

## What is a potentiometer?

A potentiometer is a device that allows the user to vary the resistance between two electrical contacts or terminals by some means, such as turning a knob. Many potentiometers have three terminals with the left and right-hand terminals being connected to either end of a fixed resistor. The central terminal is connected partway along the resistor with its exact position depending on the orientation of the knob. This provides a variable resistance between the central terminal and the other two terminals.

Turning the potentiometer knob fully clockwise results in the resistance between the central and right-hand terminals becoming  $0 \Omega$ . Turning the knob counter-clockwise increases the resistance between the central and right-hand terminals up to some maximum resistance ( $1 \text{ k}\Omega$  in the lab) and the potential difference across them.

When the LED is connected in parallel with the central and right-hand terminals, the potential difference across the LED-resistor combination is equal to the voltage across these two terminals. So, as we turn the knob counter-clockwise, we increase the potential difference across the LED.

## What is an LED?

A diode is an electronic component that has very low resistance when a current flows through it in one direction and very high resistance when it flows through in the other direction. It acts similarly to a one-way valve that allows water to flow through a pipe in only one direction. A light-emitting diode (LED) is a diode that converts electrical energy into visible electromagnetic radiation and thus emits light with a narrow frequency range when sufficient current flows through it in the low-resistance direction. LEDs are more energy efficient and have longer lifetimes than conventional incandescent light bulbs. They are used in devices such as traffic lights, digital alarm clocks, and TV remote controls.

## What is a viewing tube?

A viewing tube is a small tube made of rubber (or anything else) that can be used to block out light from other sources when you are attempting to see when an LED just begins to glow. To use a viewing tube, place one end of it over the LED and look through the other end. Such a tube can be made out of tightly rolled paper.

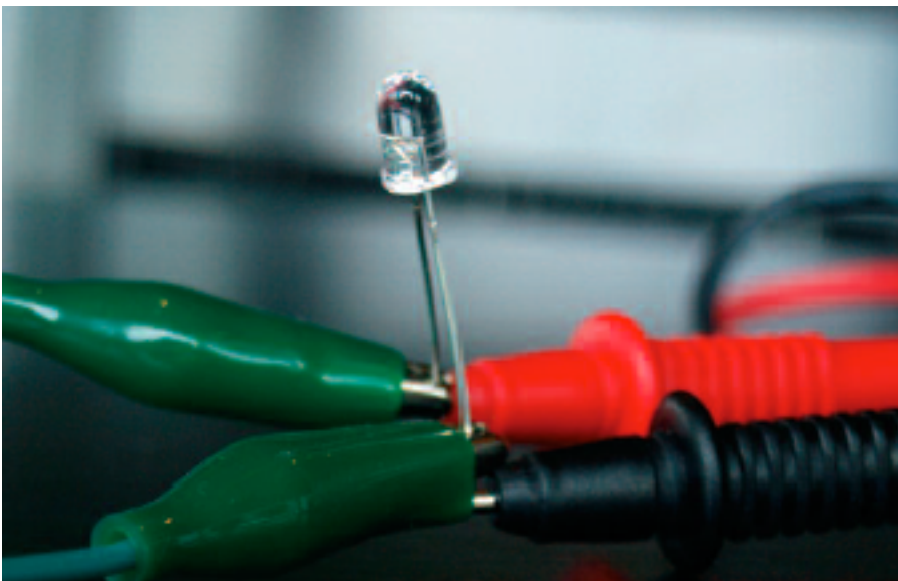


figure 1

## Structure of a light-emitting diode (LED)

An LED consists of two different types of semiconducting materials that are joined together and cased in plastic. One of the materials (A) contains a number of electrons that are free to move throughout it. The other (B) has a number of vacant spaces where electrons could be found but are not. Instead, there is the absence of an electron that is called an electron hole.

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 (as a number of electrons have left). This produces an electric field  $E$  that exerts a force  $F_e$  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.

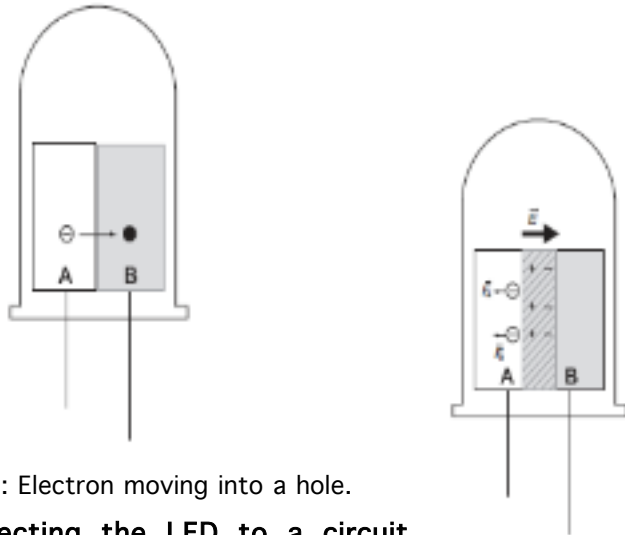


Figure 3: Electron moving into a hole.

