General questions about electrons and holes:

A 1a) What distinguishes an electron from a hole?
Ans) An electron is a fundamental particle whereas hole is just a concept. Electrons carry negative charge whereas holes are considered to carry positive charge. Hole is better understood as absence of electron from its position and cannot be explained without electron.

A 1b) Does a large effective mass correspond to a band with large curvature or small curvature?
Ans) Large effective mass corresponds to a small curvature.

A 1c) If you have an electric field pointing from left to right, in which direction does a hole move? Which direction does electron move?
Ans) Hole moves from left to right whereas electron moves from right to left.

A 2) Suppose we have a conduction band and a valence band with energies $\varepsilon_c(k)$ and $\varepsilon_v(k)$ respectively given by

$$\varepsilon_c(\vec{k}) = \varepsilon_c(\vec{k}_c) + \frac{\hbar^2}{2m_c^*}(\vec{k} - \vec{k}_c)^2$$

$$\varepsilon_v(\vec{k}) = \varepsilon_v(\vec{k}_v) + \frac{\hbar^2}{2m_v^*}(\vec{k} - \vec{k}_v)^2$$

A 2a) For these two bands, what does the bandgap equal?
Ans) Bandgap (E_g) is defined as the difference in energy of highest occupied level and energy of lowest occupied level.

Bandgap (E_g) = $\varepsilon_c(\vec{k}_c) - \varepsilon_v(\vec{k}_v)$

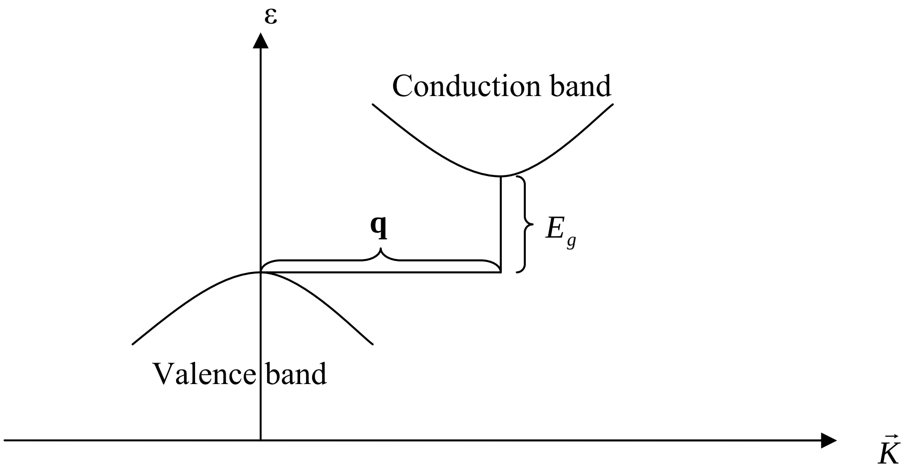
A 2b) What are the masses of the holes and of the electrons?
Ans) Mass of holes is represented by m_v^* and that for electrons is m_c^*.

A 2c) At time t = 0 and electron has a wave vector $\vec{k}_0$. It is subjected to an electric field $\vec{E}$ for a time Δt. What is its wave vector at time Δt? What is its change in energy? (Ignore scattering)
Ans)

A 2d) If a magnetic field $\vec{B}$ had been applied instead, what would the force on the electron be at time t = 0?
Ans)

A 3) Some general questions about semiconductor physics

A 3a) What is meant by an indirect bandgap?
Ans) An indirect bandgap is a bandgap in which the minimum energy in the conduction band is shifted by a k-vector relative to the valence band. This shift in k-vector (**q**) represents a difference in momentum.



A 3b) If a semiconductor with an indirect bandgap absorbs a photon, what additional thing is needed to ensure crystal momentum is conserved?
Ans) A phonon is needed. It will change the wave vector of electron to conserve its crystal momentum.

