Level 3 Condensed Matter Physics- Part II
Weekly problem 2 solutions

(1) i) The donor ionisation energy is given by [1 mark]

$$E_D = \frac{e^4 m_e^*}{2(4\pi\varepsilon\varepsilon_0\hbar)^2} = \frac{m_e^*}{m\varepsilon^2}\left[\frac{e^4 m}{2(4\pi\varepsilon_0\hbar)^2}\right]$$
$$= \frac{0.2}{(11.7)^2} \times 13.6\ eV = 19.9\ meV$$

ii) The radius of the orbit [1 mark]

$$r = \frac{4\pi\varepsilon\varepsilon_0\hbar^2}{m_e^* e^2} = \frac{\varepsilon m}{m_e^*}\left(\frac{4\pi\varepsilon_0\hbar^2}{me^2}\right)$$
$$= \frac{11.7}{0.2} \times 0.53\ \text{Å} = 31.0\ \text{Å}$$

iii) The overlap occurs when [1 mark]

$$N_D \sim \frac{1}{\frac{4}{3}\pi r^3} = 8.0 \times 10^{24}\ \text{m}^{-3}$$

(2) For an intrinsic semiconductor:

$$n = \sqrt{N_c N_v}\exp\left(-\frac{E_g}{2kT}\right)$$

so that

$$\frac{n(T)}{n(300K)} = \exp\left[-\frac{E_g}{2k}\left(\frac{1}{T} - \frac{1}{300}\right)\right]$$

[1 mark]

Extrinsic behaviour occurs when $n(T) \leq 10^{18}$ m^{-3} [1 mark]. Substituting into the above equation:

$$\frac{10^{18}}{5 \times 10^{15}} = \exp\left[-\frac{E_g}{2k}\left(\frac{1}{T} - \frac{1}{300}\right)\right]$$

we have $T \leq 400$ K. [2 marks]

(3) Since the semiconductor is in the saturation regime all phosphorus donor atoms are ionised and we assume the conductivity is dominated by the majority carrier electrons. [1 mark]

From $\sigma = en\mu_e$ with $n \sim 10^{20}$ m^{-3} and $\mu_e = 0.16$ m^{2}V^{-1}s^{-1} we get $\sigma = 2.56$ S/m. [2 marks]