.

e/m

The value of e/m is a constant for each and every kind of atom, because whatever the polar effects, mass, magnetic, momentum, frequency, energy, they derive from the same identical epns. The passage of electricity is the passage of momentum between atoms. The atoms of one electrode are momentum rich and the atoms of the other are momentum poor. A beam of atoms passing between these plates is a gaseous flow and this flow is deflected in the direction away from the momentum rich electrode. The deflection is a function of the number of epns the atom of the flow has. Their resistance to this deflection is also a function of the number of epns the atom of the flow has. The atom is deflected by the polar effects between the epns of the magnet atoms and the epns of the stream atom. The atom is defined by the atomic number, and the interaction of the atom with other atoms or groups of atoms is defined by the atomic number.

$$e/m_e = 1.758796E7 \text{ cm/g}^1$$

$$(e/m)^2 = 3.09336337E14 \text{ cm/gm}$$

$$\text{if } e/m=1 \text{ then } 1 \text{ gm} = 3E14 \text{ cm}$$

$$**h/e = 4.13556E-7 \text{ cm}^{3/2} \text{ gm}^{1/2} / \text{sec}$$

1. *Hdbk C&P 48th ed*, page f-158

Momentum exchange in a transformer

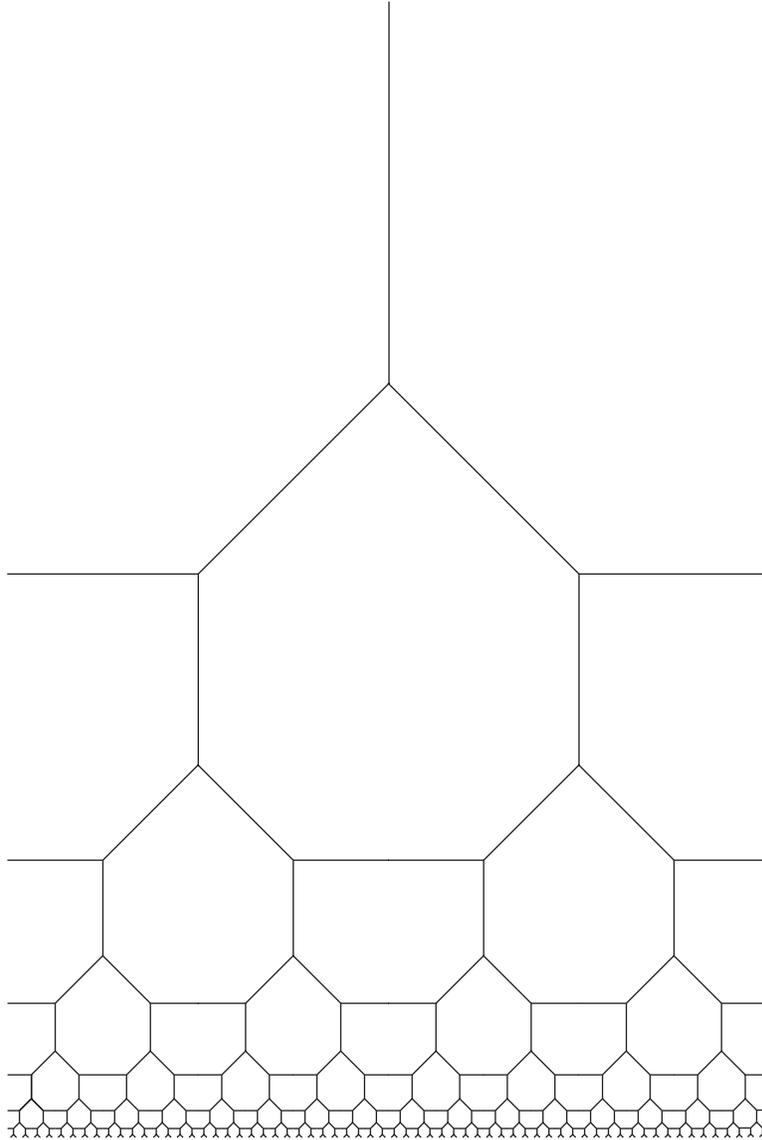
Primary coils impart momentum through polar interaction between cfus of wire and cfus of core. Polar interactions between core cfus and secondary coil cfus completes the linkage.

Electron wind

The term *electron wind* is used to describe a

phenomenon in which a “dense flow of current” produces a gap in the material of a conductor which is attributed to the flow of “electrons”. This is akin to the cup erosion and cone deposition which occurs with automobile ignition breaker points.

Absorption of momentum

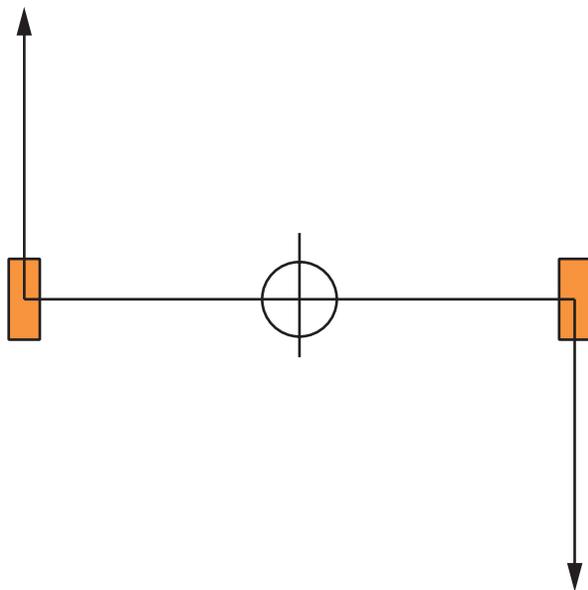


Momentum exchange: absorption.

Each line segment is a momentum vector. Each intersection is a collision between a moving particle and one which is at rest. The moving particle is deflected from its incoming path by 45 degrees; the rest particle acquires the *lost* momentum.

Gyroscope

The gyroscope has its stability from the momenta of the cfus which constitute the rotor.



When the velocities of these cfus are high, the change in their momenta due to the gravitational acceleration is small. The momenta of the cfus lies in the plane of rotation.

Paired cfus exchange momentum

The velocity of each cfu in a rotor is turned through an angle. Its velocity is normal to the radius connecting it to the hub. This change in momentum is provided by another cfu which is diametrically opposite it. This balancing cfu receives its change in momentum from the first cfu. The momentum exchange acts along the diameter connecting the two cfus. This change in momentum is frequently represented as a straight length, but this is an error. The change is always directed radially towards the hub. Because of this fact, the change in the momentum is a circular arc. The vectors for the cfu at two positions are radii with a common center and the momentum change is an arc connecting their tips.

Circular motion

The analysis¹ of the motion of a particle moving along a circular path is erroneous. The displacement of the particle in a given time is a

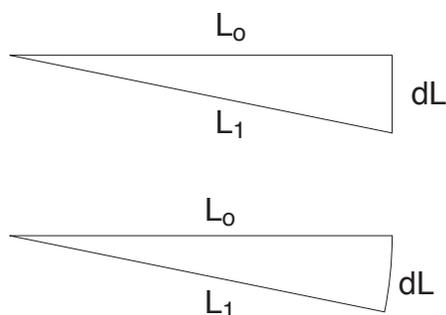
circular arc. The analysis uses the chord of that arc as the displacement. This is an instance of mathematical convenience overtaking reality.

Tethered object

Angular momentum considerations

The concept of angular momentum is employed in discussing a gyroscope. The angular momentum is shown as a vector \mathbf{L} acting radially outward from the hub. The incremental change in the angular momentum $d\mathbf{L}$ is shown acting at right angles to \mathbf{L} . If $d\mathbf{L}$ is added to \mathbf{L} vectorially at right angles then \mathbf{L} will increase. That does not happen, so the vector representation is in error.

For \mathbf{L} to be constant, $d\mathbf{L}$ must be a circular arc. The difference in the two representation is shown in the figure.



Angular momentum.

The upper representation of angular momentum change is the orthodox representation. Here, the change in the angular momentum $d\mathbf{L}$ is shown acting at right angles to the original angular momentum \mathbf{L}_0 . This results in an increased angular momentum \mathbf{L}_1 which does not conform to reality.

The lower representation of angular momentum change is true to the reality. Here, $d\mathbf{L}$ is a circular arc with radius \mathbf{L}_0 . \mathbf{L}_1 has the same length as \mathbf{L}_0 which conforms with reality.

The upper drawing is a right triangle. In this case, the change in the angular momentum is a

1. Sears & Zemansky *University Physics* 2d ed., section 6-2, p. 99.

straight length which is added to the original angular momentum \mathbf{L}_0 . The new angular momentum is the hypotenuse of the right triangle \mathbf{L}_1 . Thus, \mathbf{L}_1 does not equal \mathbf{L}_0 . This is false.

The lower drawing shows $d\mathbf{L}$ as a circular arc whose radius is \mathbf{L}_0 . When this is added to \mathbf{L}_0 , the resulting vector \mathbf{L}_1 is the same length as \mathbf{L}_0 but its direction has changed. This is true to reality.

THERMAL

Thermal Motion of CFUs

To maintain the crystalline order while vibrating, the motion of the cfu must be restricted to the directions of the joins. Adjoining units move with equal and opposite velocities along the join direction. Alternate units move with the same velocity in the same direction along the direction of this join, so that half are moving in one way and the other half are moving equally and oppositely.

The whole line of alternating linearly moving units has an identical relationship with the parallel lines of units which adjoin it in a second join direction. Alternate lines are moving with equal and opposite velocities along the join direction.

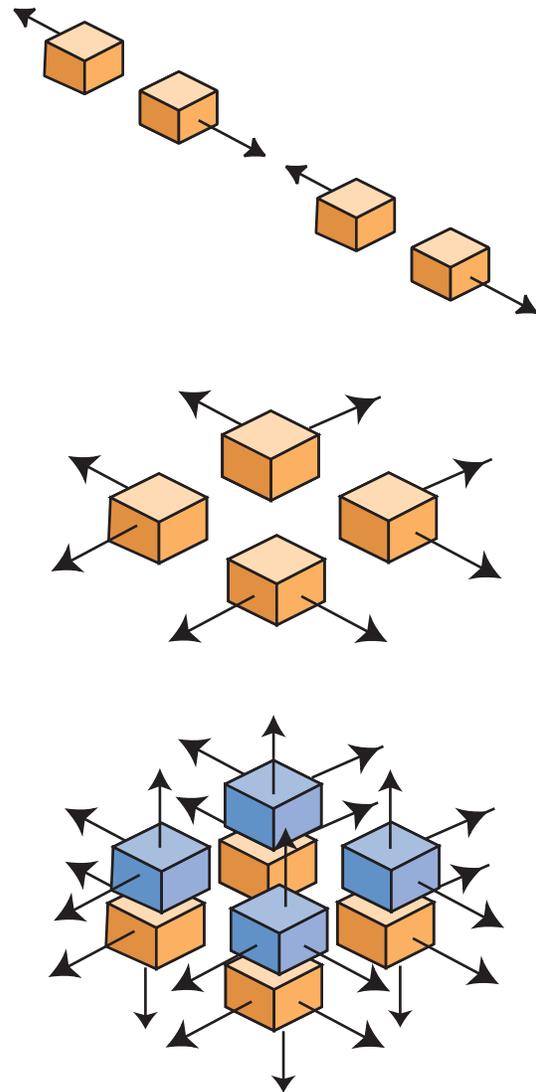
All the parallel lines of units which are parallel along the second direction are a plane, and this plane moves in a third join direction with a velocity that is equal and opposite to parallel planes in the third join direction.

The relationship between adjacent planes of units is the same as that between adjacent lines of units, which is the same as that between adjacent units within the line. Thus the motion along a join direction consists of planes of units moving synchronously.

The volume defined by the join directions of a cfu is facially congruent with an identical volume defined by the cfu to which it is joined. The join direction is parallel to a facial diameter of the cfu volume. The unit volume lies between the planes of the two faces which lie on this facial diameter. Each of the cfus which lies within these two planes moves synchronously in the join direction. The same is true for each of the join directions. For each cfu there is a synchronous plane for each join direction. Adjacent synchronous planes move with equal but opposite velocities. For each of the cfus, there is a velocity for each of the synchronous planes of which it is a part.

Surface and non-surface cfus.

For each non-surface cfu, the motion in a direction is terminated by a collision with an



Thermal motion: cfus

The orange and blue units represent cfus which are in thermal motion within a simple cubic crystalline assembly.

The top figure shows the motion of the cfus in a line which is defined by the joins between the cfus.

The middle figure shows the motion between the cfus in a plane defined by the joins between two lines of cfus.

The bottom figure shows the motion between the cfus in a volume which is defined by the joins between two planes of cfus.

adjoining cfu which reverses its velocity. Between the collisions it is polarly attracted in the direction of motion by the adjoining cfus. Its velocity will be at a maximum at the instant of contact with, or separation from, an adjoining cfu. It will be slowed on separation by the polar attraction difference between the nearer departing cfu and the approaching cfu until it is equidistant between the two. It will then be speeded by the growing proximity of contact. The spring of collision stops the cfu, and then restores it to maximum velocity in the opposite direction. The join-direction-velocity of the cfu is always a combination of its actual velocity and its potential velocity.

A cfu at the surface has no collision to limit its motion away from the surface. It must be slowed by the polar attraction of its near neighbor.

$$\text{Velocity} = \text{Maximum Velocity} + \text{Potential Velocity}$$

For a moving cfu, the volume is defined by the distance between its collisions with adjoining cfus at the instant of velocity reversal. Its potential velocity is at its maximum and the velocity is zero.