A 3c) Are the electrons in the conduction gap usually degenerate? Why?
Ans) No, the electrons in the conduction gap are usually not degenerate because $\varepsilon_c - \mu >> k_\beta T$. Fermi function describes the occupancy of degenerate electrons as

$$f(\varepsilon) = \frac{1}{e^{(\varepsilon-\mu)/k_\beta T} + 1}$$

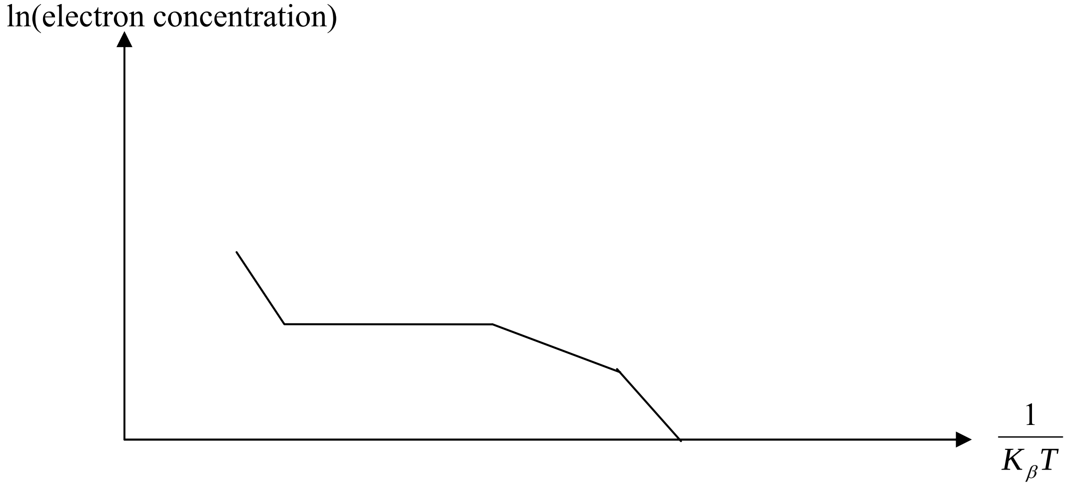
A 3d) In any intrinsic semiconductor what is the ratio of the number of electrons to the number of holes?
Ans) 1

A 3e) What is the expression for the energy of the shallow point defect?
Ans) The expression for the energy of the shallow point effect is different for donors (ε_D) and acceptors (ε_A).

$$\varepsilon_D = \varepsilon_c - \frac{m_e^*}{m_e}\left(\frac{1}{\varepsilon_r^2}\right) X 13.6eV$$

$$\varepsilon_A = \varepsilon_v + \frac{m_h^*}{m_e}\left(\frac{1}{\varepsilon_r^2}\right) X 13.6eV$$

A 3f) Sketch the graph of the logarithm of the electron concentration against $1/k_\beta T$. What are the physical explanations of the four regions?
Ans)



A 3g) How do the relaxation times for impurity and phonon scattering vary with temperature?
Ans) For impurity the relaxation time varies as $T^{3/2}$ whereas for phonon scattering it varies as $T^{-3/2}$.

A 3h) What is meant by carrier recombination?
Ans) Carrier recombination is an effect where an electron occupies the state of a hole and nullifies its effect.

A 3i) What is a heterojunction?
Ans) Heterojuntion is a junction made by a p-doped and an n-doped semiconductor.

A 3j) How does the electron chemical potential vary with position in a heterojunction at equilibrium?
Ans) At equilibrium, there's no effect of position on electron chemical potential.

A 3k) What is a depletion zone?
Ans) In semiconductors, depletion zone is an insulating region within a conductive, doped semiconductor material where the charge carriers have been swept away through charge recombination. Charge recombination is an effect where an electron occupies the state of a hole and nullifies its effect.

A 3l) In a bipolar transistor, what is the purpose of the collector?
Ans) The main purpose of the collector in a bipolar transistor is to remove the charge carriers introduced by the emitter into the base.

B 1a) What is the relation between magnetic field, magnetic induction and magnetization?
Ans) B = μ(M + H), where μ is the magnetic permeability

Electromagnetic field composes of two parts: Electric field (E) and Magnetic field (H). Thus, magnetic field is a part of electromagnetic field and is responsible for exerting a force on a moving charge. It can be caused by a moving charge or a changing electric field. Its SI unit is Tesla (T). Magnetic field (H) and Magnetic induction (B) are equal in vacuum. Magnetization (M) is defined as the total magnetic moment per unit volume. In other words, it is the magnetic field which material itself produces. Magnetization (M) and Magnetic field (H) are related by a term known as Magnetic Susceptibility (χ) as: M = χH. Magnetic susceptibility is defined as the degree of magnetization of material when placed in a magnetic field.

