2019 Ph H2 Q14

Section: Electricity

Topic: Band theory, semiconductors, resistivity

(a) Three band diagrams (X, Y, Z) are given. Identify which represents a conductor, an insulator and a semiconductor. (b) Using band theory, explain why semiconductors conduct at room temperature. (c) State effect of doping silicon with arsenic. (d) Compare resistivity of silicon (2.3×10^{3} Ωm) with copper (1.7×10^{-8} Ωm) in terms of orders of magnitude.

Worked solution

(a) From the diagrams:
• Conductor: overlapping valence and conduction bands (X).
• Insulator: large band gap, no conduction at room T (Y).
• Semiconductor: small band gap, some electrons excited at room T (Z).

Answer: X = Conductor, Y = Insulator, Z = Semiconductor

(b) In a semiconductor, the band gap between valence and conduction band is small. At room temperature, thermal energy is sufficient to excite some electrons into the conduction band. This allows limited conduction.

(c) Doping silicon with arsenic adds extra electrons (donor impurity). This increases the number of charge carriers, producing an n-type semiconductor and increasing conductivity.

(d) Ratio of resistivities:
$\rho(Si)/\rho(Cu) = (2.3\times10^{3})/(1.7\times10^{-8}) = 1.35e+11.$
= 10^11 approximately.

So silicon is about 11 orders of magnitude more resistive than copper.

Answer: $\sim10^{11}$ times higher resistivity

Final answers

(a) X = Conductor, Y = Insulator, Z = Semiconductor

(b) Small band gap → thermal excitation → conduction

(c) Doping with arsenic → more electrons → higher conductivity

(d) Silicon ≈ 10^{11} times more resistive than copper

Revision tips

- Conductors: overlapping bands, free electrons available.

- Insulators: wide band gap, electrons cannot move to conduction band.
- Semiconductors: narrow band gap, some conduction at room T.
- Doping introduces extra charge carriers (n-type = electrons, p-type = holes).
- Resistivity differences are huge: metals very low, semiconductors much higher.