Light as a Particle

Problems Worksheet

Step Up In Physics
Unit 3 and 4

1. Classical physics described light as an electromagnetic wave. Modern physics has a different interpretation of light. Describe the model of light as viewed in modern physics.

2. X rays are used in medicine for imaging bone structure but they also cause cell damage. During the design of a new X ray machine the engineers need to carefully control the exposure of the patients to the X rays. This X ray machine produces X rays with a 948 pm wavelength. The machine produces a 68.0 W X ray beam for 0.300 s while the image forms.

    a. Calculate the energy of a photon of the X rays used in this imaging process.

    b. Calculate the number of photons produced by the machine during the imaging process.

3. Electromagnetic waves have a very wide range of wavelengths; radio waves and gamma waves can have a 100 m and 1.00×10^{-12} m wavelength respectively.

    a. Calculate the energy of a single photon of a radio wave.

    b. What is the ratio of the energy of a gamma wave to that of a radio wave?

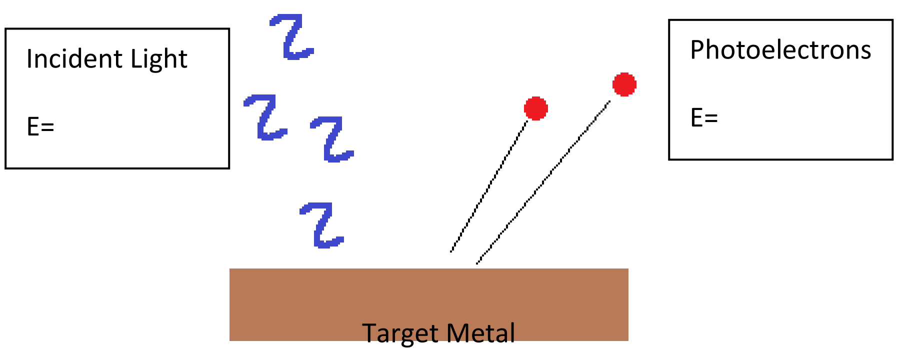
4. With the world wide use of mobile phones going from zero to 4 billion people in a little over 3 decades, any long term health issues may not be fully realised. However, short term issues are better understood. Mobile phones communicate wirelessly over long distances using microwaves. Studies have shown that human skin placed a few centimetres from a mobile phone while on a call heats up by a fraction of a degree.

    a. Explain why the skin increases in temperature.

    b. Estimate the number of photons transmitted during a 2.00 minute call by a mobile phone if its transmission power is 500 mW.

5. The photoelectric effect provided evidence that supported the early suggestion by Max Planck that electromagnetic waves exist as discrete packets of energy.

    a. In each of the blank boxes in the diagram, provide a formula that could be used to determine the energy of each named part using only the frequency, work function and/or suitable constants.



b. Describe the energy transformations that occur during the photoelectric effect.

c. If the incident light was not causing the emission of any electrons from the target metal, how could the light be changed to start causing emission of electrons? Explain your answer.

d. Rather than changing the light source, explain why changing the target metal from part (c) may allow for the detection of emitted electrons.

6. Copper has a 4.73 eV work function and tungsten has a 4.52 eV work function. During a photoelectric effect experiment a 7.30 V stopping potential is required with the copper sample.

    a. Describe what a stopping potential is in the context of the photoelectric experiment.

b. Calculate the frequency of the light incident on the copper sample.

c. If the copper sample is swapped out for the tungsten sample while the light source remains the same, calculate the kinetic energy of the electrons that are emitted from the tungsten sample.

d. What stopping potential would be required when the tungsten sample is used as the target metal.

e. Calculate the cut off wavelength for the emission of electrons from the copper sample.

f. Is the cut off wavelength calculated in part (e) a maximum or minimum value for the emission of electrons? Explain your answer.

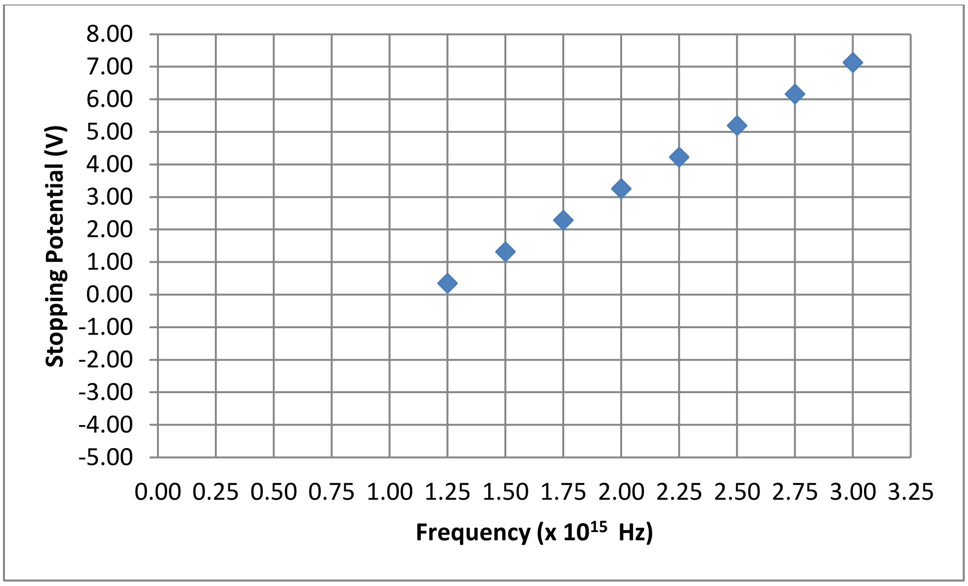
7. A photoelectric experiment was being conducted with nickel as the photoemissive material. The nickel is placed into a vacuum chamber and illuminated with ultraviolet light. An ammeter picked up a small current flowing between the photoemissive plate and the collector plate.

