Question

Energy Bands: The effective mass m^* of a current carrier in a semiconductor can be directly determined by means of a **cyclotron resonance** experiment in which the carriers (whether electrons or holes) move in helical orbits about the direction of an externally applied magnetic field **B**. An alternating electric field is applied perpendicular to **B**, and the resonant absorption energy from this field occurs when its frequency ν is equal to the frequency of revolution ν_c of the carrier. (a) Derive an equation for ν_c in terms of m^*, e, and B. (b) In a certain experiment, $B = 0.1\,T$ and maximum absorption is found to occur at $\nu = 1.4 \times 10^{10}\,Hz$. Find m^*. (c) Find the maximum orbital radius of a charge carrier in this experiment whose speed is $3 \times 10^4\,m/s$.

Solution

(a) A carrier of mass m^* and charge e moving with velocity v in a magnetic field experiences a force perpendicular to the field **B**

$$\begin{aligned} Bev &= \frac{m^* v^2}{r} \qquad \text{where } r \text{ is the orbital radius} \\ Be &= m^* \left(\frac{v}{r}\right) \\ Be &= m^*(2\pi\nu_c) \\ \nu_c &= \frac{Be}{2\pi m^*} \end{aligned}$$

Resonance occurs when ν matches ν_c.

(b) $B = 0.1\,T \quad \nu = 1.4 \times 10^{10}$

$$\begin{aligned} \nu &= \frac{Be}{2\pi m^*} \\ m* &= \frac{Be}{2\pi\nu} \\ &= \frac{(0.1)(1.602 \times 10^{-19})}{2\pi(1.4 \times 10^{10})} \\ &= 1.82 \times 10^{-31}\,kg \\ m^* &= 0.2\,m_e \end{aligned}$$

The effective mass of the current carrier is $0.2\times$ the mass of an electron.

(c) $v = 3 \times 10^4\,m/s$

$$\begin{aligned} Be &= m^* \left(\frac{v}{r}\right) \\ r &= \frac{m^* v}{Be} \\ &= \frac{(1.82 \times 10^{-31})(3 \times 10^4)}{(0.1)(1.602 \times 10^{-19})} \\ &= 3.4 \times 10^{-7}\,m \end{aligned}$$

The maximum orbital radius for this speed is $3.4 \times 10^{-7}\,m$