Appendix

The Physics Behind LEDs

The Structure of an LED

An LED (light-emitting diode) consists of two different types of semi-conducting materials that are joined together and encased in plastic (Figure 1). One of the materials (A in Figure 2) contains a number of electrons that are free to move throughout it. The other material (B) has a number of vacant spaces where electrons could be found but are not. The absence of an electron is called an electron hole.

At the boundary between the two semi-conductors, some of the free electrons in material A move into electron holes in material B (Figure 3), and this reduces their energy.

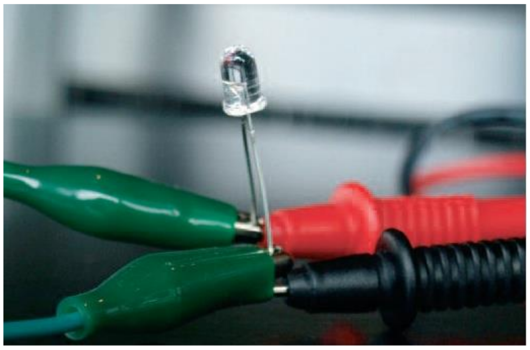

Figure 1

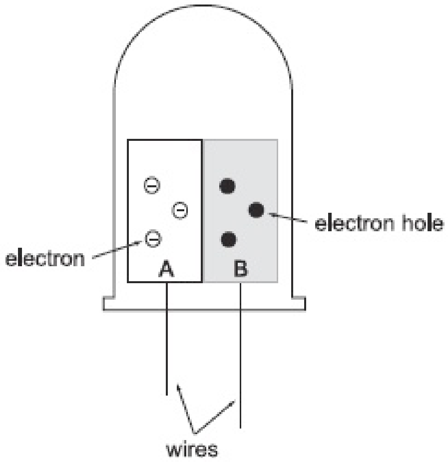

Figure 2 Schematic diagram of an LED made from two different semi-conductors (represented by white and grey rectangles, A and B, respectively)

After a short period of time, the region in material B near the boundary becomes negatively charged, and the region in material A near the boundary becomes positively charged (because a number of electrons have left). This produces an electric field, $\vec{E}$, that exerts a force, $\vec{F}_e$,on electrons in material A in a direction away from the boundary, as shown in Figure 4. The field acts as a potential barrier that prevents any more electrons from crossing.

Connecting an LED to a Circuit

When we connect an LED to a voltage source so that material A is connected to its negative terminal, electrons in this material are attracted to the boundary, as shown in Figure 5. The LED is said to be in "forward bias," and current flows when the potential difference is large enough to overcome the barrier created by the electric field. When electrons cross the boundary and move into holes, they move from higher energy states to lower-energy states. In doing so, they emit energy in the form of photons, which causes the LED to shine.

Mathematical Analysis

When the LED just begins to glow, electrons crossing the boundary move through a potential difference ΔV. In doing so, they lose an energy equal to $e\Delta V$, where e is the elementary charge ($e = 1.6 \times 10^{-19}$ C). This energy is converted into the energy, E, of a photon, given by $E = hf$, where h is Planck's constant and f is the photon's frequency. Equating E to the energy lost by each electron yields $e\Delta V = hf$, the equation used in this laboratory activity.

Connecting an LED the "Wrong" Way

When we connect an LED to a voltage source so that material A is connected to its positive terminal, the applied potential difference across the LED repels electrons in material A from the boundary. This has the effect of increasing the size of the existing potential barrier in the vicinity of the boundary, so no current flows. The LED is said to be in "reverse bias."

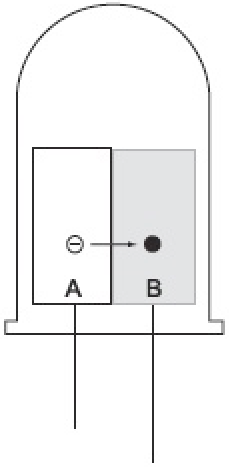

Figure 3 Electron moving into a hole

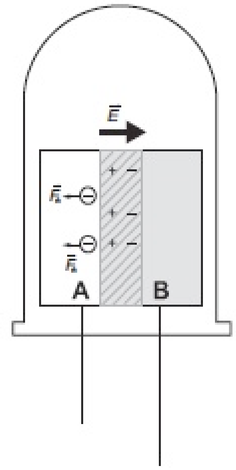

Figure 4 After a number of electrons have crossed the boundary, an electric field, $\vec{E}$, builds up that prevents more electrons from crossing. The diagonal lines in the centre rectangle represent the barrier created by this field.

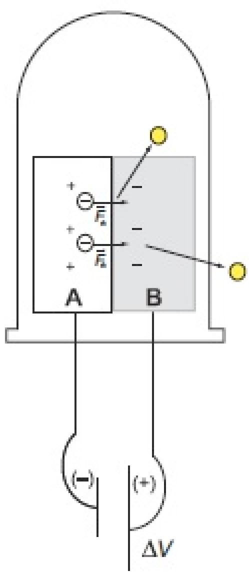

Figure 5 When we connect material A to the negative terminal of a voltage source (forward bias), current flows through the LED once the potential difference reaches a certain threshold voltage ΔV. When this happens, the LED emits photons (represented by the yellow circles).

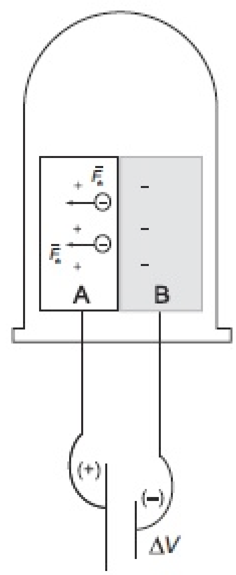

Figure 6 Connecting material A to the positive terminal leads to a force on electrons directed towards the left (reverse bias). Current does not flow through the LED.