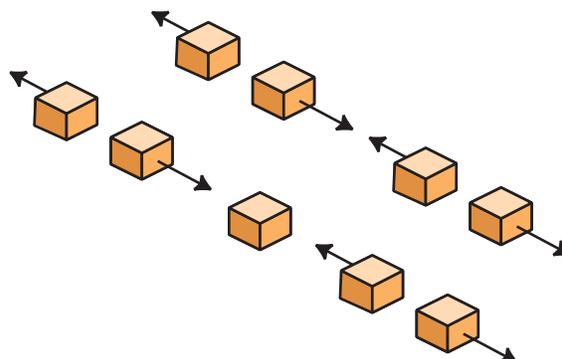
$$\text{Direction Lines} = \frac{\text{Join Directions}}{2}$$

If every cfu must move, then for more than three direction lines, the *between units* motion, *between lines of units* motion, *between planes of units* motion accounting fails. The motion must be described by the expansion and contraction of units about a center. For the BCC, the expansion is between

Motion of cfus if odd or even numbered

If the cfus in a line are even, then each will be in motion within the line except for the transition between directions. For an odd number of cfus in a line, the central cfu remains at rest since it has no partner. The figure shows the

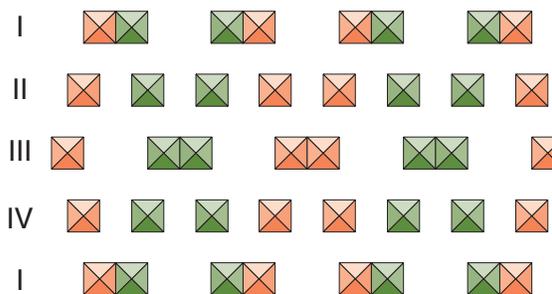
situation for the two types of line. The upper line has two pairs of cfus and the lower has two pairs of cfus on either side of a central cfu.



Thermal motion: Odd line and even line.

The upper line consists of two pairs of cfus. The lower line has two pairs with a central cfu which is not in motion within the line.

Phases of cfu thermal motion



Thermal motion: Phases

- I. Contact with unlike color cfu.
- II. In motion midway from unlike contact on way to like contact.
- III. Contact with like color.
- IV. In motion midway from like contact unlike contact.

Thermal motion in FCC crystals

The join directions of the FCC are along the directions of the six edgial diameters of the regular octahedron. Three of these diameters lie in a plane normal to a face of the octahedron. They are symmetrical and are 1/6 revolution apart. The in-line motion is taken in the direction of one diameter in this plane. The direction of the between-line motion is taken as 1/3 revolution from the in-line motion along a second edgial diameter. The between-plane motion is along the edgial direction which does not lie on either of the edgial equators which include the directions of the first two motions. The motion in the third direction within the plane is equal to the vector sum of the in-line and between line motions. This provides a fourth edgial motion equal in magnitude to the others. The vector sum of the in-line and between-plane motions provides a fifth edgial motion of equal magnitude. The sixth motion is the vector sum of the in-line, between-line, and between plane motions and is of equal magnitude. Adjoining cfus have equal but opposite motions along the line joining them.

Thermal motion in BCC crystals

Eight join directions parallel to the facial diameters of the regular octahedron.

The join directions in the BCC are along the facial diameters of the regular octahedron. When viewed along a facial diameter, the regular octahedron has a regular hexagonal profile. There is a central face which is perpendicular to the facial diameter. Three faces are seen in identical projection and their normals are 1/3 revolution apart when projected upon a plane normal to the viewing direction. Velocity in one of these three peripheral facial directions establishes the in-line motion. Motion between identical lines is established in a second peripheral facial direction. Motion between identical planes is established in the third peripheral facial direction. These three motions have a component in the fourth facial direction which is equal to 1/3 of the other motions. The sum provides that the velocity in this fourth direction is the same as the other

three directions. Thus, each cfu has a motion parallel to each of the join direction lines. Each motion is equal and opposite to the motion of an adjoining cfu along the line joining them.

Thermal motion in the HCP crystal

The motions are not the same as those of the FCC.

Thermal motion in the Hexagonal crystal

There are three motions at 1/6 revolution which lie in a plane perpendicular to a facial diameter of the regular octahedron. The in-line motion is in a direction which is the vector sum of two edgial directions which are at 1/6 revolution. The between-line motion is 1/3 revolution from the in-line motion. The third motion is the vector sum of the in-line and between-line, and this lies between them at 1/6 revolution to each. Each of the three is the same magnitude. It is possible that the edgial direction will lie directly parallel to an edgial diameter and then a single edgial direction suffices. The between plane motion is perpendicular to the plane and lies along the direction of the facial diameter. This will not be the same magnitude as the in-plane motion. The facial diameter is $EdgeLength \times \sqrt{2/3}$.

$$a = \text{Length of He-octa edge} \times \sqrt{m^2 + n^2 + m + n}$$

$$c = \text{Length of He-octa edge} \times p \times \sqrt{\frac{2}{3}}$$

$$\frac{c}{a} = \frac{p \times \sqrt{\frac{2}{3}}}{m^2 + n^2 + m + n}$$

Thermal motion in the rhombic crystal

The rhombohedron has an axis of threefold symmetry which is parallel to a facial diameter of the regular octahedron. Each face of the rhombohedron intersects the axis of symmetry

and the three faces which have a common vertex on the axis of symmetry have minor diagonals which define an equilateral triangle. The motions of the cfus in the rhombohedral crystal are parallel to the edges of the rhombohedral cell. These directions are the vector sum of integral multiples of the directions parallel to the edgial diameters of the He-octa. The three motions are accounted for by the three join lines.

Thermal motion in the tetragonal cell.

The tetragonal cell has two join directions of equal length. These lie in the plane of an edgial equator of the regular octahedron. Each is the vector sum of two integral multiples of directions parallel to the two edgial diameters of the He-octa which lie parallel to the plane. The motion between planes is parallel to the vertexial diameter of the He-octa which is perpendicular to the plane. The join direction is an integral multiple of $\sqrt{1/2}$ times the edge length of the He-octa.

$$c = \text{Length of He-octa edge} \times p \times \sqrt{\frac{1}{2}}$$

$$a = \text{Length of He-octa edge} \times \sqrt{m^2 + n^2}$$

$$\frac{c}{a} = \frac{p \times \sqrt{\frac{1}{2}}}{\sqrt{m^2 + n^2}}$$

Conductivity, Thermal and Electric

The boundaries of the vibrational domain of a cfu is determined by the polar interactions and the collisions between neighbors. When an electrode is placed in an electrolyte, the electrolyte enables cfus at the surface to leave the electrode. Because of its absence, there is nothing at its previous location for its former neighbors to collide with. Thus, their vibrational domains are altered. This alteration

causes further alterations for the neighbors of the neighbors. And the overall result is a momentum void for the entire electrode. For two electrodes which have uneven losses, one will be more momentum depleted than the other. If the void travels through the electrodes and the wire between them, then the outwardly directed momentum of each of the freed surface cfus of one electrode can satisfy the momentum void at the opposite electrode. Thus there is set up a flow of momentum voids moving through the electrodes and wire, and a flow of freed surface cfus through the electrolyte in a direction counter to the void flow. The momentum void is the "electron" in this case. The freed surface cfu is the "ion".

If an cfu in a crystal is thermally active, then it will move relative to its neighbors. It cannot rotate to any extent because it is polarly attached to its neighbors. But it will translate between collisions with its neighbors. When it is not colliding, it is affected by the polarity of the surrounding cfus. If the thermal activity the cfu is disturbed by a deflection of a neighbor, the deflection will be passed to another neighbor. In this manner the deflection will travel through the crystal passed from one cfu to another. Once the deflection is passed, the thermal activity is essentially as it was. If the thermal activity of a neighbor is altered, it will cause a change in the thermal activity of the cfu. Whether the transmission is termed "thermal" or "electric", each process involves the exchange of momentum between cfus which have different momenta. The cfu with higher momentum will be slowed and the cfu of lower momentum will be speeded. The speeding is passed in one direction and the slowing is passed in the opposite. If momentum is added at one end of a wire and taken away at the other end, a momentum flow will be established. If the momentum differential is tested with a thermometer, then the flow is thermal. If the test is performed with an ammeter, then the flow is electrical. These are manifestations of the same process.

Whether the process is the repulsive fragmentation of an atom through fission, or the escape of an cfu from a filament as photon, or the chemical freeing of an cfu from the elec-

trode of a battery, or the passage of heat or electricity, in each case there is a transfer of momentum from one cfu to another or one part of an cfu to another.

Thermal expansion of solids

Thermal path of cfu

At a given temperature the cfu of any crystal-line solid will have the same momentum capacity as any other solid. That means that a cfu with a given mass will move more slowly and have a shorter thermal path than a corresponding cfu which has a lower mass. It follows that for a given change in temperature for two materials, the amount of the path change will be greater for the cfu of lower mass.

Gruneisen has found that the coefficient of linear expansion varies directly as the specific heat. For homogeneous solids the coefficient of superficial expansion is twice the linear, and the coefficient of volumetric expansion is thrice the linear.¹ It was noted above that Dulong and Petit found that the specific heat varied linearly with the atomic weight.

If

$$\text{ThermalExpansion} \propto \text{SpecificHeat}$$

and

$$\text{SpecificHeat} \propto \text{AtomicWeight}$$

then

$$\text{ThermalExpansion} \propto \text{AtomicWeight}$$

Momentum transmission through crystal

The transmission of a velocity change through a crystal is by contact between adjoining cfus. The direction of the change is in the direction of the join. The true distance for such a change to travel is the vector sum of the join distances. A transmission between (100)

planes for a simple cubic crystal travels from cfu to cfu parallel to the plane normal. For a BCC crystal the join directions are at an $\sqrt{2}$ to the plane normal and the component of the join to join distance in that direction is $1/\sqrt{3}$.

Wiedemann-Frantz relationship

Whether the momentum transferred in this manner is part of a thermal circuit or part of an electrical circuit, the cfu to cfu transmission of velocity change is effected in the same manner. There is no "electron gas". There are no "orbiting electrons" whose thermal motions might contribute to the specific heat of the crystal. Just the cfus, and, hence, the proportionality of the two types of conduction which is called the Wiedemann-Frantz relationship.

Thermoelectricity

Seebeck effect and the Peltier heat

The cfu of one metal move with a different velocity from those of another metal at the same temperature. This results in a momentum exchange between the cfus at a common surface. If a circuit is established by another junction of the two materials and the second junction is kept at a lower temperature, the momentum flow at the hot junction causes a momentum imbalance at the cold junction.

For a given T, the momentum of any cfu is identical to that of any other. Collisions between the respective cfus results in a momentum exchange in the direction of the higher momentum. The flow is from A to B at each junction, but the momentum change is proportional to the temperature, and the flow from the hot junction exceeds the counterflow from the cold junction.

There are no electrons involved here. There is no diffusion required for the momentum flow. Only an exchange of momentum between the cfus of the respective crystals is required. The momentum imbalance is the "emf" and the "charge" is the increase in the momentum and thus is "energy" transferred as "heat", is called the Peltier heat.

1. Theodore Baumeister, ed. *Mechanical Engineers' Handbook*, p. 4-7
Expansion of Bodies by Heat

Thomson heat

The Thomson heat is additional evidence that heat and electricity are different descriptions of the same momentum transfer between adjoining cfus.

Svanberg effect

Svanberg discovered that thermoelectricity is influenced by the crystalline structure. He used different orientations of the same crystal plane at either junction.

Conductors and non-conductors

In good conductors, the velocity change maintains its direction, and the temperature differential at the surface is high. In a poor conductor, the velocity change travels in cycles so that the temperature differential at the surface is slight.

In diamond, the cfu is a pair of C_4 tetrahedrons. The transmission between the tetrahedrons requires a rotation. It comes in through one face and out through the other three faces turns back again to the original direction.

Kinetic theory: solid and gaseous

Atomic motion within the CFU

The cfu is a crystalline association of atoms. The contact between adjoining cfus is contact between atoms. The spring of the collision is provided by interatomic spacings and the polar attraction of the joins between the atoms. There is a polar potential velocity between collisions, a spring potential velocity during a collision, and a velocity for each cfu along each join line. The sum of the potential velocities and the velocity is constant for a given temperature.

Refutation of the notion of the “equipartition of energy”

If two particles collide periodically so that their directions are reversed, the exchange of momentum between the two is such that if there is a difference between the momentum of the two, then the cfu with the lower momentum leaves the collision with the higher

momentum and the cfu entering with the higher momentum leaves with the lower momentum. This occurs because the force between them is equal and oppositely directed and simultaneous. The cfu with the lower momentum loses its velocity and is then accelerated in the direction of the other cfu. The acceleration of the low entry is at the expense of the high entry and when the compression ends the lower entry has a velocity in the direction of the higher entry which is at the expense of the higher entry. The exchange is from higher to lower. No equilibrium is possible between two such cfus, and the difference in momentum is passed on. The container analysis is faulty because it does not recognize that the reality of the exchange is always between a pair of cfus. The frequency of the hits has no bearing, there will always be a momentum exchange. There will always be a flow from the higher to the lower. If the cfus have the same k.e. then there can be no equilibrium. The cfus at the same temperature must have the same momentum. No momentum can be exchanged between cfus with the same momentum. Momentum must be exchanged between cfus which have different momentum.