B 1b) What is the difference between diamagnetism and paramagnetism?
Ans) Diamagnetism and Paramagnetism are different forms of Magnetism. Both of them are exhibited by substances in the presence of an externally applied magnetic field.

Diamagnetic materials are **not** affected when placed in a magnetic field whereas Paramagnetic materials are **weakly** affected i.e. they become magnetized in the presence of magnetic field but lose their magnetic properties when the magnetic field is removed. In other words, when placed in a magnetic field, flux density is more inside a paramagnetic material than in a diamagnetic material. They can be differentiated by the properties of magnetic susceptibility as well.

Diamagnetic susceptibility	Paramagnetic susceptibility
Negative i.e. < 0	Positive i.e. > 0
Typically in range of 10^{-6} to 10^{-5}	Typically in range of 10^{-5} to 10^{-3}
Temperature independent	Temperature dependent

B 1c) Under what conditions does Curie's law apply?
Ans) Curie's law can be expressed as:
$\chi = \frac{C}{T}$ Or $M = C\left(\frac{B}{T}\right)$, where χ is the magnetic susceptibility, C is Curie's constant, M is magnetization, B is magnetic induction and T is temperature. Curie's constant is material constant and is different for different material. This law is applicable for paramagnetic materials; it states that magnetic susceptibilities of most paramagnetic materials are inversely proportional to their absolute temperatures. It is true only for paramagnetic materials and hence one of the conditions. It is applicable only when the magnetic field is weak. This law holds true only at high temperatures.

B 1d) In an atom, which interaction leads to the total spin being maximized? Why is this relevant to magnetism?
Ans) Exchange interaction is the condition which favors spins to align parallel and it maximizes the total spin. Total spin defines the magnetic moment of the material and hence it's important to magnetism.

B 1e) In the first transition series of the periodic table, why is the magnetic moment not well accounted for by Hund's rules?
Ans) For the first transition series of the periodic table, actual magnetic moment values don't match with those calculated using Hund's rules. It happens because of *crystal field splitting*. In electronic d states, two states point directly towards neighboring ions and three states point between neighbors. These states have different electrostatic energies. So the d states are locked to the crystal, and no longer behave like an *l*=2 state with 2*l*+1 *degenerate m* values. This phenomenon is called as *quenching* of the orbital angular momentum. It is found that the magnetic moments in the first transition series arise almost entirely from *spin* and angular momentum doesn't affect them.

B 1f) What interaction couples spin together to produce a ferromagnet?
Ans) Positive exchange interaction couples spin together to produce a ferromagnet.

B 1g) Why do magnetic domains form?
Ans) In short, magnetic domains form in order to reduce the total energy of the system.

B 2a) For a free electron ($l = 0$, $j = s = 1/2$), what does the *Lande g* factor equal?
Ans) The expression for *Lande g* factor (g_J) can be written as:

$$g_J = \frac{3}{2} + \frac{S(S+1) - L(L+1)}{2J(J+1)}$$

For $l = 0, j = s = ½$

$g_J = 2$ …… solution

B 2b) Supposing we could describe a free electron gas with the Curie law (which we cannot), what would the susceptibility be?

Ans) The expression for Curie's law can be written as $\chi = \frac{\mu_0 n g_J^2 \mu_B^2 J(J+1)}{3k_\beta T}$ (i.e. $\chi = \frac{C}{T}$) (referred page 192, Chiranjib Mitra). Taking $J = ½$ and $g_J = 2$ (at room temperature, referred page 190, Chiranjib Mitra), we get $\chi = \frac{\mu_0 n \mu_B^2}{k_\beta T}$.