### Connecting the LED to a circuit

When we connect the 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 ones. In doing so, they emit energy in the form of photons which causes the LED to shine.

### Connecting the LED the ‘wrong’ way

When we connect the 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 and so no current flows. The LED is said to be in ‘reverse bias’.

### Mathematical Analysis

When the LED just begins to glow, electrons crossing the boundary move through a potential difference  $\Delta V$ . In doing so, they lose an energy equal to  $e\Delta V$ , where  $e$  is the elementary charge ( $e = 1.6 \times 10^{-19} \text{ C}$ ). This energy is converted into the energy  $E$  of a photon where  $E$  is given by the equation  $E = hf$ , 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.

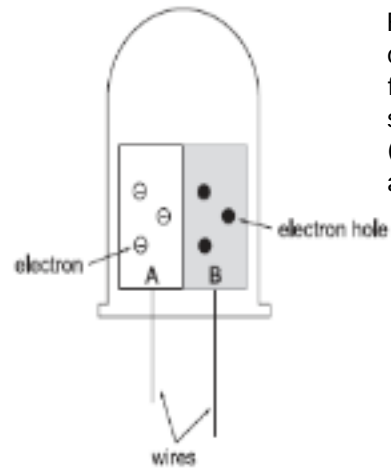


Figure 2: Schematic diagram of an LED made from two different semiconductors (represented by white and grey rectangles).

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

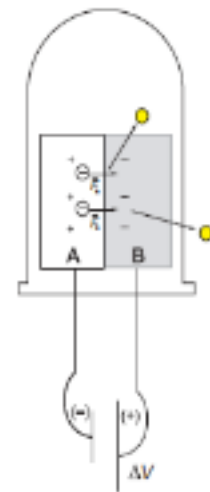


Figure 5: When we connect material A to the negative terminal of a voltage source (forward bias), current flows through the LED once the potential difference reaches a certain threshold voltage  $\Delta V$ . When this happens, the LED emits photons (represented by o).

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.



## Theory

- When we apply a large enough potential difference across a light-emitting diode (LED), it emits photons that all have the same frequency.
- When the LED just begins to glow, the energy  $E$  lost by each electron as it passes through the LED is converted into the energy of a single photon.
- The energy lost by each electron is  $E = e\Delta V$ , where  $e$  is the elementary charge ( $1.6 \times 10^{-19}$  C) and  $\Delta V$  is the potential difference across the LED.
- The energy  $E$  of a photon of frequency  $f$  is  $E = hf$ , where  $h$  is Planck's constant ( $h = 6.63 \times 10^{-34}$  Js).
- Equating the two energies yields  $e\Delta V = hf$
- Plotting  $\Delta V$  against  $f$  for LEDs of several different colors produces a straight line of slope  $h/e$ .
- Measuring the graph's slope and multiplying it by  $e$  yields Planck's constant.

## Useful Constants

$$c = 3.0 \times 10^8 \text{ m/s}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

## Cautions

**1. Do not stare directly at LEDs when they are brightly lit.** LEDs are safe when they just begin to glow, but they quickly become bright as the potential difference across them increases above the threshold value. **Be especially careful with the blue LED** as the upper part of its frequency spectrum is very close to the ultra-violet region which can cause permanent eye damage. Students should not stare at the blue LED even when it is dimly lit.

**2. LEDs can be destroyed if the current flowing through them is too large.** The purpose of the  $330 \Omega$  resistor connected in series with the LED is to limit the current flowing through the LED. This current should be no more than about 50 mA.

**3. The potentiometer can be destroyed if wired incorrectly.** Be careful when wiring the potentiometer. If you wire it incorrectly, you can create a short circuit which leads to a large potential difference across a low resistance. This can result in the potentiometer heating up rapidly, producing a visible quantity of smoke and ceasing to function. Inspect your circuit before connecting to the battery. You may also wish to label the terminals of the potentiometer and the LED (with tape, for example, or by color-coding them with paint) to indicate where they should be connected.