1)Thermal properties

Q1: A 0.4 m rod of a metal elongates 0.48 mm on heating from 20 to 100 ^{0}C . Determine the value of the linear coefficient of thermal expansion for this material.

Solve:

$\alpha_l = \Delta l / l_0 \Delta T$

$= \Delta l / l_0(T_f - T_0) = 0.48\text{x}10^{-3}\text{m} / (0.4\text{m})(100°\text{C} - 20°\text{C}) = 15.0 \text{ x } 10^{-6} (°\text{C})^{-1}$

Q2: Briefly explain why the thermal conductivities are higher for crystalline than noncrystalline ceramics.

Solve:

Thermal conductivities are higher for crystalline than for noncrystalline ceramics because, for noncrystalline, phonon scattering, and thus the resistance to heat transport, is much more effective due to the highly disordered and irregular atomic structure.

Q3 (a) If a rod of brass 0.35 m long is heated from 15 to 85 ^{0}C while its ends are maintained rigid, determine the type and magnitude of stress that develops. Assume that at 15 ^{0}C the rod is stress free. **(b)**What will be the stress magnitude if a rod 1 m long is used? **(c)** If the rod in part (a) is cooled from 15 ^{0}C to -15 ^{0}C to what type and magnitude of stress will result? 97 GPa the modulus of elasticity of brass and α_l = 20.0 x 10^{-6} $(°C)^{-1}$ for brass.

Solve:

$\boldsymbol{\sigma = E\alpha_l (T_0 - T_f) = (97 \text{ x } 10^3 \text{ MPa}) [20.0\text{x}10^{-6}(°\text{C})^{-1}](15°\text{C} - 85°\text{C}) = -136 \text{ MPa}}$

The stress will be compressive since its sign is negative.

(b) The stress will be the same [–136 MPa], since stress is independent of bar length.

(c) Upon cooling the indicated amount, the stress becomes

$\sigma = E\alpha_l (T_0 - T_f)$

$= (97 \text{ x } 10^3 \text{ MPa})[20.0\text{x}10^{-6}(°\text{C})^{-1}] [(15°\text{C} - (-15°\text{C})]$

= +58 MPa

This stress will be tensile since its sign is positive.

Q4: (a) Briefly explain why thermal stresses may be introduced into a structure by rapid heating or cooling. **(b)** For cooling, what is the nature of the surface stresses? **(c)** For heating, what is the nature of the surface stresses?

Solve:

(a) Thermal stresses may be introduced into a structure by rapid heating or cooling because temperature gradients will be established across the cross section due to more rapid temperature changes at the surface than within the interior; thus, the surface will expand or contract at a different rate than the interior and since this surface expansion or contraction will be restrained by the interior, stresses will be introduced.

(b) For cooling, the surface stresses will be tensile in nature since the interior contracts to a lesser degree than the cooler surface.

(c) For heating, the surface stresses will be compressive in nature since the interior expands to a lesser degree than the hotter surface.

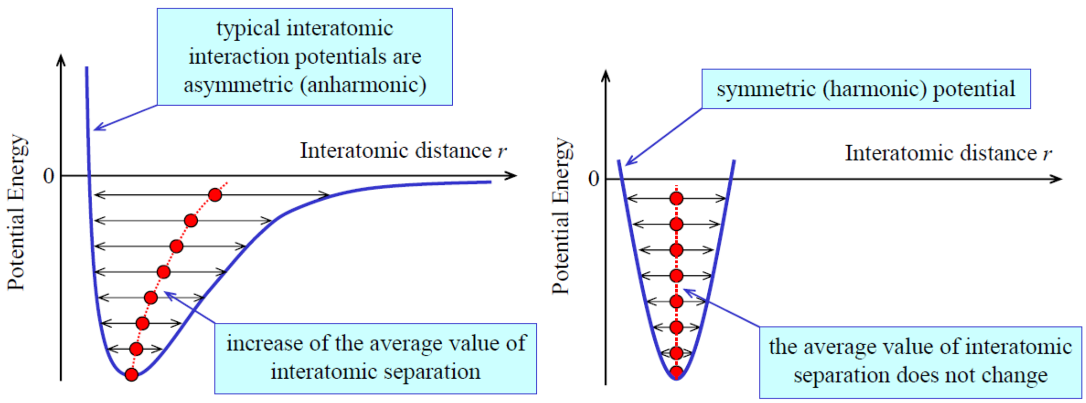
Q5: A steel wire is stretched with a stress of 70 MPa at (20 ^{0}C). If the length is held constant, to what temperature must the wire be heated to reduce the stress to 17 MPa? If values for *E* and α_l for steel of 207 GPa and 12.0 x 10^{-6} (°C)$^{-1}$, respectively

Solve:

We want to heat the steel wire in order to reduce the stress level from 70 MPa to 17 MPa; in doing so, we reduce the stress in the wire by 70 MPa – 17 MPa = 53 MPa, which stress will be a compressive one (i.e., σ = –53 MPa) $T_f = T_0 - (\sigma / E\alpha_l) = 20°C - [-53MPa / (207x10^3MPa)(12.0x10^{-6}(°C)^{-1}] = 20°C + 21.3°C = 41.3°C$

Q6: Explain effecting of heat temperature on materials in terms of thermal expansion.

