ATOMS: PHOTONS AND THE PHOTOELECTRIC EFFECT QUESTIONS

SODIUM LAMPS (2012;2)

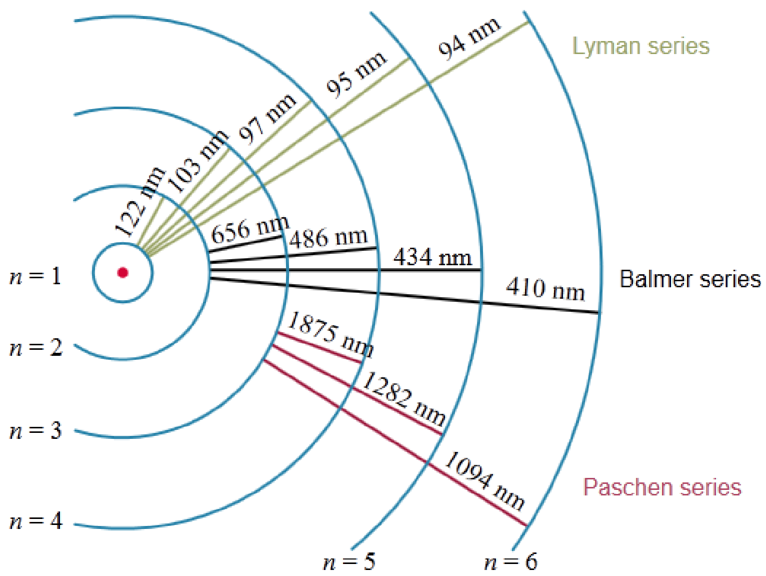
Low pressure sodium lamps are widely used in street lighting. The lamps produce light when an electric current is passed through sodium vapour. Almost all the light from these lamps has a wavelength of 5.89×10^{-7} m.

(a) Calculate the energy for a photon of light emitted from a sodium lamp.
(b) The work function for sodium is 2.28 eV. Calculate the threshold frequency for the emission of photoelectrons from the surface of sodium metal, and hence the maximum wavelength of light that can cause photoemission.
(c) Show that light from a sodium lamp cannot cause photoemission of electrons from sodium metal. By considering the energy transitions involved in light production and absorption, suggest a possible reason for this.

ATOMS AND PHOTONS (2011;2)

(a) State what a photon is, and describe how it can be produced by electrons within an atom.
(b) X-rays are used to take photographs of bones inside the body. X-ray photons typically have frequencies in the range 10^{16} Hz to 10^{19} Hz. An X-ray photon has energy of 191 eV. Calculate the frequency of the photon.
(c) When X-ray photons hit calcium, electrons are released. The frequency of a photon will have to be **more** than the threshold frequency if an electron is to be **released**. Discuss this statement in terms of the underlying physical principles.
(d) X-rays of frequency 1.53×10^{16} Hz cause the emission of electrons from a material with a maximum kinetic energy of 2.18×10^{-18} J. Calculate the threshold frequency for the release of electrons from the material.
(e) Explain why, if a photon causes an electron to jump to a higher energy level, the exact energy of the photon is critical, but if it is used to release an electron from the atom, it is only the minimum energy of the photon that is critical.

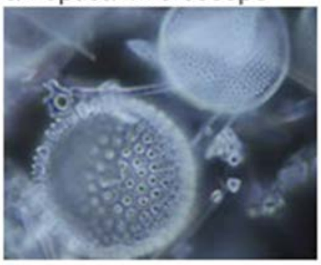
ATOMIC SPECTRA (2010;1)



(d) Light caused by a transition between the $n = 2$ and $n = 1$ levels is shone on to the surface of magnesium, causing emission of electrons. Magnesium has a work function of 3.66 eV. Calculate the maximum kinetic energy of the emitted electrons, in joules.

LIGHT AND ELECTRON MICROSCOPES (2010;2)

Image observed with an optical microscope



Specimen: Diatom
* Note that the diatom in these images observed with optical and electronic microscopes are not the same.

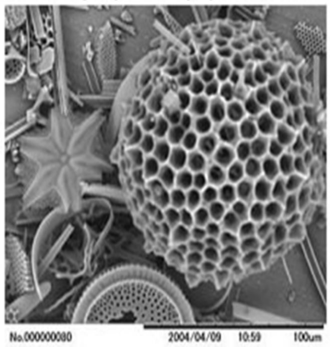
Most microscopes use light (photons) to form an image.

