Objective:
In this experiment you will demonstrate that light can behave as a particle and also determine Planck’s constant.

Equipment:
Photoelectric apparatus with a phototube, Light Emitting Diodes (LEDs) of several colors, and two digital meters.

Theory:
When light strikes a metal, electrons can be emitted from it and collected by a nearby electrode. The metal in this case is known as a photocathode.

If the photocathode and a nearby collecting electrode (anode) are placed inside of a container evacuated of air, then an electron current will flow from the photocathode to the anode. Conventional current would flow in the opposite direction. The air, if not removed, would scatter
the electrons and prevent them from flowing to the anode. An ordinary light bulb is an example of such a highly evacuated container.

The electrons emitted from the photocathode have kinetic energy. This energy can be measured by applying an electric field by means of a voltage between the photocathode and the anode. If the electrode has a negative voltage relative to the photocathode, then the electron current will be reduced. As the applied voltage is made larger and larger eventually the electron current vanishes because no electrons can overcome the applied voltage. This stopping voltage ($V_s$) is then a measure of the maximum kinetic energy of the emitted electrons.

Applying conservation of energy and assuming light is quantized in units of energy $h\nu$, gives the famous Einstein equation.

$$eV_s = h\nu - W_0 \quad (1)$$

where $e$ is the charge on an electron ($1.602 \times 10^{-19}$ coulombs), $V_s$ is the stopping voltage, $h$ is Planck’s constant, $\nu$ is the frequency of the light, and $W_0$ is the minimum energy needed to liberate an electron from the photocathode i.e. the work function.

To verify the Einstein equation above, the photocathode is illuminated with several different color LEDs. Each LED produces a narrow spectrum of wavelengths $\lambda$ and hence a narrow range of light frequencies $\nu = c/\lambda$. The wavelengths are in meters, the frequencies are in Hertz (Hz) and $c$ is the speed of light ($2.998 \times 10^8$ meters/second).

For each LED the corresponding stopping voltage $V_s$ is measured so a plot of stopping voltage $V_s$ and LED frequency should give a straight line with a slope of $h/e$.

Note that the stopping voltage in the Einstein equation $V_s$ is only dependent on the frequency of the light $\nu$ and not on its intensity. By using only one color LED and measuring $V_s$ for several different light intensities, it can be shown that while the number of electrons emitted per second i.e. the photocurrent does change with the LED intensity, the stopping voltage $V_s$ does not. The conclusion is that electrons must absorb the light in packets of energy $h\nu$ and these packets are known as photons.
**Experimental Procedure and Questions:**

**Part 1: Determination of Planck’s constant.**

![Photoelectric Box Diagram](image)

1) Connect the meters to the photoelectric box as shown in Fig. 2. The meter connected to VSTOP is set to the 2 volt DC scale. The meter connected to the PHOTOCURRENT is set to the 200mV DC scale. Notice that this meter measures the voltage across the 100kohm resistor. By the use of Ohms Law (I=V/R) the photocurrent can be found for any reading of the meter. What is the photocurrent when the meter reads 200mV?

2) There are four LEDs to use as the light sources. The wavelength λ of each LED is given in nanometers. One nanometer (nm) = 10⁻⁹ meter.

3) Turn on the photoelectric box and set the INTENSITY switch to position 4.

4) Turn the VSTOP knob fully counterclockwise. The VSTOP meter should read zero.

5) Plug the 631nm LED into the socket attached to the red and black wires. The longer wire on the LED should go to the red wire. Insert the LED down into the hole in the plastic window. The LED light should be seen shining on the curved surface of the photocathode. A narrow strip of black tape shields the light from the collecting electrode. Why is this necessary? Place a plastic cup over the window to keep out the ambient light.

6) Slowly turn the VSTOP knob until the meter reading the photocurrent just reads zero. Record the voltage on the meter connected to VSTOP. Reset the VSTOP fully counterclockwise. Repeat step 6 four more times and calculate the average VSTOP voltage.
7) Repeat steps 5 and 6 for the 593nm, 525nm and 470nm LEDs.

8) Calculate the LED frequency for each LED wavelength by using the \( \nu = \frac{c}{\lambda} \) equation.

9) Make a graph of the data showing the average stopping voltage (VSTOP) verses the LED light frequency. Determine the slope of a line through the data and calculate Planck’s constant. The slope is \( \frac{h}{e} \) and has units of volt seconds so that Planck’s constant has units of electron volt seconds or Joule seconds. Calculate the percentage change of your measured value to the accepted value of Planck’s constant (6.63x10^{-34} \text{ Joule second}).

**Part 2: Determination of Photocurrent and Stopping Voltage as a Function of LED Light Intensity**

1) Plug the green LED (525nm) into the socket attached to the red and black wires. The longer wire on the LED should go to the red wire. Insert the LED down into the hole in the plastic window. The LED light should be seen shining on the curved surface of the photocathode. Place a plastic cup over the window to keep out the ambient light.

2) Set the Intensity Switch to position 1. The switch positions are calibrated so the LED intensity is proportional to the switch position. In other words, the LED intensity of position 2 is twice that of position 1, that of position 3 is three times that of position 1 and that of position four is four times that of position 1.

3) Set the Stopping Voltage (VSTOP) to zero and record the PHOTOCURRENT. Remember to use Ohms law to convert this voltage to a current.

4) Slowly turn the VSTOP knob until the meter reading the PHOTOCURRENT just reads zero. Record the voltage on the meter connected to VSTOP.

5) Repeat steps 3-5 for the other Intensity Switch settings 2, 3, and 4.

6) Make a graph of the magnitude of the PHOTOCURRENT verses the four LED intensities 1, 2, 3, 4. The LED intensities are just relative and so have arbitrary units. Fit a line through the plotted points.

7) Make a graph of the Stopping Voltage (VSTOP) verses the four LED intensities 1, 2, 3, 4. The LED intensities are just relative and so have arbitrary units. Fit a line through the plotted points.

8) Explain in your own words why these data suggest that light is quantized?