Should the mass of a vibrator differ from that of an adjoining vibrator while its momentum is identical to that of the adjoining vibrator, the collision will only reverse the direction of the velocity of each vibrator. If the momenta differ, then the momentum of one is exchanged with that of the other. Thus, it is not possible for a vibrator to maintain a momentum which differs from that of an adjoining vibrator. If a difference of momentum cannot be maintained, then the equipartition theory is false.

The reference for the motion of a cfu is the surface of the crystal. The steps of the collision are

Contact, begin compression of springs. Springs equally loaded.

Least velocity is zero. Momentum of greater is equal to difference between momenta at contact.

Least velocity is equal to most velocity, the common velocity is equal to the difference between the momenta at contact divided by the sum of the two masses.

Most velocity is zero, least momentum is equal to the difference between the momenta at contact.

Separation. Springs restored. Momentum has been added to each which is equal in magnitude to that of the least at contact. The most has the momentum that the least had at contact. The least has the momentum that it had at contact plus the difference between the two at contact. This is equal to the momentum of the most at contact.

Throughout the period of the collision, the force which acts upon each vibrator is equal to, and oppositely directed to, and simultaneous with, that which acts upon the other vibrator. The force exerted by the one is the force which acts upon the other.

Specific heat

Explanation

If a substance is composed of identical oscillators of a given mass at uniform temperature, then the number of oscillators in a given weight is inversely proportional to the mass of the oscillator. The greater the mass of the oscillator, the fewer the oscillators. If the oscillators of the iron and lead are their respective atoms, then a given weight of iron has more oscillators than the same weight of lead by the inverse ratio of their atomic weights, or 207/55.

The momentum of an oscillator of a substance at a given temperature is precisely that of the oscillator of any other substance at the same temperature. Because the iron has more oscillators than the equal weight of lead, there is a greater amount of momentum for the iron to exchange with the water than there is for the lead.

Dulong and Petit

Molecular or atomic heat equals the specific heat times the atomic weight. Dulong and Petit's Law states that the atomic heat is about 6.3 for high atomic weight elements. This law suggests validity of molecular momentum heat exchange.¹

$$\frac{\text{weight}}{\text{AtomicWeight}} = \text{NoOfAtoms}$$

Specific heat depends upon the number of atoms.

$$\text{SpHt} \times \text{AtWt} = 6.4 = \text{Heat} \times \frac{\text{TempDiff}}{\text{Mass}}$$

The constant 6.4 or 6.3 is dependent on the dimensional units chosen. The number of atoms of a body times their mass times their average velocity is the "heat" of the body. The temperature is the velocital expression.

The temperature of a body or system is the momentum of any molecule of that body or system.

For melting or evaporating, consider an increase in the number of molecules as the "heat" storage or conversion. Thus, the "temperature" or molecular momentum is constant while the number of molecules grows. This must happen through the breakup of larger molecules. By molecules in the heat sense is meant any association of atoms that behaves as if it were a microbody, that has coherency as a structure, that the spatial relationship between its atoms is constant or nearly so.

Think of gas or vapor as an extended solid. The molecules are moving in the same manner as in the liquid that preceded it and the solid that preceded the liquid. The molecules are just further apart. This is preferred to the notion of molecules flitting enormous distances from container wall to container wall. The structure of a gas is tenuous. That of a liquid is less so. Still, in each of these states, each molecule should have a domain of activity in accord with the domains of neighboring molecules.

Bond-breaking. Think of same number of

1. Max Planck *Treatise on Thermodynamics*, Alexander Ogg translation, 3d ed., 1927, p 36 secs. 48 & 49. See also *Hdbk of C & P* p F-109.

molecules but with fewer bonds.

Think of molecules as systems. Each molecule comprised of atoms vibrating within the molecular system. Now, the molecular system vibrates with the body. So that specific heat is determined by the number of molecules, or molecular systems. Like living organisms appear as bodies and move within certain limits that can be physically defined without considering the cellular or subcellular activities.¹

1. Arthur Edward Ruark and Harold Clayton Urey *Atoms, Molecules and Quanta*, 1st ed, 5th impression, McGraw-Hill, 1930, ch 1, sec 6, pp 9 & 10.

LIGHT

Optical phenomena

The understanding of the phenomena related to light is confused by the conflict between particle and wave. The two views are not reconcilable. The particle is required to explain blackbody radiation and the photoelectric effect. The wave concept has persisted only because the manner in which particles produce the phenomena of diffraction and refraction had yet to be discovered. That explanation is provided here.

Diffraction: a phenomenon due to particles

Diffraction is observed when light passes through a cylindrical hole in an opaque material such as a pinhole or a slit. The pattern which is focussed upon a retina or viewing screen consists of concentric rings of varying brightness which have the shape of the perimeter of the cross-section of the hole. The analysis produced here is for light of any color which will reflect from the material which defines the slit in accordance with geometric optics; i.e., the angle of incidence equals the angle of reflection and the incident ray and the reflected ray define a plane which is perpendicular to the reflective surface at the point of incidence. It requires that the light pass through a homogeneous medium from source to observer so that there is no refraction other than by the lens of the observer in focussing the pattern on the retina or film.

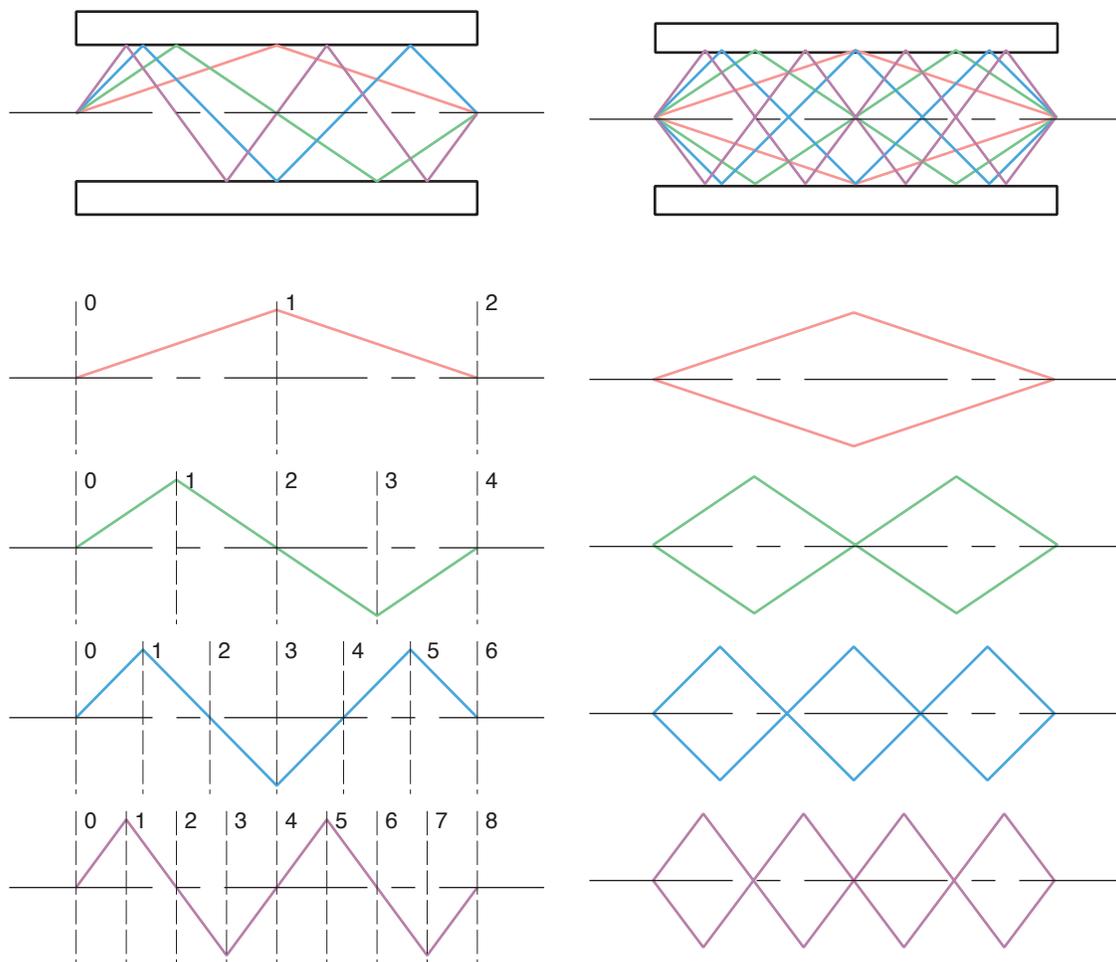
Light trajectories and slits

The following analysis discovers the manner in which particles are geometrically compelled to define the patterns observed when light passes through a pinhole or slit.

A plane slit is defined by two parallel lines of equal length L and separated by width w whose termini lay upon perpendiculars common to both. Each line represents a reflective surface. An aperture is defined by a perpendicular to each of the surface-lines at a terminus. There are two apertures.

If a particle hits a surface, it bounces from the surface so that its exit trajectory makes the same angle with the surface-line as does its entry trajectory. Each reflection is symmetrical about the normal to the surface line at the point of contact. The trajectory of a particle is composed, then, of straight-line segments each of which lies in the same plane as the surface-lines. The segments have one of two orientations. The first is the orientation prior to entering the slit and the second is the orientation of the segment after the first reflection. The orientations alternate, and the number of bounces determines the number of segments. The portion of each segment which is subtended by the pair of surface-lines, or their extensions, is identical in length to that of any other.

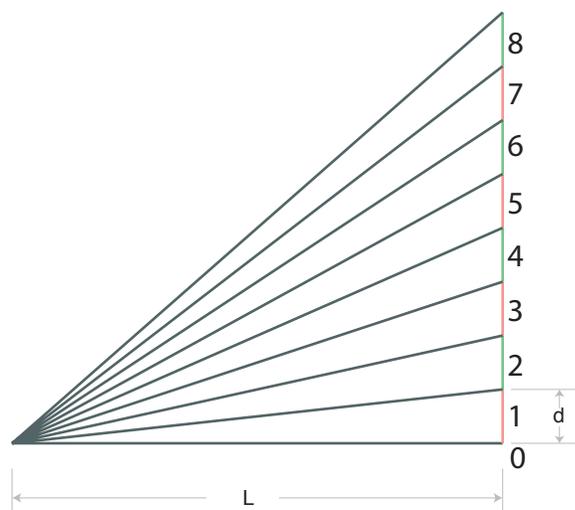
If the number of bounces is odd, the particle will exit the slit in a direction which is parallel to the first reflected path. If the number is even, the trajectory on leaving will be parallel to the original trajectory. Each of the odd-numbered reflections takes place on the far surface; each of the even-numbered reflections takes place on the near surface. The angle which the trajectory makes with each surface is the same for both incidence and reflection and is identical for each bounce of a multiple bounce trajectory.



Pinhole diffraction: Photon bounce trajectories.

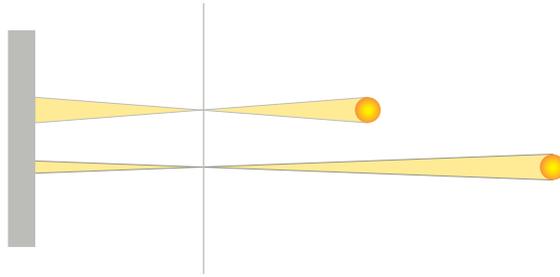
In the left column of the figure, the top view is a section through a pair of parallel reflectors. At the left end, a point source of light is the origin of four photon paths which are represented by line segments of the same color whose direction is altered by reflections, the first of which occurs at the upper reflector. The paths terminate at the viewpoint of the observer. Paths are shown for reflections numbering one, two, three, and four. Each of these paths is shown separately below the top view. Numbered stations mark equilength segments which represent the photon path from source to reflector, from reflector to centerline, from centerline to reflector, and reflector to observer.

In the right column of the figure, the paths whose first reflection is from the upper reflector are combined with the paths whose first reflection is from the lower reflector.



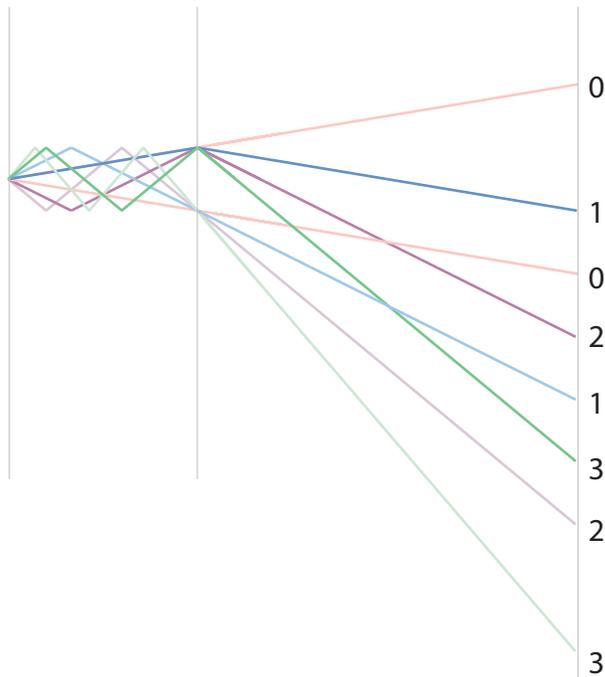
Pinhole diffraction: Photon bounce path lengths.

The length of the path traveled by a photon depends on the number of bounces it undergoes. The sum of the abscissas of the path segments for a given photon equals the distance between source and observer. It is the same for each of the observed photons. The sum of the ordinates of the photon path segments is equal to the number of bounces the photon undergoes times the diameter of the aperture. The path length is the hypotenuse.