(a) The details seen with a light microscope are limited by diffraction. Light microscopes cannot image details that are smaller than the wavelength of the light which is being used. Calculate the size of the smallest details that can be seen with visible light photons of energy 4.97×10^{-19} J.

(b) Describe and explain one piece of experimental evidence which shows that light is not simply a wave, but that it also has a particle nature.

Some microscopes form an image using electrons rather than light. Electron microscopes illuminate the specimen with an "electron gun", rather than a lamp.

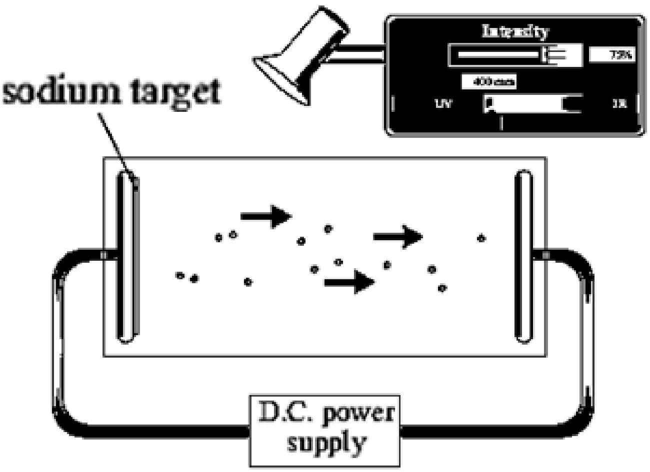
Images observed with an electronic microscope (Miniscope)



(c) In an electron microscope the electron gun accelerates electrons through a potential difference of 10 kV. Calculate the kinetic energy gained by an electron crossing this potential difference. State your answer in joules.

(d) When the electrons hit a sample, they may excite the atoms they hit and cause X-ray photons to be emitted. Calculate the minimum voltage needed in the electron gun to produce electrons with sufficient energy to cause emission of X-rays from oxygen atoms, with a wavelength of 2.36×10^{-9} m. State any assumptions you make.

THE PHOTOELECTRIC EFFECT (2009;2)



The diagram shows a simulation of the photoelectric effect. As violet light is shone on the sodium target, electrons leave the sodium and move to the right, causing a small current in the circuit.

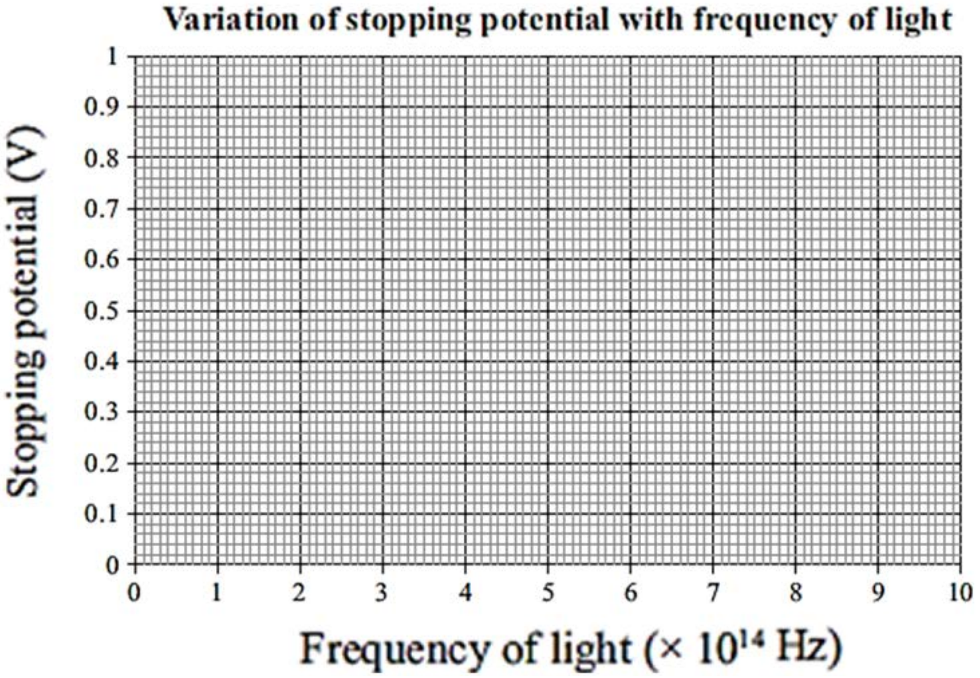
(a) When the wavelength of the light is increased, the light becomes red and no electrons leave the sodium. Explain why violet light, but not red light, causes electron emission.

