Quantum Physics

IB 12

What are photons?

Properties of photons:

Energy of a Photon

1. A beam of monochromatic light has a frequency of 4.4×10^{14} Hz. Determine the energy of each photon of this light in both joules and electron-volts.

2. Light from a 2.5 mW laser has a wavelength of 670 nm.

   a) Find the energy of each photon in joules and electron-volts.

   b) How many photons does it emit in 3.0 minutes?

   c) The laser beam falls normally on a plane surface and appears as a small circle whose diameter is 1.5 mm. What is the intensity of the laser beam?

Intensity –

Formula:

Symbol:

Units:

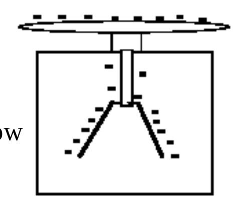
	Energy of each photon	Total energy	Number of photons
If the frequency of the light is constant, as the intensity of the light increases….			
If the intensity of the light is constant, as the frequency of the light increases….			

3. Which contains more photons – 1 joule of red light or 1 joule of blue light?

4. Which emits more photons per second – a 1 W laser of red light or a 1 W laser of green light?

The Photoelectric Effect:

The Experiment:



1. Light of varying frequencies and intensities are shone on a metal surface (photoemissive surface).

2. Light below a certain frequency will not emit electrons (photo-electrons) no matter how intense it is or how long it shines on the surface. Light at or above a certain frequency will immediately emit electrons no matter how intense it is.

Threshold frequency (f_o):

How are these results in conflict with the classical theory about light?

Classical Theory says . . .

	Classical predictions	**Experimental evidence**
Whether electrons are ejected or not depends on . . .		
The maximum kinetic energy of the ejected electrons depends on . . .		
At low intensities, ejecting electrons . . .		

Einstein's explanation of the photo-electric effect:

4. Light acts like a particle (not a wave) in which its energy is proportional to its frequency.

5. Electrons at the surface of the metal need *a minimum energy in order to be ejected from the surface*, called the ***work function***, an amount which varies from metal to metal. (Electrons under the surface of the metal need more energy to be emitted.)

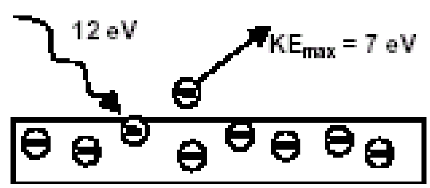
Work Function (ϕ):

1. There is a one-to-one interaction in which one electron absorbs one photon. If the photon has enough energy (high enough frequency) to overcome the work function, the electron will leave surface immediately with no time delay. If not, the electron will still absorb the photon but will remain bound to the metal.

2. Any "extra" energy (above the work function) is retained by the electron in the form of kinetic energy. The maximum kinetic energy (E_{kmax}) is retained by electrons that were most loosely held on the very surface of the metal.

3. The number of photons arriving per second, and therefore the rate of emission of electrons, is determined by the intensity of the light, not its frequency. The intensity of the light plays no role in the energy each photon has.

Einstein's
Photoelectric Effect
Equation



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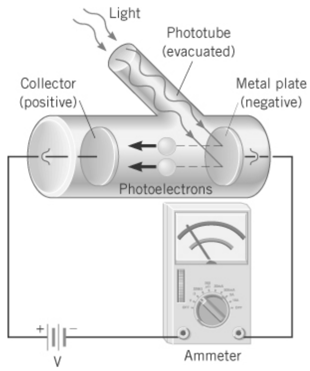
1. Photons strike a metal surface whose work function is 2.1 electronvolts, ejecting electrons with a maximum kinetic energy of 7.5 electronvolts.

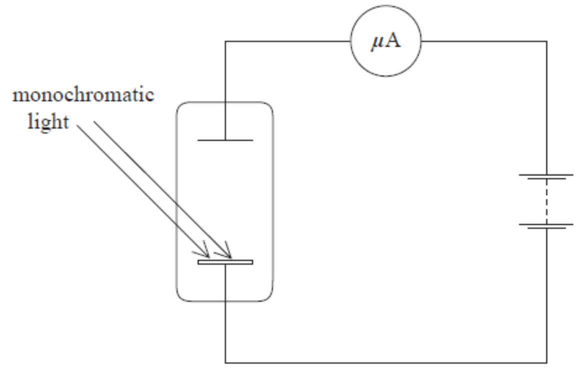
   a) Find the energy of the photons.

   b) Find the threshold frequency of the metal.