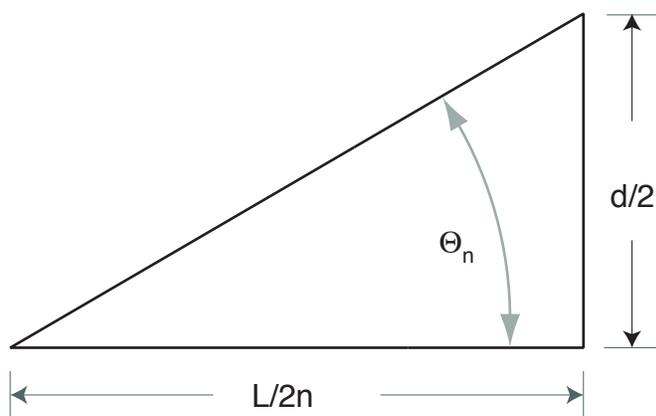
Pinhole diffraction: Reflected image reduction.

The images that result from reflected light are reduced in size because of the greater distance traveled by the photons from the source. The figure represents the images projected upon the screen at the left by the lens for two cases. The upper representation is for unreflected light; the lower representation is for light which has been reflected which places the source at a greater distance.

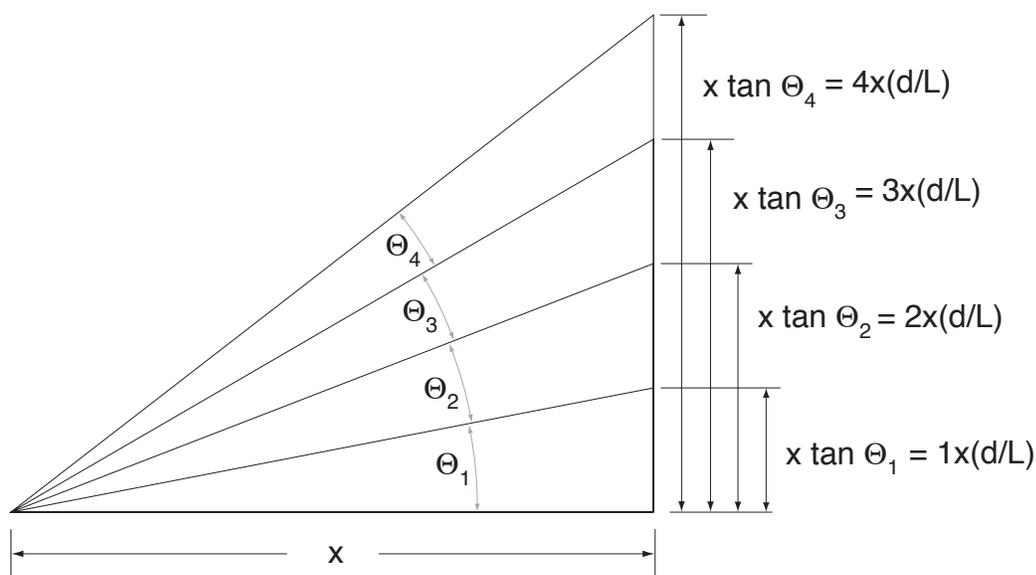


Pinhole diffraction: Bounce trajectory limits.

The figure shows the trajectory limits for those photons which bounce the indicated number of times and whose last bounce was from the upper reflector. The trajectory of every photon which bounces twice and whose last bounce was from the upper reflector will lie between the violet colored lines. The red lines mark the boundaries for the photons which pass through the cylinder without reflecting from the surface.

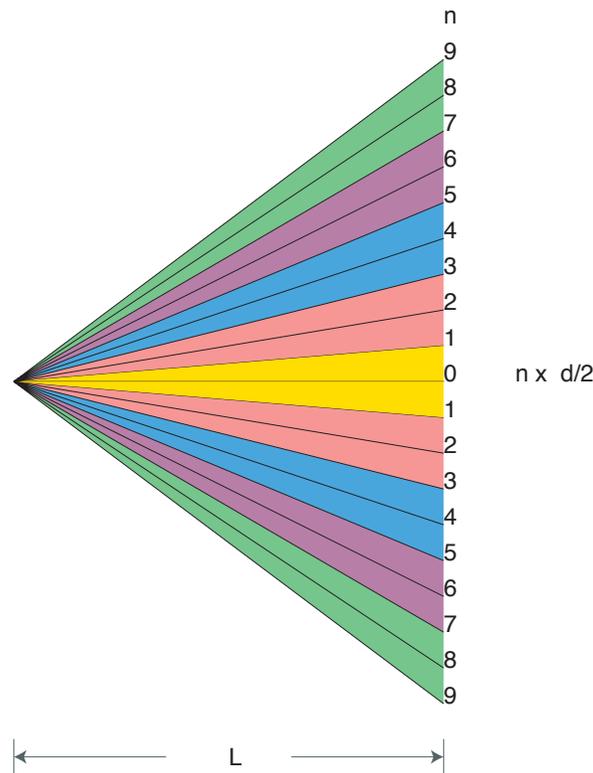


$$\tan \Theta_n = \frac{d/2}{L/2n} = \frac{nd}{L}$$



Pinhole diffraction: Photon trajectories.

Each of the reflected photon paths consists of equilateral segments which are delimited by the reflector wall and the centerline joining source and observer. For a given number of bounces, each segment makes the same angle with the centerline. The relationship between these angles for the paths involving differing numbers of bounces is shown in the bottom view. For a given abscissa, the ordinate is an integral multiple of the ratio of reflector diameter to reflector length.



A particle which approaches a slit on a trajectory which makes an angle with the surface-lines can enter an aperture at one of its extremes by just missing the terminus of the near surface-line and at the other extreme of the aperture by just hitting the terminus of the far surface-line. The former will be undeflected and the latter will be fully reflected.

A particle can leave an aperture at either of its extremes by just missing a terminus of a surface-line or by just hitting a terminus of a surface-line.

Each particle which passes through a slit is characterized by a direction which is the angle that its trajectory segments make with the surface-line. It is further characterized by the number of bounces that it undergoes in the passage. For a given number of bounces, n , and a given slit L and W , the angle that a trajectory may have lies between two limits. The limits are defined by the extremes within which the number of bounces can take place. Each of the equilengthed segments terminated by bounces requires an interval in the direction of the surface-line which is equal to the width

of the slit times the cosine of the angle of the trajectory. The bounces take place within the length of the slit. There are $n-1$ intervals between n bounces. If the first bounce is at the far terminus at the entrance and the last bounce is at a terminus at the exit, then the full length of the aperture is used by the $n-1$ equal intervals between the n bounces and the interval is $L/(n-1)$. Since each bounce takes place on the surface opposite to both the previous bounce and the subsequent bounce, the trajectory is the hypotenuse of a right triangle whose abscissa is the interval and whose ordinate is the width of the slit. Since the width is constant and the interval here is a maximum, the angle is a minimum for the number of bounces.

$$\text{Minimum Angle} = \text{atan} \left\{ \frac{W}{\left[\frac{L}{n-1} \right]} \right\}$$

The other extreme is where both the first bounce and the last bounce take place as far from the near aperture as possible. This occurs where the trajectory just misses the near

terminus at the entrance and just misses a terminus at the exit. The number of intervals between the bounces is n-1 and there is an interval preceding the first bounce and another following the last bounce for a total of n+1 intervals using the full length of the slit.

$$\text{Maximum Angle} = \text{atan} \left\{ \frac{W}{\left[\frac{L}{n+1} \right]} \right\}$$

For each of the angular extremes, there is but one trajectory. If the first trajectory is shifted parallel to a surface-line in either direction it will lose a bounce. If the second trajectory is shifted in one direction it will not enter the aperture and in the other direction a bounce will be added.

For any given angle between the extremes, the trajectory may be shifted to a parallel position without changing its bounces or blocking its access. The shiftable trajectories are of two types, one type is limited by just misses and the other type is limited by just hits. The normal distance between equivalent segments of the trajectory at the limits of its shift is the linear access for that trajectory.

I, interval

$$I = W / (\tan \theta)$$

H, access for hit-hit limits

$$H = (n \times I - L) \times \sin \theta$$

M, access for miss-miss limits

$$M = [(n + 1) \times I - L] \times \sin \theta$$

The access is a maximum for the trajectory which just misses on entering and just hits on leaving the slit at one shift limit. At the other it just hits on entering and just misses on leaving. It fits into both the miss-miss and hit-hit shift types. This trajectory has n equal intervals, n-1 between bounces and another preceding the

first bounce or following the last bounce.

Θ, angle at maximum access

$$\Theta = \text{atan} \left(\frac{W}{\frac{L}{n}} \right)$$

L_{max}, maximum access length

I, interval

$$L_{\text{max}} = I \times \sin \Theta = \left(\frac{L}{n} \right) \times \frac{W}{\sqrt{W^2 + \left(\frac{L}{n-1} \right)^2}}$$

For the maximum access for each of the bounce numbers, the projection upon a screen line which is perpendicular to the surface-line has a length which is equal to the width of the slit.

S, screen line

A, access line

θ, angle

$$S = \frac{A}{\cos \theta}$$

$$I = \frac{W}{\tan \theta}$$

A here is Access, not access line?

$$A = I \times \sin \theta = \left[\frac{W}{\tan \theta} \right] \times \sin \theta = W \times \cos \theta$$

$$S = \frac{A}{\cos \theta} \times W \times \cos \theta = W$$

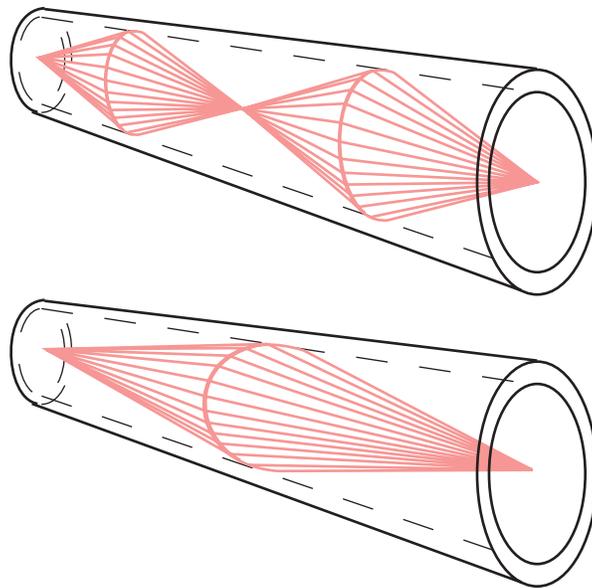
Pinhole diffraction: Seeing is believing

A pinhole is a circular cylinder. The interior of a piece of metal tubing is a circular cylinder. The difference between the two cylinders is a matter of size. The unaided eye can see into the tube to observe the light which reflects from any portion of the interior surface. The indicator light of a computer or a cordless phone is small enough to be positioned variously within or near the aperture opposite the eye and pow-

erful enough to provide multiple reflections which can be seen.

If the light is located on the axis of the tube, the eye sees concentric circular reflections. The smaller circles are nearer to the light end of the tube, the larger are closer to the eye. The intervening space between the bright rings is dark. This pattern formed on the retina of the

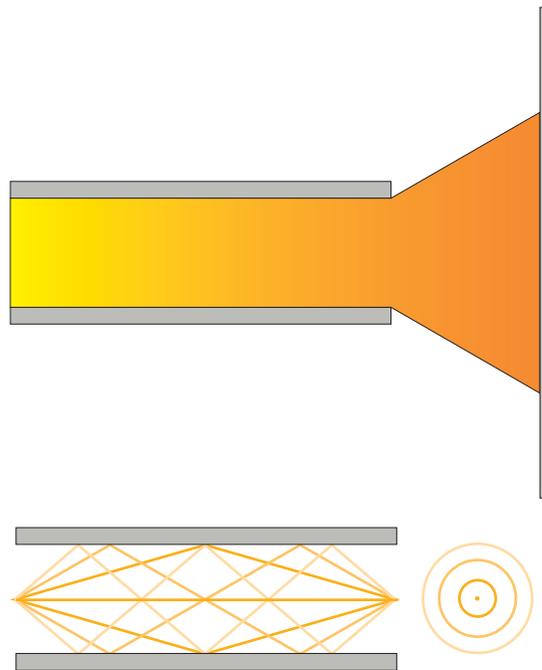
eye is the same as the pattern that light emerging from a pinhole and focused by a lens forms on a screen. There is no interference or reinforcement here. There is only light multiply reflected. There is no conflict here between the observed pattern and the behavior of bouncing particles. The brightest innermost ring is



Conical distributions of particle trajectories in a tubular reflector.
Bottom, pattern for a single reflection; top, pattern for two reflections.

remotest from the eye; it is described by photons which travel the shortest distance from the source to the eye; and it is due to a single reflection. The second ring is next in brightness, next in apparent size, next in remoteness and is due to two reflections; it is described by

photons which travel the second shortest distance from source to eye. The third is due to three reflections and so on. This has nothing to do with waves. This is geometric optics. This is diffraction.



Pinhole diffraction: geometry

The figure shows six particle paths passing through the junctions of the two apertures with the axis. The six trajectories are symmetrically paired about the axis. Each of the pair nearest the axis is the result of a single bounce. Each of the next adjacent pair is due to two bounces. And so on to the outermost pair each of which results from three bounces.

