Potassium Chloride (KCl) 707

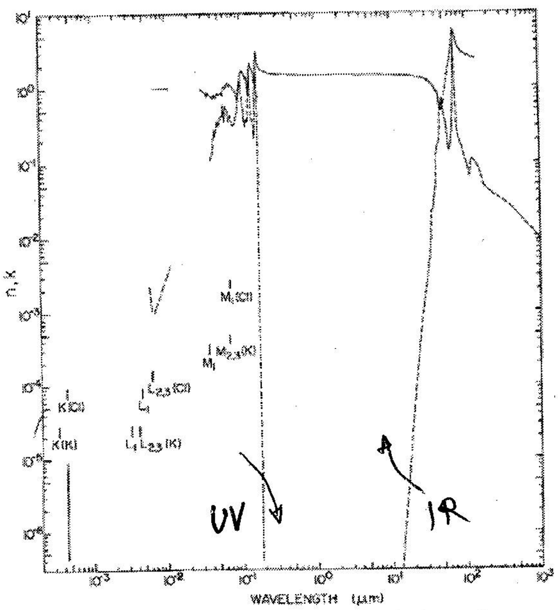
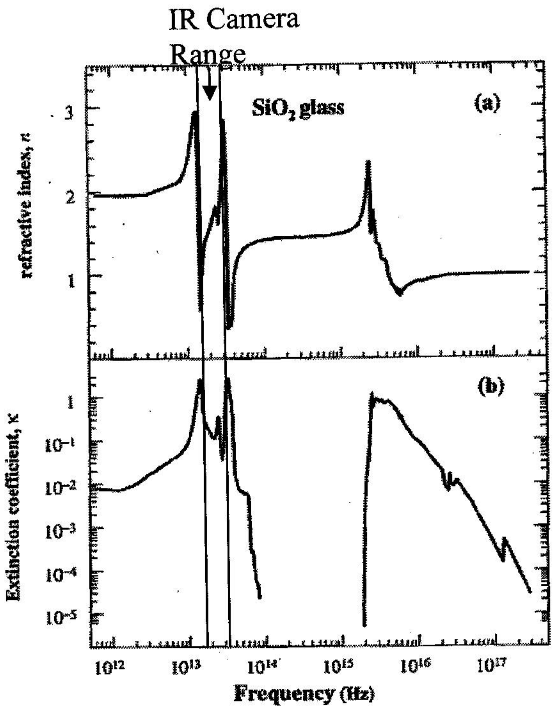


Fig. 8. Log–log plot of n (——) and k (- - - -) versus wavelength in micrometers for potassium chloride.



1. (6) (a) The figures above show the refractive indices, $n \cong (\varepsilon')^{1/2}$, and extinction coefficients, $\kappa \cong \varepsilon''/n$, of SiO_2 and KCl. Which material would you choose to use in a lens for a night vision system operating at wavelengths between 10 to 20 μm? Justify your answer in terms of the influence of κ and n on lens properties.

As seen in the figure, extinsion coefficient k for SiO_2 has a peak in infra red, which means a high power loss for IR. But KCl does not have a peak, so loss is small and ε_r' is also constant leading to less image distortion by the lens.
So we choose KCL.

(b) (2) Both the KCl and the SiO_2 exhibit transitions in index of refraction in the ultraviolet (UV wavelength below 0.4 μm) and in the infrared (IR wavelengths above 0.750 μm). What mechanism of polarization is responsible for each transition?

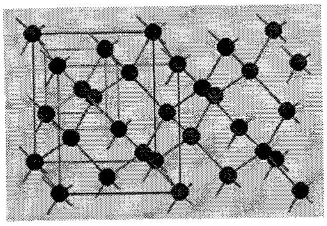
(i) IR: ionic (ii) UV: electronic

(c) (3) Diamond (solid carbon) has a UV transition at wavelengths below 0.25 μm, but no transition in the IR. What is it about the atomic composition of diamond that makes it transparent deep into the IR, as opposed to KCl, SiO_2, (and also other salts and oxides e.g. sapphire Al_2O_3, sodium chloride NaCl)? Explain.

Diamond has only C atoms, so crystal is symmetric with no atomic dipoles. So there will be no ionic polarization, only electronic is present.

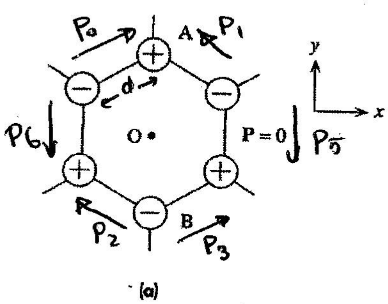
(d) (3) Metals generally reflect visible light as free electrons prevent deep penetration of the electric fields associated with visible electromagnetic waves. Can metals be transparent at some frequencies? Explain.