   a. Explain why the nickel is placed inside a vacuum chamber.

   b. If the light intensity was decreased slightly, what would happen to the current picked up by the ammeter? Using a suitable model of light, explain why this occurs.

   c. If the light frequency was increased slightly, what would happen to the current picked up by the ammeter? Using a suitable model of light, explain why this occurs.

8. The results of a photoelectric experiment designed to experimentally determine the value of Planck's constant are shown in the graph below.



a. What is the work function of the target metal?

b. Calculate the gradient of the slope. Include the units.

c. Using the gradient of the slope, calculate the experimentally determined value of Planck's constant.

d. Calculate the percentage difference between the experimentally determined value of Planck's constant and the currently accepted value of Planck's constant.

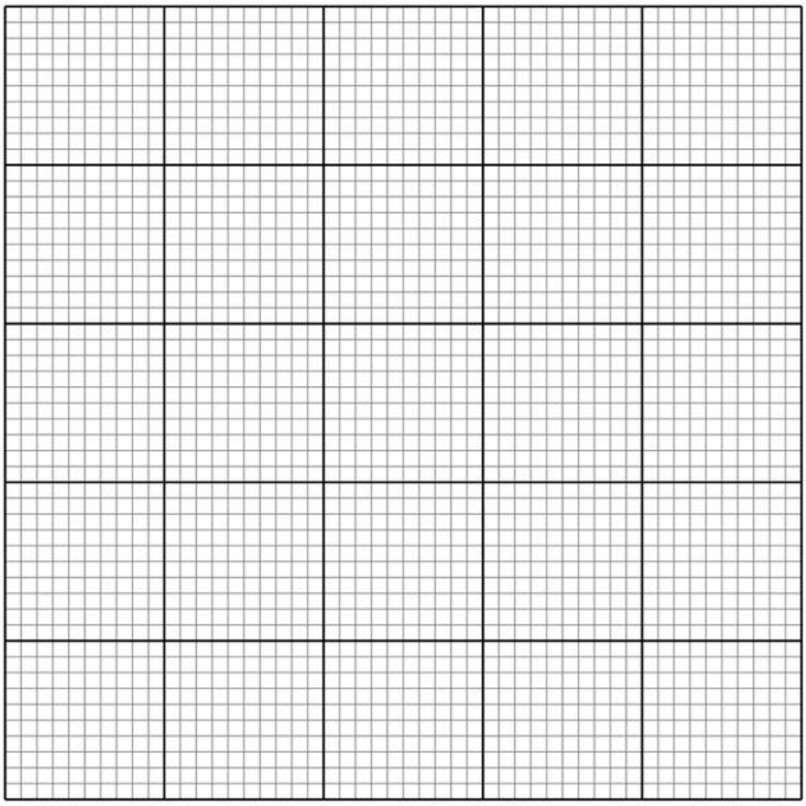
e. A new target metal with a 2.50 eV work function is used in the same experimental setup. Sketch the graphical results of the experiment on the same set of graph axes given above. Assume all sources of error between the experiments are the same.

9. Two students were attempting to determine Planck's constant using a set of coloured LED lights of known wavelengths, a variable EMF source and a voltmeter. Their results are contained within the table below. In order for the LED to produce any light, the voltage applied to the LED must be large enough to give the electrons in the LED an energy greater than the monochromatic coloured light the LED emits. The minimum voltage that could cause the LED to light up is called the threshold voltage.

LED colour	**Wavelength of light (nm)**	**Threshold voltage (V)**	**Uncertainty of threshold voltage (V)**
Red	623	1.9	±
Orange	586	2.1	±
Green	555	2.3	±
Blue	490	2.5	±

a. The voltmeter used to measure the threshold voltage across each LED has a 5.00 % uncertainty. Add the absolute uncertainty of the threshold voltage values to the table.

b. The students suspected there was an inverse relationship between wavelength and the threshold voltage. Make a plot of the data, placing the threshold voltage on the vertical axis. Choose a suitable form of the wavelength data for the horizontal axis such that the plotted data is linear. Include error bars.



c. Using the gradient of the graph, calculate the experimentally determined value of Planck's constant.

d. When the threshold voltage is applied to an LED by the EMF source, the electrons in the LED lose their energy to the formation of photons. Assuming that other losses in the LED are negligible, explain why different coloured LED lights have different threshold voltages.