For a pinhole or tube, the drawing is a section through the axis. If the section is rotated one half-turn about the axis, the possible trajectories for the tube are described. Each segment of a trajectory describes a conical surface, and each symmetrical pair of segments describes a cone. At a distance from the tube, the emerging trajectory cones intersect a plane perpendicular to the axis as concentric circles. A point source of light placed at the trajectory intersection at one end of a tube will produce the concentric ring pattern that emerges at the other end. This is what the observer sees when he looks into the metal tube with an indicator light on the axis at the opposite aperture of the tube.

Pattern resulting from source not on centerline

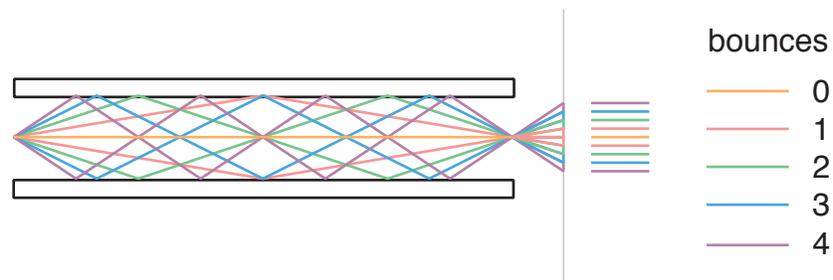
A piece of tubing can represent a pinhole. If one looks through the tube in a direction near the red indicator light of a cordless phone, one will see that the light is reflected as an arc from the side of the tube away from the source. This arc is reflected several times from both sides of the tube. Each of the reflections is a secondary source of light. If the outlet of the tube is some distance from a screen, the angle between each of the sources of this light and the location of the tube axis screen intersection will be small. It will appear as if there is only one source. As the spot on the screen moves radially outward, there will be less and less of the inside of the tube visible, and there will be fewer and fewer sources and these will be weaker and weaker. But there will be banding on the screen of bright and dark rings or half rings corresponding to the individual secondary sources of photons in the tube. These are not due to interference of waves or particles; these are due to the geometry of the reflections. Even if the light is passed through a slit, the same size as the tube slit, when viewed through the tube it will only fill a small area of the opening because of its distance. And even if it is viewed so that it is directly on the axis of the tube, reflections will be seen as circles of light spaced along the length of the tube. The light from these secondary sources will illuminate the screen in the same manner as previously. If one photon came through at a time, as long as all paths are probable, the pattern on the screen will be the same.

If a second slit is opened through the screen adjacent to the first, the portion of the screen between the slits will be cast as a shadow. If the slits are the same and are in the same relationship to the source, then the secondary sources will be radiating from similar positions. A pattern develops from this relationship which is spatial. If a set of lines is drawn from a point so that the separation of the lines is a given angle, a uniform pattern results in which the rays intersect a line perpendicular to the central ray. The space between adjacent rays is closest at the center and becomes progressively larger away from the center. If a second center

of propagation which lies on a line parallel to the screen and near to the first, its rays will cross the rays of the first source. This results in circular bands of light and dark which are caused by the patterns of intersecting rays. The screen cuts off these rings and this results in bands of light and dark corresponding to the circular patterns. The screen will have a dark band at its center if it intersects a dark band at this point. A little closer or a little further away and it will intersect a light band. Again, the rays represent particle paths. The pattern is produced by the paths. If the paths are probable paths for photons, and the source of the rays is a slit and the screen is a photographic plate, a pattern of light and dark banding will develop on the plate. There is no required interference between the photons to produce this pattern. It is purely geometrical.

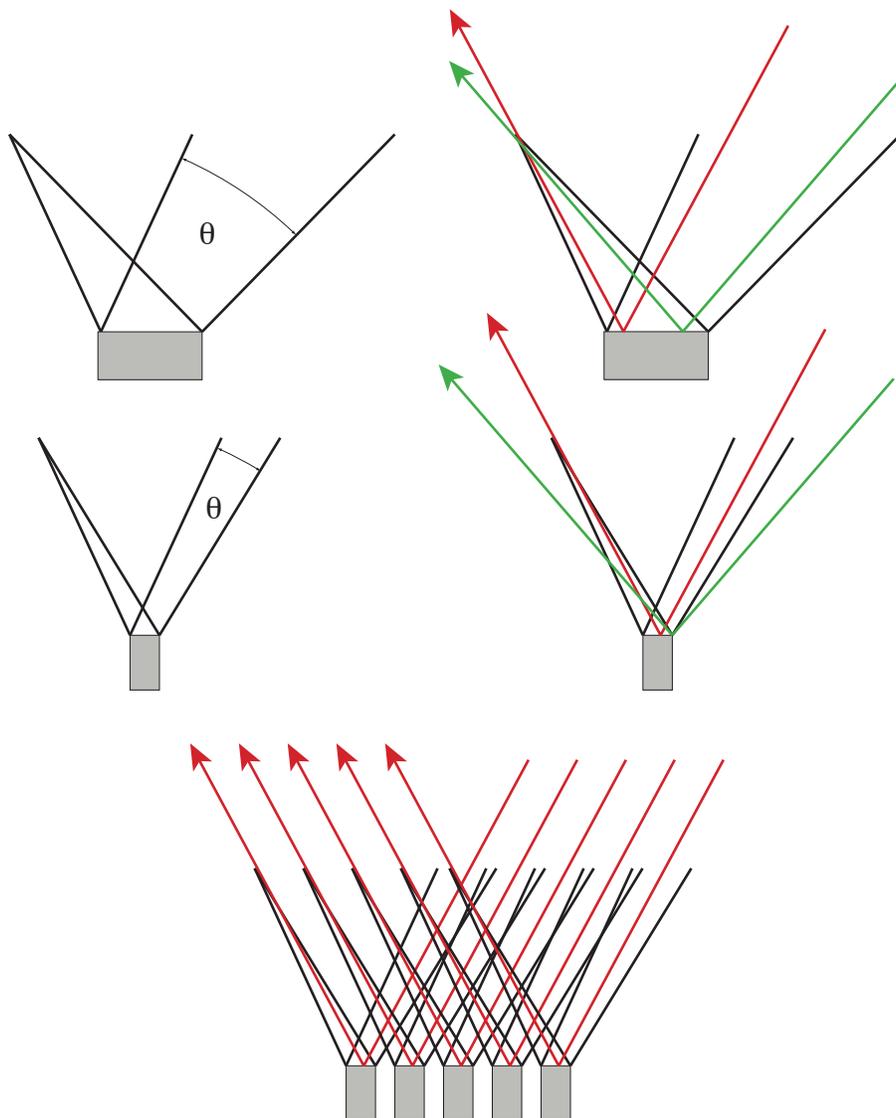
The intersecting lines define four sided figures. The opposite sides are from the same source. There are two from each source. The angle between each pair of crossing lines is small, so that they appear as one line to either side of their intersections. This provides an element of a light band. Midway between the intersections the lines are nearly equidistant. This provides an element of a dark band. The dark bands produced by the trajectory lines will be more widely exposed portions of film. The light bands will be more restrictively exposed.

If there is just one slit, but through reflection separate images are produced of the slit, then the same geometrical pattern of intersecting trajectories will be formed. This is seen in a Michelson interferometer when the mirrors are not perpendicular, in a Lloyd's mirror, and Pohl's mica interferometer.



Slit diffraction: geometry.

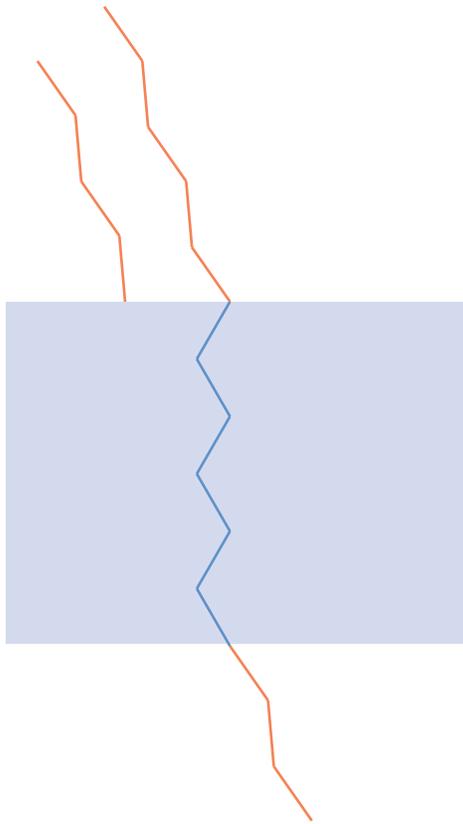
The trajectories for the bounce vectors from each surface of a plane slit are identified by color. The band of colors to the right of the slit are the projections of the bounce vectors upon a screen which is indicated by the gray line. The regular pattern is a function of the bounce geometry.



Diffraction: Reflective grating

The light which reaches the earth from the sun is refracted by the earth's atmosphere. The amount of the deflection is dependent on the color of the light. Two colors arrive at an observer as two concentric cones. Where the cones overlap, the color is white. A reflective diffraction grating is an array of parallel mirrors, each very small. Each reflects the light which strikes it so that the incoming and outgoing photon trajectories are symmetrical about a normal to the reflecting surface. Because the two colors arrive at the reflector at different angles, they reflect in two different directions. To observe one reflected color, the eye must be at position *A*; to observe the other reflected color, the eye must be at position *B*. This phenomenon has nothing to do with the spacing of the mirrors. The effect is the result of the atmospheric bending of the paths of the particles of the two different colors so that they are no longer parallel.

The photons which arrive at the observer from a small mirror must fall within the angle subtended by the mirror. The smaller the mirror at a given remoteness, the narrower the trajectory angle which can be seen reflecting from the mirror.

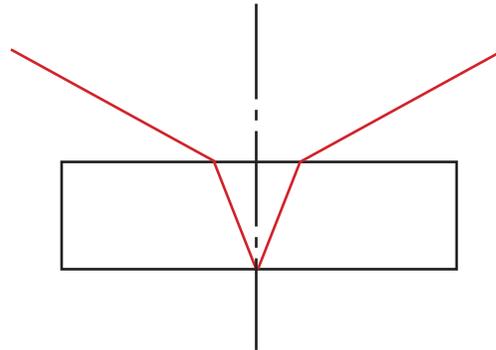


Refraction: Photon paths through media.
 The red colored segments represent the path of the photon through one medium and the blue colored segments represent the path of the photon through a denser medium. The general direction of the photon is restored after traversing the denser medium.

The path shown in red is composed of two differently oriented segments which represent the reflective collisions with the particles which make up the medium. They are equal in length but adjoining segments have a different direction. There are two orientation that the photon might have on reaching the interface between the media. The two ways are shown above the blue which represents the denser medium.

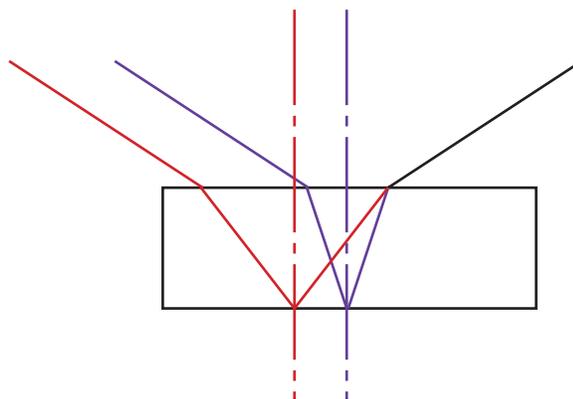
Refraction

The reduction in the apparent velocity of a photon in its passage through a gas or a solid, if there is no permanent loss of velocity, is due to the delay caused by its collisions with the groups of atoms which compose the medium. If the collisions are like those in a probability maze, uniform throughout its path, then most of the photons will proceed in a given general direction. The seeming loss in velocity will depend on the time required for each collision and will include the increased length of its path due to deflections from the general direction which it undergoes.



Refraction: symmetrical relationships of photon path.

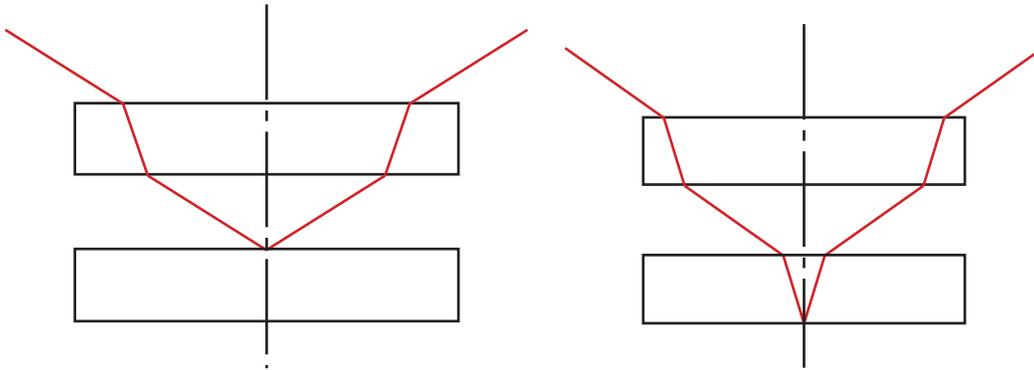
For a given wavelength both the source and the observer must lie along a branch of the path. Only light of a specific wavelength will travel this path.



Refraction of light beam consisting of two wavelengths. Reflection after refraction, followed by a second refraction.