At very high frequencies when free electrons cannot follow field oscillations, metals can become transparent to some extent.
Example: X-ray.



2. (3) (a) Diamond, Silicon and Germanium have the crystal structure shown at left. Are these materials piezoelectric? Explain.

No. crystal is symmetric. No atomic dipoles.



(b) (5) Assuming the material whose shown at left has equal bond lengths with an angle between bonds of 120°, and that all charges are either $+e$ or $-e$, compute the dipole moments about the point, **o**, in the x and y directions. Show your work.

$P_0 = ed$ $\qquad \vec{P_0}+\vec{P_1}+\vec{P_2}+\vec{P_3} = 2|\vec{P_0}|\hat{y} = 2ed\,\hat{y}$

$\vec{P_5}+\vec{P_6} = -2|\vec{P_0}|\hat{y} = -2ed\,\hat{y}$

$$P_{total} = \sum_{i=0}^{6} \vec{P_i} = 0$$

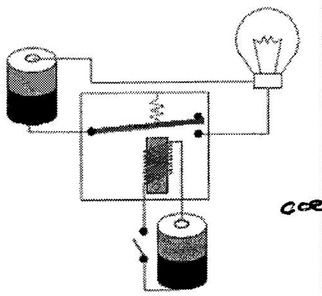
(c) (1) Could this material be piezoelectric? yes, Under mechanical strain we can get a non zero P.

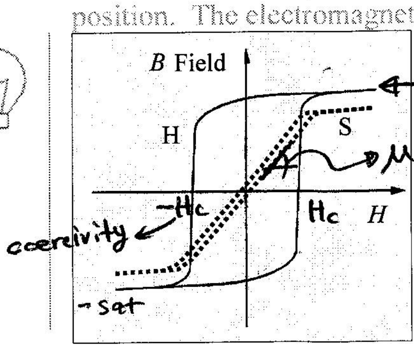
3. (3) A cylindrical ferromagnet of length L and diameter $d \ll L$ has a uniform magnetization, M along its axis. A current is passed in an empty solenoid of the same geometry. If the solenoid has N turns and an air core, how much current is required to generate the same magnetic field as is produced by the magnetized cylinder?

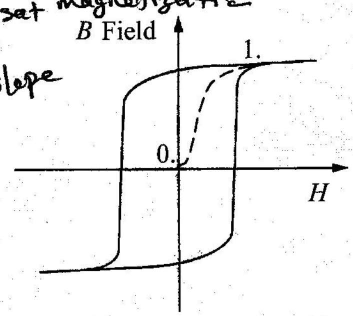
$M = I_m \longrightarrow B = \mu_0 M$

Solenoid: $B = \mu_0 n I \longrightarrow \frac{NI}{L} = I_m \longrightarrow$ $\qquad I = \frac{LM}{N}$

4. In a normally open relay an electromagnet is used to pull a soft magnetized bar against a spring to close the circuit. When the electromagnet is off, the spring pulls the relay into the open position. The electromagnet is tested with two different cores with B-H curves "H" and "S".







$B = \mu H$

(a) (1) For the "S" core draw a line indicating the slope of the permeability.

(b) (1.5) For the "H" core, indicate with arrows on the middle diagram the saturation magnetization, the remnance magnetization and the coercivity.

(c) (1) The "H" core material initially has no net magnetization. Current is gradually increased and the field is found to rise along path 0 - 1. The relay closes. Based on the fact that the "S" core is known to work well, how could you have predicted this?

Because when "H" is at point 1, the B is higher than what is achieved with "S". So it can attract the relay.

(d) (1) The current is turned off. What state will the relay be in (open or closed) and how do you know?

For "H" close. For "S" open.

(e) (2) The current is now reversed (left half plane of the *B-H* curve). How will the state of the relay change as the magnitude of this current is steadily increased until the core is saturated?

The relay remains closed for "H" until just before applying a negative -Hc coercive magnetization field.

**(f) (3.5) Why is the relay more difficult to control when it uses the "H" core?

Because of the high memory and hysterisis.

5. A long thin material is modeled as a 3D infinite square well, with a potential inside of $U=0$.
(a) (8) Express the energy, E, as the sum of the energies E_x, E_y, *and* E_z and use separation of variables, $\psi(x,y,z)=\psi_x(x)\psi_y(y)\psi_z(z)$ to generate equations representing the variation of the wavefunction in each dimension. Show that each of these equations has the same form as the 1D Schrödinger Equation for an infinite potential well.

