Unit 24 Diode junction characteristics

- The current through a pn diode junction is given by:

$$I = I_0 \left(\exp\left(\frac{eV}{kT}\right) - 1 \right)$$

  where I_0 is the magnitude of the diode reverse current and V is the voltage across the diode.

- For a forward biased diode at room temperature, this reduces to:

$$I = I_0 \exp\left(\frac{V}{25\,\mathrm{mV}}\right)$$

$$\frac{kT}{e} = 25\,\mathrm{mV}$$

The equation $I = I_0 \left(\exp\left(\frac{eV}{kT}\right) - 1 \right)$ can be derived by a detailed analysis of the flow of charge carriers across the pn junction based on the distribution of carriers as a function of energy (Fermi-Dirac statistics). The derivation is treated in many texts on solid state physics (see, for example, *The Physics of Semiconductor Devices*, D. A. Fraser, OUP). The derivation is beyond the scope of this course and we will simply use the result.

Some points must be noted about this equation. If the voltage across the diode is zero, then $\exp(\frac{eV}{kT}) = 1$ and the junction current is zero. If the voltage across the diode is negative, corresponding to a reverse bias, then the term $\exp(\frac{eV}{kT}) \ll 1$ and the junction current is a constant $-I_0$ as expected. When a forward bias is applied, the current increases exponentially. A few representative values of junction currents, calculated using the diode current equation at room temperature, $T = 293\,\mathrm{K}$, are shown in the table.

A cursory inspection of these calculated currents shows that the currents for forward bias voltages of 0.6 V and greater are not realistic currents. Other factors come into action to limit the currents at these forward voltages. For instance, a conductor carrying 100 A would have to have a cross section of about $100\,\mathrm{mm}^2$ instead of the $0.5\,\mathrm{mm}^2$ wire used in a diode if the wire is not to melt like a fuse.

Voltage V	Current A
-10	-1×10^{-10}
0	0
0.1	5.5×10^{-9}
0.4	0.9×10^{-3}
0.5	4.8×10^{-2}
0.6	2.65
0.7	144
0.9	4.3×10^{5}

It is found, however, that the currents measured for small voltages across a diode (less than 0.5 V) correspond well to these predicted currents.

A very useful simplification is made if the numerical values for Boltzmann's constant, $k = 1.38 \times 10^{-23}\,\mathrm{JK^{-1}}$, the electronic charge, $e = 1.6 \times 10^{-19}\,\mathrm{C}$ and an assumed room temperature of $t = 20\,°\mathrm{C} = 293\,\mathrm{K}$ are substituted to give:

$$\frac{kT}{e} = \frac{1.38 \times 10^{-23} \times 293}{1.6 \times 10^{-19}} = 0.025\,\mathrm{V} = 25\,\mathrm{mV}$$

The junction diode forward current then becomes:

$$I = I_0 \exp\left(\frac{V}{25\,\mathrm{mV}}\right)$$

This is a result which we will use very frequently in our analysis of circuits.

24.1 Problems

24.1 Explain why the diode reverse current appears as a multiplying factor in the equation for the diode forward current.

24.2 If the reverse current for a particular diode is $I_0 = 5 \times 10^{-10}\,\mathrm{A}$, calculate the diode current for forward voltages of 0.25 V, 0.26 V, 0.40 V, 0.41 V. Estimate the rate of change of current with voltage, $\frac{dI}{dV}$, at 0.25 V and at 0.40 V.

24.3 Plot the log of the calculated current versus the forward voltage for a diode junction. Use the data in the table at the top of this page.

24.4 A particular diode has a reverse current, $I_0 = 10^{-10}\,\mathrm{A}$. The forward bias voltage is set at 0.45 V. Plot a graph of the diode forward current as a function of temperature for a temperature range from 10 °C to 80 °C.