Analysis of the Photo-Electric Effect Experimental Data

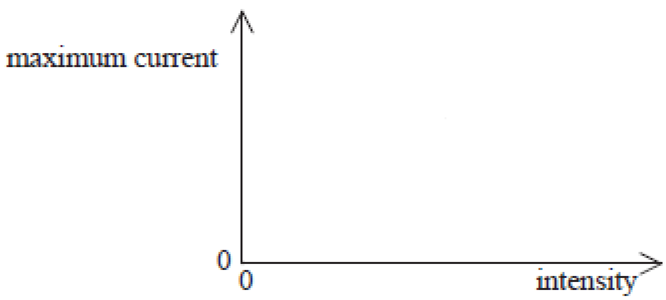
Monochromatic light is incident on a metal surface in a photo-cell as shown. The frequency of the light is above the threshold frequency for this metal. The current in the photo-cell is measured using a microammeter. The potential difference of the voltage source is varied until the reading on the microammeter is a maximum (called the "saturation current.")





Schematic of Experimental Apparatus

1. Sketch a graph of how this maximum current varies with the intensity of light if the frequency of the light is kept constant.

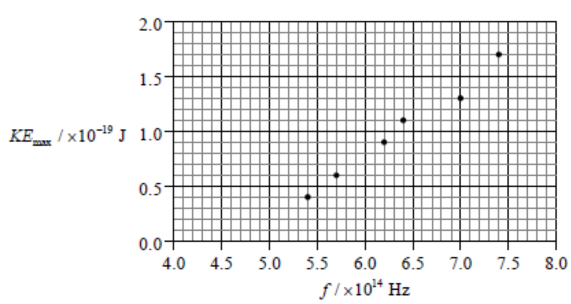


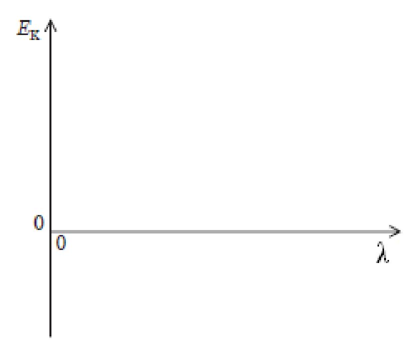
Explanation:

2. Describe and explain what will happen to the current if the intensity is kept the same but the frequency of the light is increased. Sketch the resulting graph on the axes above.

A plot of the maximum kinetic energy of the ejected electrons versus frequency of the incident light is shown. Discuss the features of this graph. Sketch a graph of maximum kinetic energy versus wavelength.

Mathematical Model





x-intercept =

Slope =

y-intercept =

Millikan's Stopping Potential Experiment

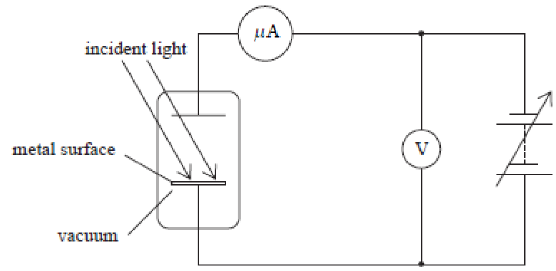
Purpose:

Method:

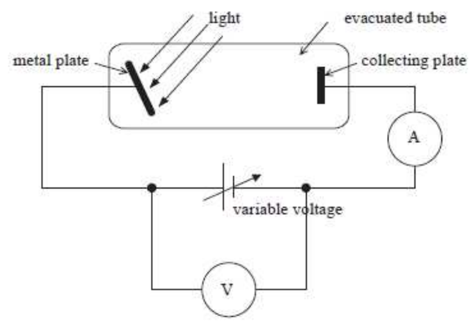
1) Make collecting plate (electrode) negative to repel electrons emitted from the surface (reverse the normal polarity).

2) Increase the potential difference until the current drops to zero.

3) Electrons emitted from metal surface have a maximum energy. If this maximum energy is less than the energy required for electrons to move between plates (against the potential difference), electrons will not reach the collecting plate.