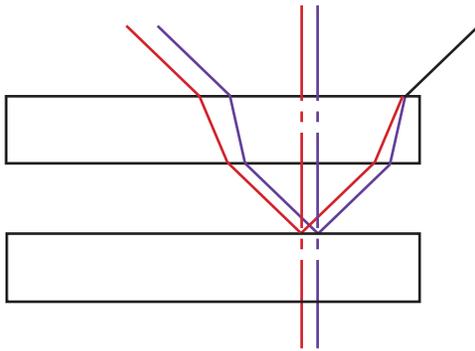
Refraction: Air gap between two glass plates

The eye sees a ray which reaches it from a point on the lower surface of the upper plate only after it is refracted at the upper surface of the upper plate.

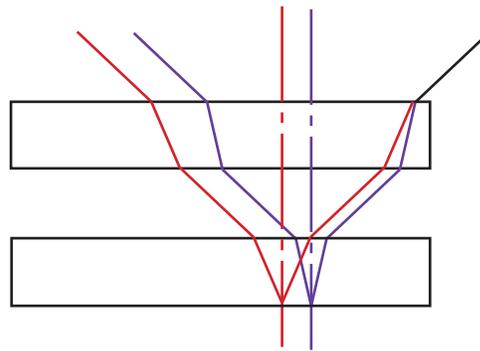


A beam of a single wavelength passing through the upper plate, reflected at the surface of the lower plate, and passing through the upper plate again.

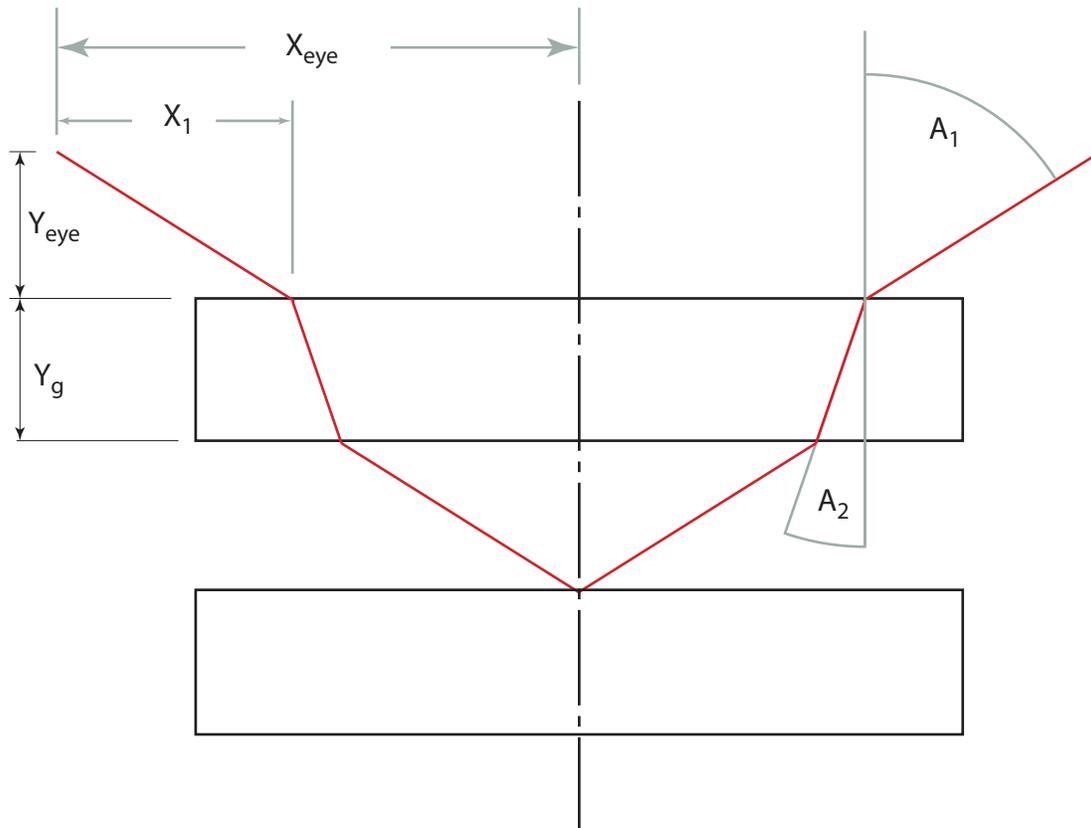
A beam of a single wavelength passing through two plates, reflected at the lower surface of the lower plate, and passing through the two plates again.



A beam of two wavelengths passing through the upper plate, reflected at the surface of the lower plate, and passing through the upper plate again.



Multiple refractions with splitting of original beam into two beams of different wavelengths.



Refraction: equation

The equation relates the ratio of the indices of refraction with the point of intersection of the emergent ray. For each point of emergence, there exists a single index ratio. The eye can see from that point only light with that particular index ratio which has arrived there from the specified point on the lower surface. This is the result of the geometry and the refraction. It has nothing to do with interference. It is the way the photon bounces.

The inertial force of a collision upon a particle increases with its velocity. The greater inertial force causes a greater deflection of the particle. Where the collision is elastic, the spring compression takes longer and the restoration is longer as well. Faster particles will be more greatly deflected at a surface and take longer to pass through a transparent layer.

Construct normal to the lower surface at the point where it is intersected by the ray

- X_{eye} , distance from normal to eye
- Y_{eye} , distance from upper surface to eye
- Y_g , thickness of upper plate
- N_1 , index of refraction of air
- N_2 , index of refraction of glass
- A_1 , angle of ray in air with perpendicular to upper surface
- A_2 , angle of ray in glass with perpendicular to upper surface
- X_1 , distance between normal to upper surface at point of ray emergence and eye

$$N_1 * \sin(A_1) = N_2 * \sin(A_2)$$

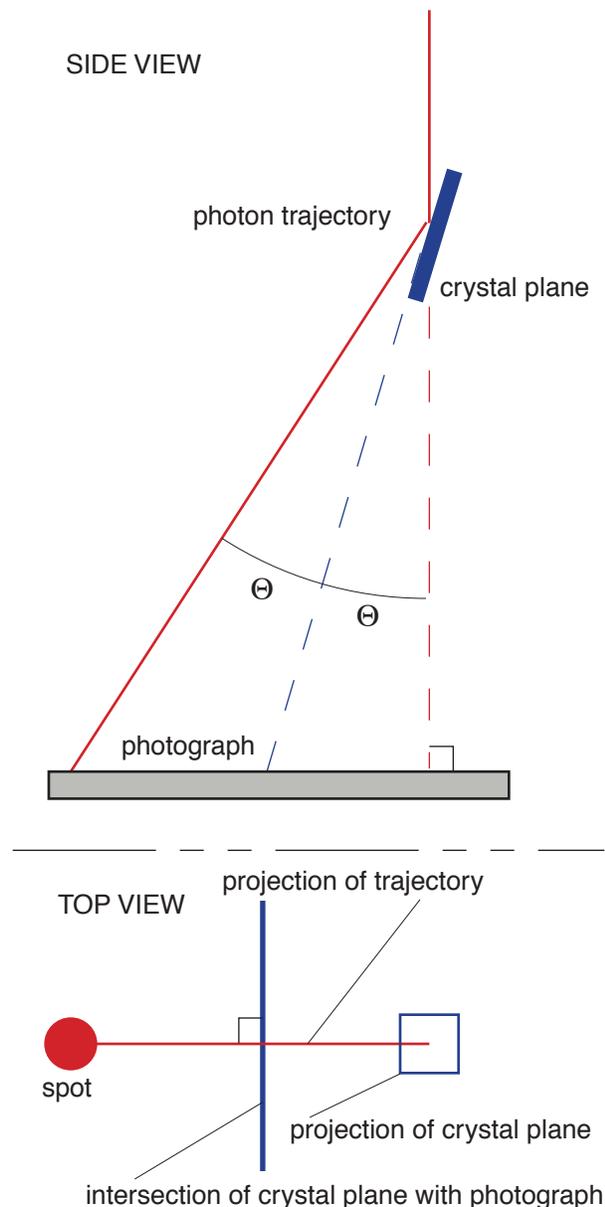
$$\sin(A_1) = X_1 / \sqrt{X_1^2 + Y_{eye}^2}$$

$$\sin(A_2) = (X_{eye} - X_1) / \sqrt{(X_{eye} - X_1)^2 + Y_g^2}$$

$$N_2 / N_1 = [X_1 / (X_{eye} - X_1)] * \sqrt{[(X_{eye} - X_1)^2 + Y_g^2] / (X_1^2 + Y_{eye}^2)}$$

LAUE

X-ray photon trajectory



Geometry of the Laue reflection by a crystal plane.

The photon trajectory begins normal to the plane of the photograph. The photons are reflected by the crystal plane so that the angle

which its trajectory makes with the crystal plane on entry and the angle which the trajectory makes with the crystal plane after reflection are equal. The two portions of the trajectory define a plane which is perpendicular to both the crystal plane which reflects it and the photograph which is exposed by it. This is shown in the diagram which consists of two views of the reflection. The side view is normal to the plane of the trajectories and parallel to the planes of the photograph and the crystal plane. The top view is normal to the plane of the photograph and parallel to the plane of the trajectories.

The top view shows that the trajectory plane is perpendicular to the intersection of the photographic plane and the crystal plane.

Laue x-ray reflections

A Laue photograph is made by bouncing photons from the surfaces of a single crystal. The direction of the bounce is determined by the orientation of the face from which the photon bounces. The incoming direction of the photon is perpendicular to the plane of the photograph. The plane of the face intersects the plane of the photograph as a line. The trajectory of the photon on its approach to a crystal face and its trajectory on leaving that face define a plane which is perpendicular to the plane of the face and to the plane of the photograph and to the line of intersection of the plane of the photograph and the plane of the face. If the plane of the face is perpendicular to the plane of the photograph, no reflection. If the two are parallel, there is no reflection. The direction that the deflection takes is determined by the orientation of the face. The angle of the face to the incoming beam determines the angle at which it leaves the face. If the angle of the face to the incoming beam is θ , then the angle of the outgoing beam is also θ . So, the angle which the outgoing beam makes with its original direction is $2 \times \theta$. The radial distance from the original beam direction is the distance from the crystal to the plate times the tangent of twice the angle of incidence. These trajectories are determined solely by the geometry of the crystal and its orientation relative to

the x-ray beam. The place where those trajectories intersect the plane of the photograph is determined by the distance between the crystal and the photograph.

Effect of crystal surface on x-ray reflection

A. H. Compton found that grinding and polishing the face of a calcite crystal used in a x-ray spectrometer doubled the intensity of the reflected x-ray beam.¹ This doubling could not have occurred if the Bragg reflection was other than a surface phenomenon.

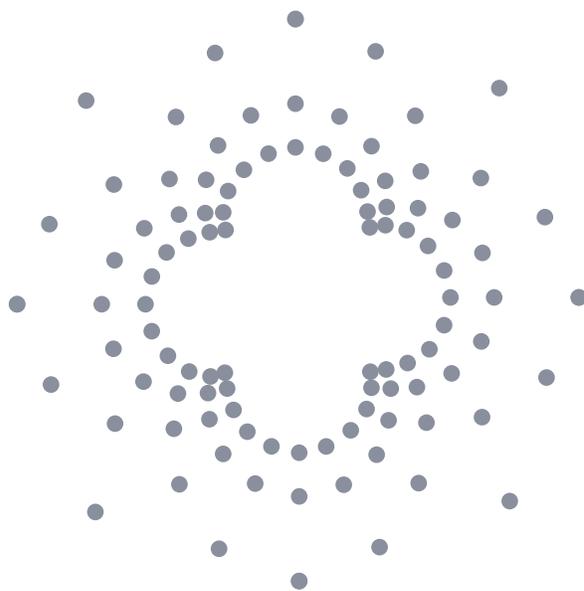
Laue and powder diffraction difference

For the Laue, the normal to the plate through the crystal is the abscissa for each of the spots and the radius from this normal is the ordinate. The relationship between ordinate and abscissa is the tangent of twice the glancing angle, which is the angle between the crystal plane and the incident beam.

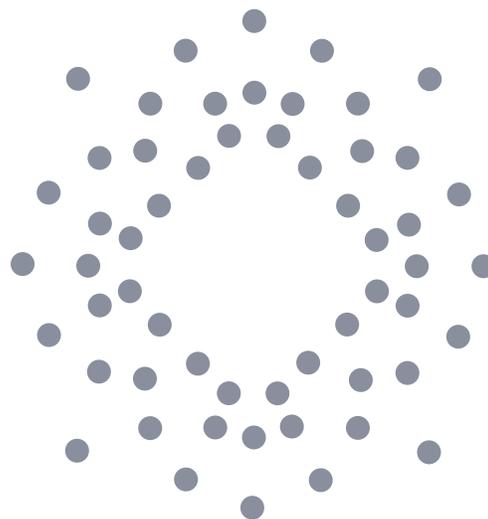
For the powder diffraction camera, the photo is a cylindrical surface and the crystal powder is on the axis of the cylinder. The distance from the crystal to the photo is the hypotenuse, and the deflection is the circumferential distance. It is the radius times twice the glancing angle.