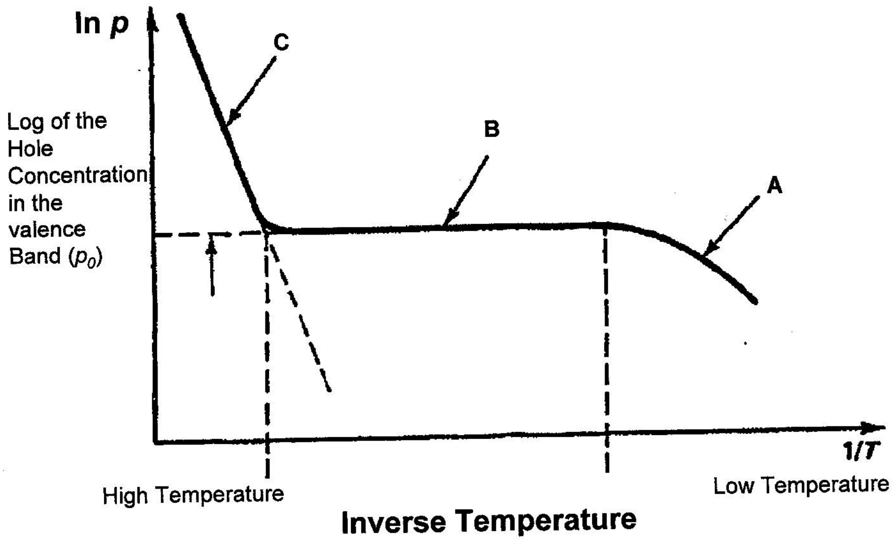
Solutions for this part is already given.

(b) (6) Assume that the x and y dimensions are of length d and that the z dimension is L. Use the boundary conditions to solve for $\psi_x(x)$ in terms of quantum numbers n_x, n_y and n_z. Write out the solutions for $\psi_y(y)$, & $\psi_z(z)$ in terms of the boundary conditions. (no normalization required).

(c) (1) Write out the normalization condition for ψ(x,y,z) showing the limits of integration (no need to solve).

(d) (4) Show that $E = \frac{\hbar^2\pi^2}{2m}\left[\frac{n_x^2 + n_y^2}{d^2} + \frac{n_z^2}{L^2}\right]$.

(e) (6) If L=1000d, then E=$\frac{\hbar^2\pi^2}{2d^2m}\left[n_x^2 + n_y^2 + \frac{n_z^2}{10^6}\right]$. Is the density of states increasing or decreasing between the states n_x=n_y=n_z=1 and n_x=2, n_y=n_z=1? Show this by writing out the energies of the lowest 5 states and sketching the energies relative to the ground state.



6.The hole concentration as a function of inverse temperature for a semiconductor is shown above.

(a) (1) Is the material n type, p type or intrinsic?

p-type

(b) (2) Explain the rise in p_o with increasing temperature in segment A.

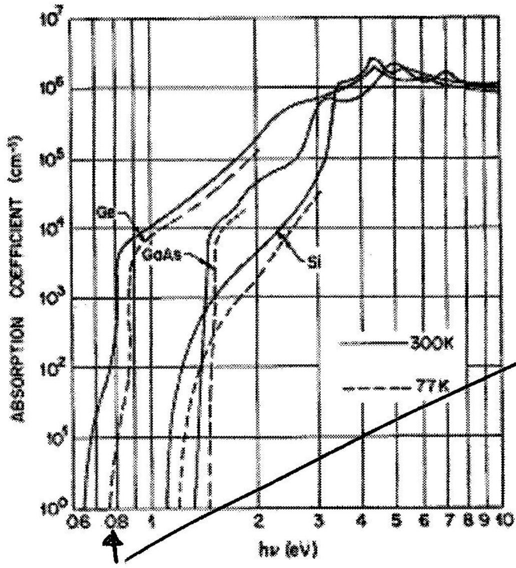
Not all dopants are ionized. Increasing temperature increases the number of accepter atoms that give a free hole.

(c) (3) Explain the plateau (flat response) in section B. What does the magnitude of p_o along B represent?

All dopants are ionized. Increasing temperature does not add to free holes.

(d) (2) Why is p_0 rising as a function of temperature in C?

At high temperatures, intrinsic holes are large in number. So their density becomes higher than holes given by dopants



7. (2) Based on the absorption spectrum at left, what is the band gap of Germanium at 77 K?

0.75 eV

8. (a) (4) In the left hand box below draw horizontal lines representing the occupied orbitals, spaced according to their energies. Show the filling of orbitals in the ground state.

(b) (6) 10^{22} Sodium atoms are brought together to form a cube. In the right hand box sketch the resulting bands in the solid. Indicate the degree of filling of the bands at 0 K via shading and write in the number of electrons in each band.

Energy (Atoms)	Energy (Solid)

(c) (1) Is this sodium solid a metal, semi-conductor or an insulator?

(d) (4) Write an expression for the number of electrons per unit volume having energies above the Fermi Level, E_F and below the top of the band, E_{MAX} as a function of temperature, T, and effective mass. (Do not solve.)

**(e) (4) Write an expression for the energy these electrons add to the solid. (This is part of the heat capacity. Do not solve.)