Two comparable schematics of the stopping potential experimental apparatus



Stopping Potential (V_s):

1)

2)

Maximum kinetic energy of ejected electrons (E_{max}):

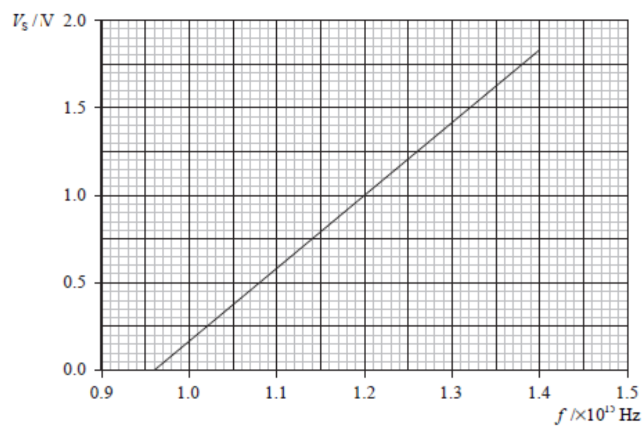
Experimental Results

Mathematical Model

x-intercept =

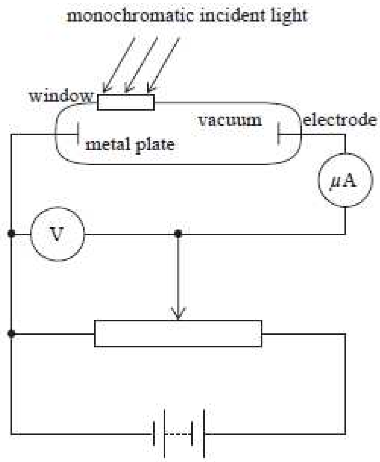
Slope =

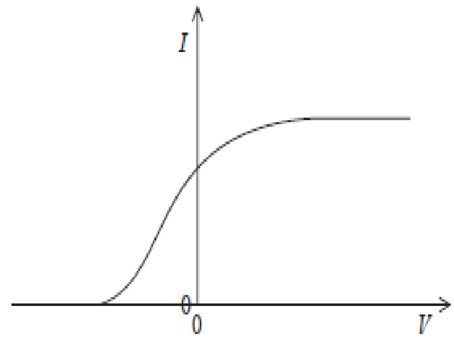
y-intercept =



Use the graph above to determine a value for the work function in electronvolts and for Planck's constant.

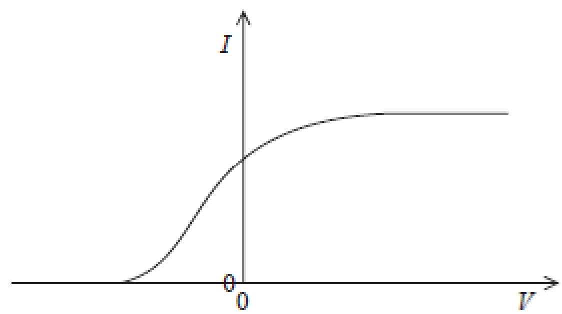
The apparatus shown is used to investigate the photo-electric effect. The potential difference *V* applied between the metal plates and electrode may be varied in magnitude and direction. In one particular experiment, the frequency and intensity of the light are held constant. The graph shows the variation with the potential difference of the current measured on the microammeter.



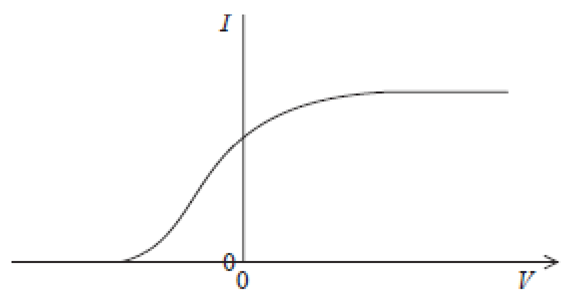


1. Discuss the features of the graph.
   a)

   b)



2. How would this graph change if the intensity of the light increased at the same frequency? Sketch it on the axes.



3. How would this graph change if the frequency of the light increased at the same intensity? Sketch it on the axes.

4. The potentiometer is adjusted to give the minimum voltage at which there is zero reading on the microammeter. State and explain what change, if any, will occur in the microammeter when

   a) the intensity of the incident light is increased but the frequency remains unchanged.

   b) the frequency of the light is increased at a constant intensity.