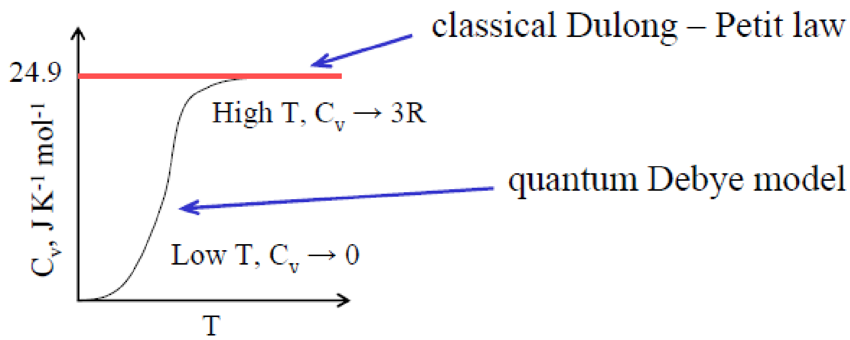
Solve: Rising temperature results in the increase of the average amplitude of atomic vibrations. For an anharmonic potential, this corresponds to the increase in the average value of interatomic separation, i.e. thermal expansion.



Thermal expansion is related to the asymmetric (anharmonic) shape of interatomic potential. If the interatomic potential is symmetric (harmonic), the average value of interatomic separation does not change, i.e. no thermal expansion.

Q7: Describe heat capacity dependence on temperature.

Solve: The constant value of the heat capacity of many simple solids is sometimes called Dulong – Petit law In 1819 Dulong and Petit found experimentally that for many solids at room temperature, cv ≈ 3R = 25 $JK^{-1}mol^{-1}$ This is consistent with equipartition theorem of classical mechanics: energy added to solids takes the form of atomic vibrations and both kinetic and potential energy is associated with the three degrees of freedom of each atom.The low-T behavior can be explained by quantum theory. The first explanation was proposed by Einstein in 1906. He considered a solid as an ensemble of independent quantum harmonic oscillators vibrating at a frequency ν. Debye advanced the theory by treating the quantum oscillators as collective modes in the solid (phonons) and showed that



Q8: Compute the electrical conductivity of a 7.0-mm diameter cylindrical silicon specimen 57 mm long in which a current of 0.25 A passes in an axial direction. A voltage of 24 V is measured across two probes that are separated by 45 mm. Compute the resistance over the entire 57 mm of the specimen.

Solve:

(a) $\sigma = 1/\rho = Il / VA = Il / V\pi(d/2)^2$

And, incorporating values for the several parameters provided in the problem statement, leads to

$\sigma = (0.25A)(45x10^{-3}m) / (24V)(\pi)(7.0x10^{-3}m /2)^2 = 12.2\ (\Omega\text{-m})^{-1}$

(b)

$R = l / \sigma A = l / \sigma\pi(d/2)^2$

$= 57x10^{-3}m / *12.2(\Omega\text{–}m)^{-1} + (\pi)(7.0x10^{-3}m/2)^{2} = 121.4\ \Omega$

2) Electrical properties

Q1: Explain heat transfer mechanisms of materials.

Solve: Heat is transferred by phonons **(lattice vibration waves)** and **electrons**. The thermal conductivity of a material is defined by combined contribution of these two mechanisms:

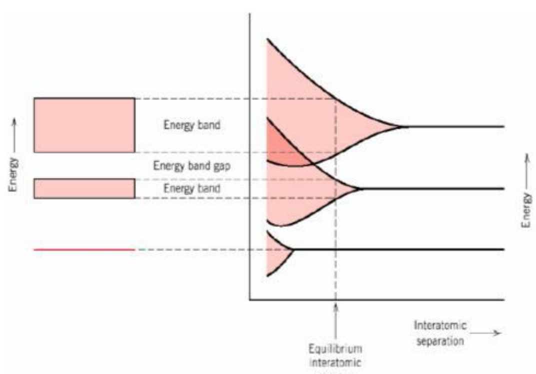
$k = k_l + k_e$

where $\mathbf{k_l}$ and $\mathbf{k_e}$ are the lattice and electronic thermal conductivities. Lattice conductivity: Transfer of thermal energy phonons Electron conductivity: Free (conduction band) electrons equilibrate with lattice vibrations in hot regions, migrate to colder regions and transfer a part of their thermal energy back to the lattice by scattering on phonons. The electron contribution is dominant in metals and absent in insulators.

