

Chapter 3

Problem Solutions

3.1 If α_c were to increase, the bandgap energy would decrease and the material would begin to behave less like a semiconductor and more like a metal. If α_c were to decrease, the bandgap energy would increase and the material would begin to behave more like an insulator.

3.2
Schrodinger's wave equation

$$\frac{-\hbar^2}{2m} \frac{\partial^2 \Psi(x, t)}{\partial x^2} + V(x) \cdot \Psi(x, t) = j\hbar \frac{\partial \Psi(x, t)}{\partial t}$$

Let the solution be of the form

$$\Psi(x, t) = u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right]$$

Region I, $V(x) = 0$, so substituting the proposed solution into the wave equation, we obtain

$$\begin{aligned} \frac{-\hbar^2}{2m} \frac{\partial}{\partial x} \left\{ jku(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right. \\ \left. + \frac{\partial u(x)}{\partial x} \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right\} \\ = j\hbar \left(\frac{-jkE}{\hbar}\right) \cdot u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \end{aligned}$$

which becomes

$$\begin{aligned} \frac{-\hbar^2}{2m} \left\{ (jk)^2 u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right. \\ \left. + 2jk \frac{\partial u(x)}{\partial x} \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right. \\ \left. + \frac{\partial^2 u(x)}{\partial x^2} \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right\} \\ = -E u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \end{aligned}$$

This equation can then be written as

$$-k^2 u(x) + 2jk \frac{\partial u(x)}{\partial x} + \frac{\partial^2 u(x)}{\partial x^2} + \frac{2mE}{\hbar^2} \cdot u(x) = 0$$

Setting $u(x) = u_i(x)$ for region I, this equation becomes

$$\frac{d^2 u_i(x)}{dx^2} + 2jk \frac{du_i(x)}{dx} - \left(k^2 - \alpha^2\right) u_i(x) = 0$$

where

$$\alpha^2 = \frac{2mE}{\hbar^2}$$

Q.E.D.

In region II, $V(x) = V_{ce}$. Assume the same form of the solution

$$\Psi(x, t) = u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right]$$

Substituting into Schrodinger's wave equation, we obtain

$$\begin{aligned} \frac{-\hbar^2}{2m} \left\{ (jk)^2 u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right. \\ \left. + 2jk \frac{\partial u(x)}{\partial x} \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right. \\ \left. + \frac{\partial^2 u(x)}{\partial x^2} \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \right\} \\ + V_{ce} u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \\ = E u(x) \exp\left[j\left(kx - \left(\frac{E}{\hbar}\right)t\right)\right] \end{aligned}$$

This equation can be written as

$$\begin{aligned} -k^2 u(x) + 2jk \frac{\partial u(x)}{\partial x} + \frac{\partial^2 u(x)}{\partial x^2} \\ - \frac{2mV_{ce}}{\hbar^2} u(x) + \frac{2mE}{\hbar^2} u(x) = 0 \end{aligned}$$

Setting $u(x) = u_o(x)$ for region II, this equation becomes

$$\begin{aligned} \frac{d^2 u_o(x)}{dx^2} + 2jk \frac{du_o(x)}{dx} \\ - \left(k^2 - \alpha^2 + \frac{2mV_{ce}}{\hbar^2}\right) u_o(x) = 0 \end{aligned}$$

where

$$\alpha^2 = \frac{2mE}{\hbar^2}$$

Q.E.D.

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