Thermal

Robert William Whitby
4 July 2004
http://homepage.mac.com/whitby/

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

Reference

Octahedron1stEd.pdf–bookmark THERMAL–pages 435-442

Introduction

This material is excerpted from *Octahedron*.

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.

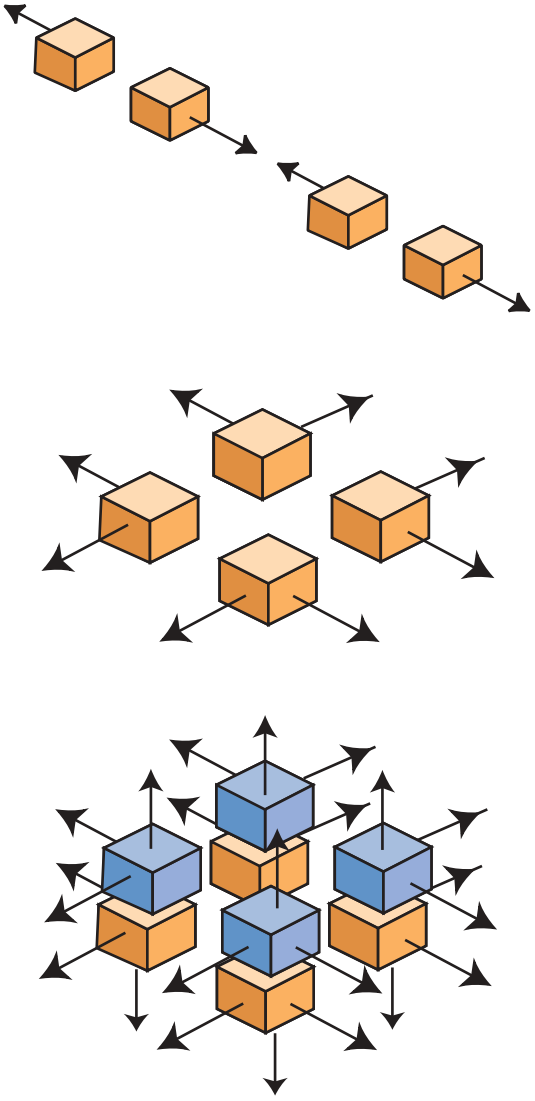
All the parallel lines of units which are parallel along the second direction are a plane, and this plane moves in a third join direction with a velocity that is equal and opposite to parallel planes in the third join direction.

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.

$$\text{Velocity} = \text{Maximum Velocity} + \text{Potential Velocity}$$

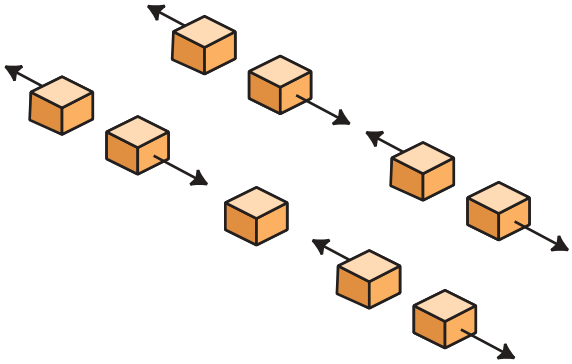
For a moving cfu, the volume is defined by the distance between its collisions with adjoining cfus at the instant of velocity reversal. Its potential velocity is at its maximum and the velocity is zero.

$$\text{Direction Lines} = \frac{\text{Join Directions}}{2}$$

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

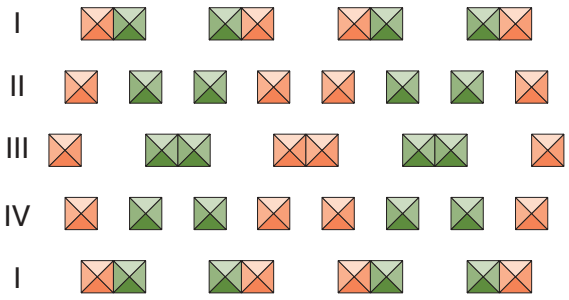
Motion of cfus if odd or even numbered

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 is 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 sqr(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 crystalline 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

$$ThermalExpansion \propto SpecificHeat$$

and

$$SpecificHeat \propto AtomicWeight$$

then

$$ThermalExpansion \propto AtomicWeight$$

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 $\operatorname{atan}\sqrt{2}$ 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 exchange 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]

$$\frac{weight}{AtomicWeight} = NoOfAtoms$$

Specific heat depends upon the number of atoms.

$$SpHt \times AtWt = 6.4 = Heat \times \frac{TempDiff}{Mass}$$

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.