Q2: Explain the effects of specific quantum mechanics when atoms come together to form a solid.

Solve:

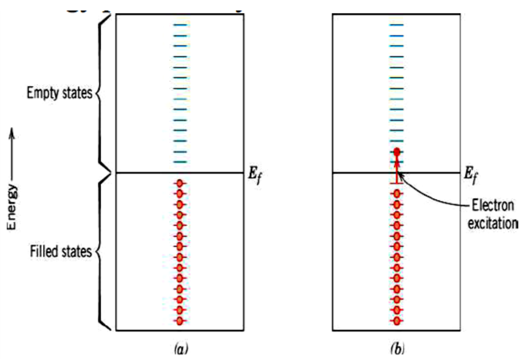
valence electrons of atoms interact with each other and with nuclei due to Coulomb forces. **The First effect** by Heisenberg's uncertainty principle, constraining the electrons to a small volume raises their energy, this is called *promotion*. **The second effect**, due to the Pauli exclusion principle, limits the number of electrons that can have the same energy.



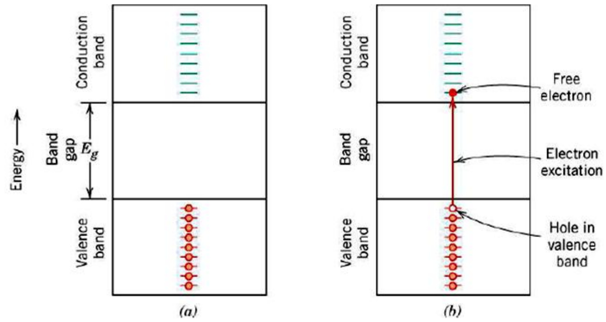
Q3: Explain energy band structures and conductivity of (metals, semiconductors and insulators).

Solve:

In **metals (conductors)**, highest occupied band is partially filled or bands overlap. Conduction occurs by promoting electrons into conducting states, that starts right above the Fermi level. Energy provided by an electric field .



In **semiconductors and insulators**, the valence band is filled, no more electrons can be added (Pauli's principle). Electrical conduction requires that electrons be able to gain energy in an electric field. The excitation energy can be provided by heat or light.
Insulators: wide band gap (> 2 eV)
Semiconductors: narrow band gap (< 2 eV)



Q4: An n-type semiconductor is known to have an electron concentration of 5×10^{17} m^3 . If the electron drift velocity is 350 m/s in an electric field of 1000 V/m, calculate the conductivity of this material.

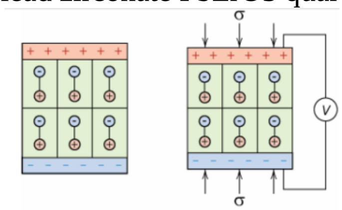
Solve:

$\mu_e = v_d / E$
$=350 m/s / 1000 V/m = 0.35 m^2/V.s$
$\sigma = n|e|\mu_e$
$=(5x10^{17} m^{-3})(1.602x10^{-19} C)(0.35 m^2/V.s)$
$= 0.028\ (\Omega.m)^{-1}$

Q5: Describe the generation way of piezoelectricity in some materials.

Solve:

In some ceramic materials, application of external forces produces an electric (polarization) field and vice-versa. Applications of **piezoelectric** materials is based on conversion of mechanical strain into electricity (microphones, strain gauges, sonar detectors)
Examples:
barium titanate $BaTiO3$
lead zirconate $PbZrO3$ quartz.



Without stress with applied stress

Q6: (i) Calculate the drift velocity of electrons in silicon at room temperature and when the magnitude of the electric field is 500 V/m. (ii) Under these circumstances, how long does it take an electron to traverse a 25-mm length of crystal? (use μe=0.14 at room temperature).

Solve:

(i) Since the room temperature mobility of electrons is 0.14 m^2/V-s
$v_d=\mu_e E$
$=(0.14\ m^2/V\text{-}s)(500\ V/m)=70 m/s$
(ii) The time, t, required to traverse a given length, l (= 25 mm), is just
$t = l / v_d = 25x10^{-3} m / 70 m/s = 3.6 \times 10^{-4} s$