Quiz 6

1

(a)

Doping silicon with arsenic creates an n-type semiconductor. This is because arsenic has five valence electrons, one more than silicon, and the extra electron is free to move within the crystal, providing an additional charge carrier. Since the extra carrier is an electron, which is negatively charged, the semiconductor is termed as n-type.

(b)

For an n-type semiconductor are fully ionized at room temperature (300K). The each arsenic atoms given as $n_{\mathrm{As}} = 10^{17}\mathrm{cm}^{-3}$ offersone electron when ionized.

So, the free carrier concentration (n) for the majority carriers, which are electrons in this case, is also $n = 10^{17}\mathrm{cm}^{-3} = 10^{23}\mathrm{m}^{-3}$.

(c)

The fermi energy is given by:

$$E_F = E_C - k_B T \ln \frac{N_C}{n}$$

where, E_C is the energy at the bottom of the conduction band, for Si $E_C \approx 0$;

N_C is the effective density of states in the conduction band;

n is the electron concentration which is equal to the arsenic atom concentration $10^{17}\mathrm{cm}^{-3}$.

$$N_C = 2(2\pi m_e k_B T/\hbar^2)^{3/2}$$

We arrive:

$$E_F = -1.3928\mathrm{eV}$$

In an n-type semiconductor, the Fermi level (chemical potential) is closer to the conduction band due to the presence of extra free electrons.

2

a: $1E-4$: This is a small, positive value, suggesting that material a is paramagnetic.

b: $2E5$: This is a large, positive value, suggesting that material b is ferromagnetic.

c: $-3E-5$: This is a negative value, suggesting that material c is diamagnetic.

3

Diamagnetic susceptibility for a Helium atom (χ_{atom}) can be calculated using:

$$\chi_{\text{atom}} = -e^2 r^2/(6m_e c^2)$$

And molar susceptibility (χ_m) can be obtained by:

$$\chi_m = 2\chi_{\text{atom}} N_A$$

Here, e is electron charge;

m_e is electron mass;

c is speed of light;

N_A is Avogadro's number;

and we have the electron radius r is $r = 0.58\text{Å} = 0.58 \times 10^{10}\text{m}$.

We arrive:

$$\chi_m = 2\chi_{\text{atom}} N_A \approx -2.1138742735358325e - 22$$

4

For a magnetic dipole moment (ţ) rotates in a magnetic field (B). The energy change (ΔE) can be given by:

$$\Delta E = -\mu \times \Delta B$$

In this case, the magnetic moment rotates from antiparallel to parallel, the total change of magnetism is $2B$, then, we infer:

$$\Delta E = -2\mu\mu_0 H$$

and:

$$\Delta E = -2 \times 2\mu_B \mu_0 H$$

To obtain the energy change in units of $k_B T$, we divide ΔE by $k_B T$:

$$\frac{\Delta E}{k_B T} = \frac{-4\mu_B \mu_0 H}{k_B T}$$

As a result, we arrive:

$$\frac{\Delta E}{k_B T} \approx 0.01125470421668071$$