B 2c) By comparing the results for the susceptibility you have just obtained with that derived by Pauli, show that the effective temperature of the electrons is $2E_F/3k_\beta$, where E_F is the Fermi energy. Why does this make sense?
Ans) The expression for susceptibility given by Pauli can be written as:

B 2d) For a spin $\frac{1}{2}$ system we have the Brillouin function being given approximately by $\mathrm{B_J(x)} \approx x - {x^3}/{3}$, where

$$x = \frac{\mu_B \lambda M_s}{k_B T}\left(\frac{M}{M_s}\right)$$

and M is the magnetization, λM is the Weiss field and M_s is the saturation magnetization. Hence, using the mean field condition ${M}/{M_s} = B_J(x)$, show that spontaneous magnetization can occur provided that $k_B T < \mu_B \lambda M_s$.

Ans) $\frac{M}{M_s} = \frac{k_\beta T}{\mu_B \lambda M_s} x$, which is also equal to $B_J(x)$ i.e. $\approx x - {x^3}/{3}$

=> $\frac{k_\beta T}{\mu_B \lambda M_s} x = x - {x^3}/{3}$

=> $x\left(1 - \frac{k_\beta T}{\mu_B \lambda M_s} - \frac{x^2}{3}\right) = 0$

=> either $x = 0$ or $\left(1 - \frac{k_\beta T}{\mu_B \lambda M_s} - \frac{x^2}{3}\right) = 0$

=> $1 - \frac{k_\beta T}{\mu_B \lambda M_s} = \frac{x^2}{3}$

=> $x = \pm\sqrt{3\left(1 - \frac{k_\beta T}{\mu_B \lambda M_s}\right)}$

x must be real and positive for spontaneous magnetization to occur i.e. x > 0

=> $\frac{k_\beta T}{\mu_B \lambda M_s} < 1$

=> $k_\beta T < \mu_B \lambda M_s$, hence the condition for spontaneous magnetization

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General questions about superconductivity:

B 3a) What is the principal characteristic of superconductivity?

Ans) A superconductor has very high conductivity and it can behave like a conductor with no measurable DC electrical resistivity. It can behave like a perfect diamagnet. It usually behaves as if there were a gap in energy with 2Δ centered about the Fermi energy, in the set of allowed one-electron levels. Thus an electron of energy ε can be accommodated by a superconductor only if ε – ε_F exceeds Δ. The energy gap Δ increases in size as the temperature drops, leveling off to maximum value Δ(0) at very low temperatures.

B 3b) What is Meissner effect and what is the physical mechanism behind it?
Ans) Meissner effect or Meisnner-Ochsenfeld effect is the effect by which a weak magnetic field decays rapidly to zero inside a superconductor. If a metal is kept in a magnetic field and cooled below its superconducting transition temperature, then the magnetic flux inside the metal is abruptly expelled. This effect is called as Meissner effect.

B 3c) What is the difference between Type I and Type II superconductors?
Ans) Type I class of superconductors mainly consists of metals and metalloids, and shows some conductivity at room temperature, whereas Type II class of superconductors mainly consists of metallic compounds and alloys. Type I superconductors require very low temperature to show superconductivity and their surface energy is positive ($\lambda < \xi$) whereas Type II superconductors have negative surface energy ($\lambda > \xi$). Type II superconductors have much higher critical fields and therefore can carry much higher current densities while remaining in superconducting state.

Type I: Below a critical field $H_c(T)$ that increases as T falls below T_c, there is no penetration of flux; when the applied field exceeds $H_c(T)$ the entire specimen reverts to the normal state and the field penetrates perfectly.

Type II: Below a lower critical field $H_{c1}(T)$ there is no penetration of flux; when the applied field exceeds an upper critical field $H_{c2}(T) > H_{c1}(T)$, the entire specimen reverts to the normal state and the field penetrates perfectly. When the applied field strength is between $H_{c1}(T)$ and $H_{c2}(T)$, there is partial penetration of flux, and the material develops a complicated microscopic structure of both normal and superconducting regions, known as *mixed* state.

B 3d) What is the physical mechanism that generates the superconducting electrons?
Ans) It's a known fact that warmer the material the more is its lattice vibration and conversely, the colder the material the less is its lattice vibration. In case of superconductors, electrons pair up into teams (also called as ***Cooper pairs***) and pass all the obstacles which cause resistance in the conductor. It's because of this pairing up of electrons which generates superconducting electrons.