CFU determines x-ray diffraction

The intensity of x-ray reflections from a plane is a function of the spacing of the cfus of the plane. The greater the area of the plane-defining moves, the fewer the cfus per unit area of the reflecting surface. The fewer the cfus, the fewer the reflections. The fewer the reflections, the lower the intensity



Laue pattern for sylvite crystal



Laue pattern for halite crystal

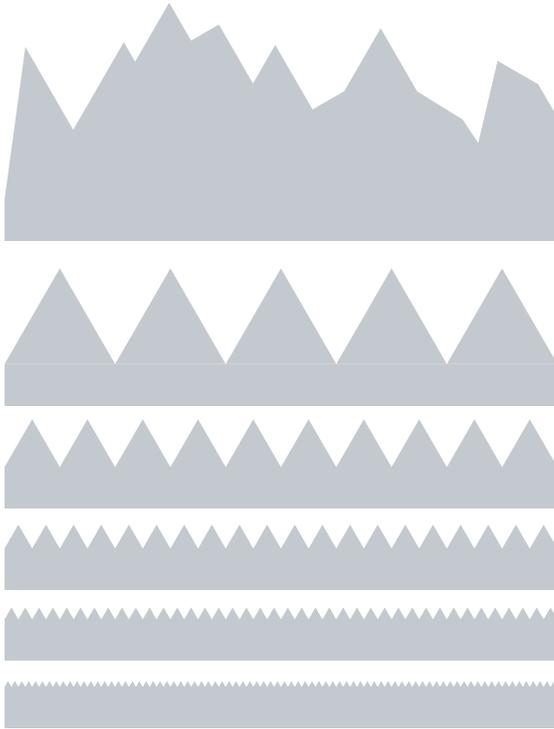
1. Roger H. Struwer *The Compton Effect: Turning Point in Physics*, Science History Publications, N.Y., 1975, p. 201

SURFACE

The nature of a surface

A surface of a crystal is defined by topological features of the epns of the atoms of the outermost cfus. The cfus are thermally in motion. The position of a cfu varies in time in three dimensions. Its velocity varies in the same three dimensions. Its inertia is composed of its motion and the polar interactions of the edges of the epns of which its atoms are composed.

The atom or group of atoms which comprise a photon collides not with a *surface* but with one or more of the outermost cfus which constitute the body.



Polishing: metallographic specimen.

In each of the above drawings, the upper perimeter represents a sectional profile of a stage in the preparation of a metal specimen for examination by an optical microscope. The specimen is cut from a larger coupon by a saw. The saw produces grooves which are represented by the top drawing. These are abraded away by a coarse grit. Which results in the topography of the second drawing. A finer grit is applied at right angles until the grooves of the coarse grit are removed. The resulting topography is indicated in the third drawing. The process of applying successively finer grits at right angles to remove the grooves of the previous grits is indicated by the next three drawings. The process is complete when the grooves of the final grit are not optically detectable at the desired magnification.

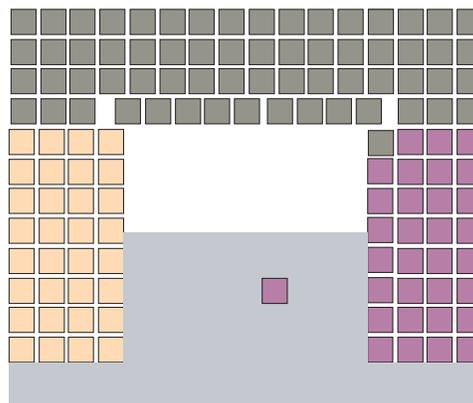
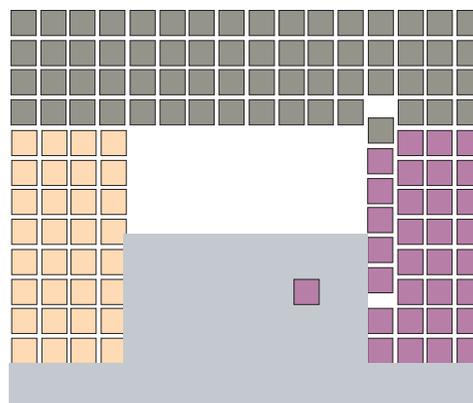
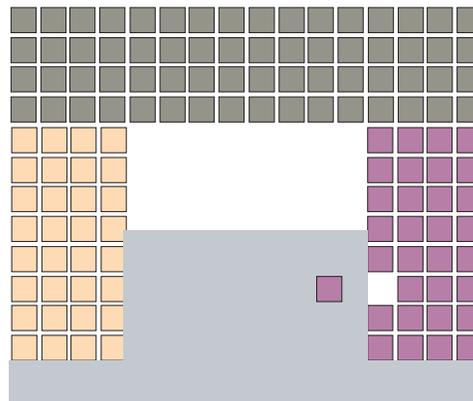
Polishing a metallographic specimen

Optically examining a stainless steel specimen on a metallograph requires a “smooth surface”. The specimen is cut from a bar with a saw. The saw marks are then removed by applying a coarse grit in a given direction which produces uniform grooves. The specimen is then rotated 90° to the previous sanding direction and a finer grit is applied until all traces of the markings of the previous grit have been removed. The process continues using successively finer grits until there are no optically detectable grooves.

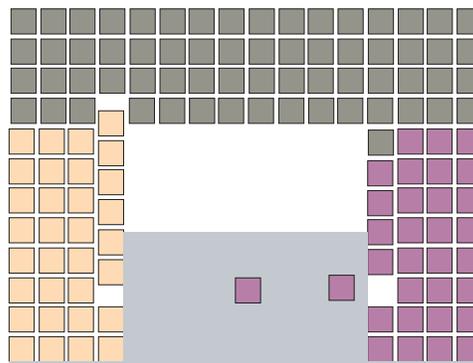
In the figure on the right, each of the topographical representations of the specimen is a “surface”. The polishing method is to take a rough surface and smooth it. For a given area, the height of the peaks is reduced as is the width. There are more peaks per length.

Electrolysis

One electrode of an electrolytic cell is etched by the electrolyte—cfus of the electrode enter the electrolyte with their thermal momentum and leave a void in the thermal structure of the electrode. This disrupts the thermal motions of the adjoining cfus and this, in turn, disrupts the motions of those cfus which adjoin them. In this manner, the disruption is propagated through the electrode to the circuit connecting it to the opposing electrode.

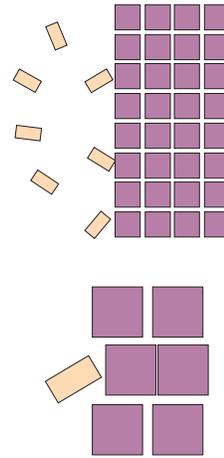


Electrolysis



Kinetic theory

Kinetic theory treats the inner surface of a container of gas as a continuum. It speaks of the gas molecule striking the surface. But the surface is not a continuum. It is composed of cfus which are in thermal motion. It is a cfu that is struck by a gas molecule. The gas molecule comes to rest relative to the cfu which it strikes. It is then accelerated to a velocity in a direction which is opposite to its approach direction. When the container cfu and the gas molecule have the same temperature, the restored velocity of the gas molecule is equal to its pre-collision velocity.



Momentum exchange: Gas molecule-surface cfu.

The top drawing represents gas molecules in the vicinity of a container surface which is represented by a rectangular array of squares. Below it, the effect of the collision of a gas molecule with a cfu of the container is shown in an enlargement.

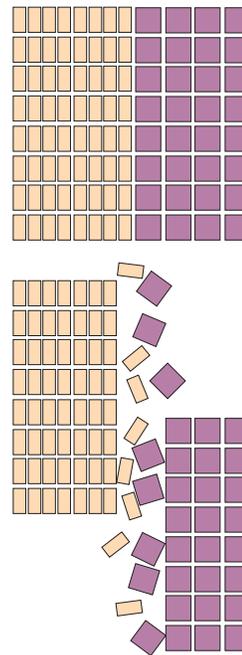
Friction between surfaces

Static electricity

Static electricity is produced by relative motion between the surfaces of two bodies which are in contact. The motion dislodges cfus from each of the bodies. Each dislodged cfu is free of the structural constraints of the other cfus of the body from which it came. The dislodged cfus are attracted to the bodies but are jostled by one another and are spread apart by their disjointed relative motions. The dislodged cfus orient to conform to the ambient polar influences.

Surface wear

The physical removal of cfus from the surfaces of bodies in contact is termed surface wear. The mechanism of removal is the same as for the production of static electricity. The cfus of one body are dislodged by the cfus of the other body. Over time, the loss of material becomes apparent through a change in the appearance of the surface.



Static electricity.

Two bodies in contact are depicted at the top of the figure. The effect of relative motion between the bodies is shown below. The cfus of the contacting surfaces are being dislodged and are disoriented and free of the structural constraints of the bodies. These are the "charge".

Thermal emission

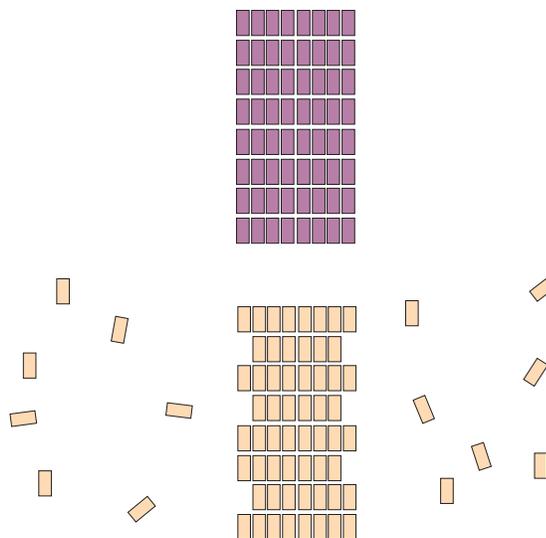
Lamp filament

The surface cfus of the lamp filament acquire momentum which is sufficient to overcome the polar attractions of the adjoining cfus which constitute the filament. The momentum of the cfu determines the character of its effect on other cfus which it contacts. The escaped cfus of the filament are termed “photons” or “electrons” depending upon the observed effects.

In the figure, the top array of rectangles represent the cfus of the cold filament. Below it, the filament is heated to the point that its surface cfus are freed and have become detectable as “radiation”.

Blackbody radiation

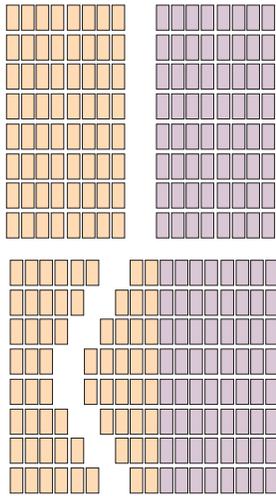
Because radiation was fallaciously thought to be in the form of a “wave”, it was thought that the thermal equilibrium within a blackbody was due to a balance between “energy emission” and “energy absorption.” The true situation is analogous to the momentum exchange between the molecules of a gas and the cfus of the gas container’s surface. See “Kinetic theory” on page 466



Lamp filament.

The upper rectangular array represents an unheated lamp filament. Below it, the filament is heated to incandescence and emits the cfus of which it is composed. The emitted cfus are the photons and constitute the emitted radiation.

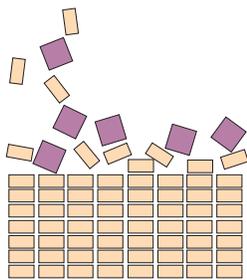
Ignition breaker points



Ignition breaker points.

At the top are representations of a pair of breaker points before use. At the bottom, the typical cup erosion and cone deposition is depicted. The cfus of one of the points carry the momentum of the electrical discharge to the opposite point.

Photoelectric effect



Photoelectric effect.

The cfus (violet) which constitute the photons collide with the cfus (yellow) which constitute the metal dislodging them. The dislodged cfus are the "electrons".

X-ray tube

The x-ray tube accelerates the cfus emitted by a heated filament towards a metal plate which is called a target. As in the photoelectric effect, the filament cfus collide with the target cfus and dislodge them. The dislodged cfus are the x-ray photons.

Photon-cfu collision

In addition to the undisturbed thermal motion, there is the modification caused by the collisions with the atoms or groups of atoms which constitute the photons. These disturbances are transmitted throughout the crystal. The photon may be rotated with respect to its neighboring photons and this rotation may affect the resulting collision with the cfu. It is this variation with time which causes the collision of a given photon to differ with the collision of a similar photon at the same *place*. One photon encounters a given cfu when the cfu is moving towards the body; another cfu encounters the same cfu when it is moving away from the body. The vagaries of these encounters result in reflection in one instance and refraction in another.

Reflection

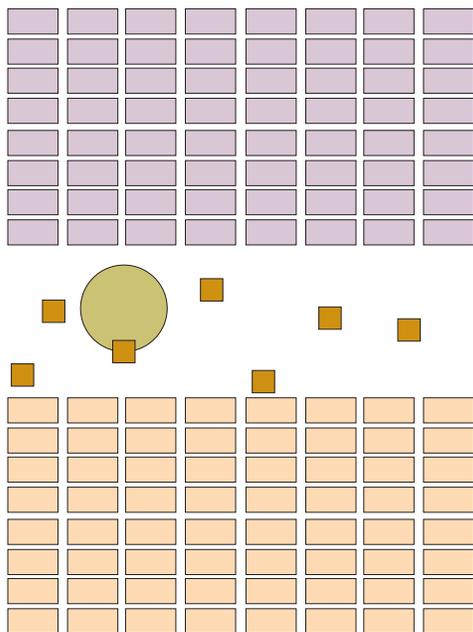
The photon collides with a cfu and gives up the component of its velocity which is normal to the surface and the recoil restores it.

Refraction

The momentum of the photon must be absorbed by the cfu and its neighbors and restored to the photon during the recoil. The greater the momentum the longer the time for the absorption and the longer the time for the recoil. The multiple photon-cfu collisions which constitute the passage of the photon through the crystals increase the passage time. This time is directly proportional to the entering momentum of the photon.

Millikan oil drop experiment

Millikan observed the motions of droplets of

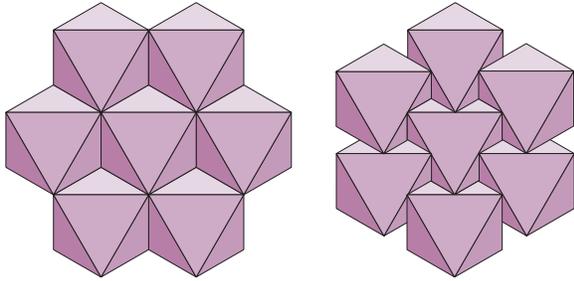


oil between metal plates which were attached to a battery. He noted sudden incremental changes in the momentum of the oil droplets which were in a common direction relative to which plate was attached to which battery terminal. The space surrounding the oil drops was filled with the molecules which constitute air. These molecules are propelled perpendicularly from the plate whose $cfus$ have a higher momentum. Some of these molecules collide with the oil drop and cause the observed accelerations. In the figure, the plate which is composed of $cfus$ of higher momentum is below the oil drop. The squares represent the molecular constituents of air. The circle is the oil droplet. The molecules which collide with the upper plate $cfus$ lose the momentum they acquired from collisions with the lower plate $cfus$.

STAR

Atoms are composed of incompressible octahedra.

The epn has no parts, so it is not compressible. The crystalline atom has tetrahedral voids, but its epns are in edgial contact. As we



Octahedra: Close packing.

Regular octahedra can be arranged in a facially planar assembly so that each of the octahedra abuts each of its six neighbors so that one of its vertexes is congruent with a mid-edge of the neighbor. The assembly is shown on the right. The assembly on the left is a crystalline assembly of regular octahedra where each octahedron shares an edge with each of its neighbors. The volume occupied by the crystallinely assembled octahedron is $4/3$ the volume occupied by the close packed octahedron.

know from the architectural arch, compression resistant bodies can resist convex inward loading. In any spheroidal body composed of compression resistant entities, the very concentricity produces archlike resistance to radially inward loading. In any concentric layer, the parts within the layer will inhibit each other from radially inward displacement. So, a spheroidal body which is composed of crystalline atoms of any number, however large, could be at a temperature approaching absolute zero and be in no danger of collapsing. The crystalline atom sustains its volume without motion.

Thermal activity, mass and internal pressure within stars

The ability of the epn or group of epns to rotate so as to enhance the attraction between it and the polar surround is determined by the rigidity of its position. With increased thermal activity, the atom travels a longer distance between contacts and the increased space this enables a greater rotation to accommodate the polar surround. Thus, as a planet is heated by the atomic disintegrations at its surface, its atoms will have more thermal space and this will enhance the polar attraction that exists between it and its neighbors. This will be evidenced as an increase in the mass of the planet and also its diameter. The luminosity to mass dependence of stars is understandable, since luminosity, in turn, is dependent upon temperature.

Stars and Planets

Stars and planets are composed of the same elements. Atoms leave stars, like the Sun, as the photons of radiation. These atoms collect to form planets, like Earth. If planets were to be always planets, the stars would dwindle away and the Universe would coalesce. If the Universe is to continue, the planets must re-radiate their atoms. They must become stars.

By finding unstable atoms and collecting them, humans here on Earth have produced more unstable atoms. There are many more unstable atoms now than there were when the first radioactive atoms were discovered. In the reactors of electrical power plants, so many unstable atoms have been produced that there is no place to put them.

A stable atom is made unstable when it is fragmented by a particle ejected from an adjoining unstable atom. Its fragments fission in turn, and cause additional stable atoms to fragment. As this process continues, the surface of the Earth comes to be composed of unstable atoms. As an atom breaks up, its fragments are repelled at high velocity. Each fragment dissipates its motion through collisions with other atoms. The increased motion is heat, and the increased heat eventually causes the surface to glow, sending its atoms outward.

The Earth has become a sun.

Converting a planet to a sun requires life. It requires life with each of the forms and attributes which have been essential to produce the human of today. It requires the discovery and gathering together of the unstable atoms. It requires the production of great numbers of additional unstable atoms.

The conversion of a planet to a star produces a "binary solar system". The sun and new star separate due to the impacts of the photons of one upon the other. The new star gains its own planets, one of which becomes its own earth-like planet. *Ad infinitum*.

Star

There is an abundance of hydrogen and a dearth of other elements with odd atomic numbers in the Sun. This suggests that an odd-atomic numbered element gives up its triplet first. There is an abundance of helium, too. This suggests that the even atomic-numbered atoms break up into helium atoms. This is consistent with the bombardment of the light atoms with alpha particles in the laboratory. It is consistent with the disintegration of unstable atoms found naturally on Earth.

KNOWING

MATH

Geometry

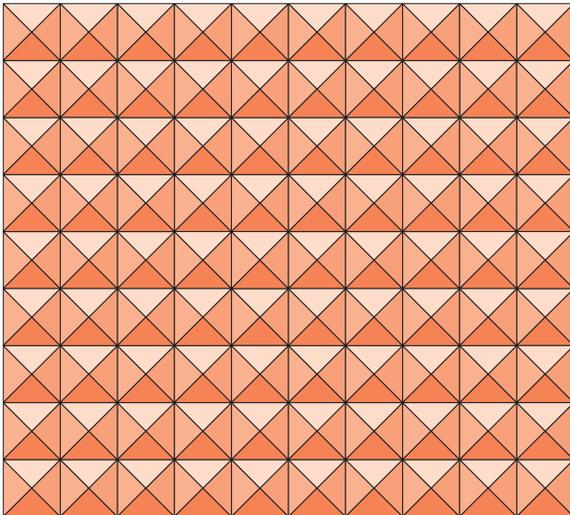
The geometry of a real plane

The mathematics of the plane has been based upon an imaginary continuous expanse. Upon the imaginary plane, imaginary lines can be constructed which are also continuous. And upon the line imaginary points can be placed. And between any two such imaginary points an infinite number of additional imaginary points might be imagined.

But, the discovery that each of the atomic elements is composed of identical particles, each of which is a regular octahedron whose edges are magnetic poles, reveals that any real plane is discontinuous. Real points are topological features of the particles which compose the plane. These real features define the real plane.

A plane of epns

If a plane could be constructed so that the vertexes of epns defined the plane, and these



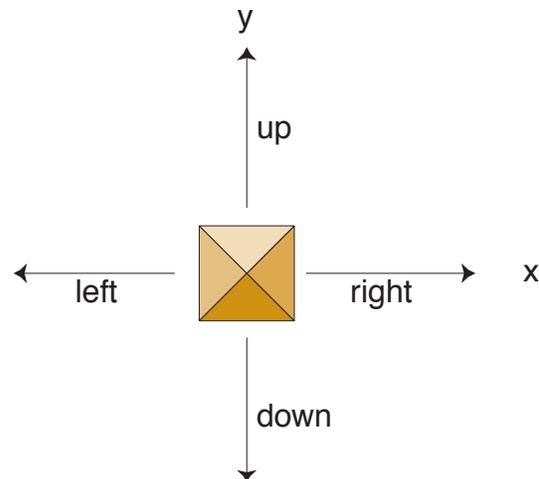
Topology of a real plane.

A vertexial plane of identical regular octahedra

vertexes were locatable, then these vertexes would constitute the points of a plane in which the distance between adjacent points is a minimum. Each of these points could have an address which would be two integers. The points would be numerable and discrete. Each of the coordinates of a point address could be an integral multiple of the edgial diameter of the epn. The coordinate axes would be mutually perpendicular.

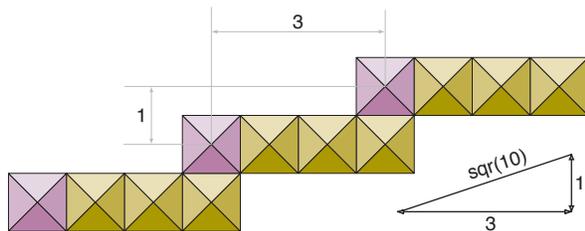
Edgially coordinated plane of points

A line on the octahedral plane is defined by a move or pair of moves by which one point on



the line is accessed from another: 3 *right*, 1 *up*. This could be *change in x* is 3 and *change in y* is one. Stated as a formula, $x = 3y$. The parts of the move are mutually perpendicular and the line portion between the points terminating the move is a hypotenuse. This has the value $h = \sqrt{x^2 + y^2}$ which is $\sqrt{10}$. This discrete distance is precisely and exactly the $\sqrt{10}$. This value cannot be found or located in either the x -direction or the y -direction, but on this line all points are separated by integral multiples of $\sqrt{10}$.

In its most perfectly precise definition as the topologically most defined location, the vertex of the octahedron of which all is composed, is discrete. It is not a continuum. It is the feature which defines the line. The line cannot be continuous. And, because of this, Richard Dedekind's effort to deal with irrational numbers is



The line $x = 3y$

invalid. The irrational numbers do not lie on the same line as the rational numbers.

Decimals require points

To express a number as a decimal requires points. Each digit requires ten points; two digits requires one hundred points and three requires a thousand. In such a system, the number 1.0000 is a length spanning ten thousand points. In an imaginary world, decimal points may be created at whim; but in the real world, for the points to be meaningful, they must be realizable upon the plane.

Pure number

<“A mathematician never defines magnitudes in themselves, as a philosopher would be tempted to do; he defines their equality, their sum and their product, and these definitions determine, or rather constitute all the mathematical properties of magnitudes”>¹

To paraphrase, the mathematician chooses to deny his origins, to ignore the reality that produced the stuff of his thoughts, to undefine magnitude, and to proceed to define what might be done with magnitudes in a totally artificial, and unrealizable conceptualization.

1. L. Couturat's definition of magnitudes from *De l'infini mathématique*, Paris, 1896, page 49 excerpted from Eric Temple Bell's *Men of Mathematics*, page 565

From this blackhole of fantasy no truth escapes.

What is the square of sheep? Or the square root of sunrise? The notion of number without entity is absurd. It is equally absurd to apply arithmetical processes to numbers without regard for the entity that provides the meaning of the numbers.

Take a length. Suppose it is 2 inches. Now square that length. We would say that we now have 4 square inches. A unit now different. A recognition that our number has a new identity. But two inches and two square inches are the same pure number two. There is nothing to prevent the mathematical thinker from adding 2 inches and 2 square inches and 2 sheep and 2 sunrises and so arrive at the pure number conclusion that the number 8 says all that need be said.

Units of measure

If each edge of the epn is a magnetic pole, and the interaction of epn edges accounts for mass, then those equations make sense wherein each of the magnitudes are expressible either as lengths or as the ratio of lengths, and each of those lengths is expressible in terms of that one invariable length, the edge of the epn.

OBSERVER

The edge is the unit of sense

The periodicity of the atomic elements reveals that each atom is composed of identical regular octahedra which join edge to edge in crystalline order. This joining indicates that each edge is magnetically polar.

The polar interaction between the edge of one epn and the edge of another is the minimal *sense*. Just as the structural complexity of the universe derives from the association of identical regular octahedral particles, the complexity of sensation derives from the polar interactions of the edges of these same particles.

The self

The self is an experimenter whose laboratory is the universe. The self learns to discriminate between self and unself through sensation. The self learns of space through collision with unself. It learns of time through waiting. It recognizes pattern, color, taste, smell, shape, thought, warmth, cold, wet, dry, slippery, rough, hard, soft, bright, dark, murmur, bang, gentle, abuse, fear, joy, embarrassment. These are not *a priori* concepts, but responses provoked in the self by the universe of which it is a part. The concepts are discoveries made by the most absorbed and exquisitely attentive experimenter in the absolute and only real laboratory, the universe. These discoveries are in every way *scientific*. They are absolutely controlled experiments whose outcome cannot be contrived or falsely interpreted. Without this acquired knowledge, the self cannot survive. This *commonsense* is the hardest, most exact science that universe imposes upon its selves. The self which surrenders commonsense for concepts which are non-commonsensical is in jeopardy.

The self is linked to other selves by sympathetic responses. These responses are involuntary and identical. Tears beget tears, anger begets anger, laughter begets laughter, nausea begets nausea, fear begets fear, pain begets pain. There is no need for language here. The commonality of the experience, the common-

sense of the reality, are mutually and simultaneously experienced by selves through the involuntary sympathetic response. Applying clocks and measuring rods to quantify and abstractly describe the response will only falsify the reality of the response. Self responds to self.

Physical Laws

Outside of human society, reality does not observe laws. There are no legislators nor lawyers nor justices. Law is a metaphor for actuality.

Reality

Each individual of the life forms is a collection of atoms. Each is matter. Each is a manifestation of the physical on Earth. It is futile to ponder the physical properties of matter, to codify concepts of reality, to express the idea that all of reality can be described from a supposed beginning of time in a mathematical treatise, while ignoring the life forms. Matter has ideas. Matter invents. Matter chooses. Matter is happy, angry, sad, vicious, sexy. Matter builds atomic bombs. Matter ignites Earths to produce Suns.

Evolution

Discovery and invention are the steps of evolution. The process occurs with the simplest of organisms and is recorded by them in their genes. The smallest self is in nearest intimacy to the smallest environment.

Discovery and invention result from explorations of the environment by the self, the properties of which self include awareness and inquisitiveness and need. The self records discoveries by altering its proximate environment including itself. The altered environment is the basis for further explorations by the self. All of this is physical and substantive and objective and real.

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