(b) While violet light shines at the sodium, a student studies the effect of varying the intensity of the light. Describe and explain how this will affect the rate of electron emission, the maximum speed of the emitted electrons and the current in the circuit.

(c) With violet light of wavelength 4.00×10^{-7} m shining at the target, the D.C. power supply is changed until there is no current. This stopping potential is 0.80 V.

(i) Calculate the maximum kinetic energy (in joules) of the electrons leaving the surface of the sodium.

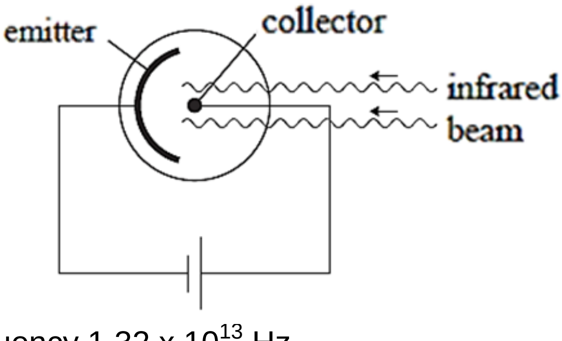
(ii) Calculate the threshold frequency for sodium. Use this value to draw a line on the graph which shows how stopping potential varies with the frequency of the light shone at the sodium surface. Clearly show your method for the calculation of all quantities.



PHOTOELECTRIC EFFECT (2008;3)

Planck's constant = 6.63×10^{-34} Js

One way in which automatic doors operate is to have a beam of infrared radiation directed on to a photocell. The beam is arranged so that it is broken if someone approaches the door and stops the radiation hitting the photocell. A simple model of the operation of the system is shown in the diagram below. A sensor sends a signal to the door opener when the current in the circuit stops.



The infrared radiation has frequency 1.32×10^{13} Hz.

(a) Calculate the energy of the infrared photons.

(b) Explain how the infrared photons cause current in the circuit.

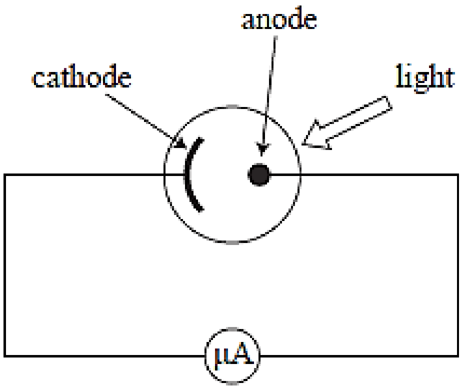
(c) One of the materials considered for the emitter plate has a work function energy of 8.94×10^{-21} J. Explain whether this material would be suitable.

(d) The material that is finally chosen for the emitter plate has a threshold frequency of 9.85×10^{12} Hz. Calculate the maximum energy of the photoelectrons released.

PHOTOELECTRIC EFFECT (2007;3)

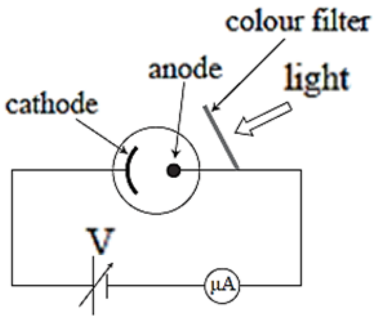
Speed of light = 3.00×10^{8} m s^{-1}
Charge on the electron = 1.6×10^{-19} C
Planck's Constant = 6.63×10^{-34} J s

Historically, photographers have used light meters containing photocells that are modelled on the photoelectric effect.
A photocell consists of a vacuum tube containing a curved sheet of zinc metal as the cathode and a metal pin as the anode, as shown in the diagram below. When light shines on the photocell, there is a current in the circuit. A very sensitive meter measures this current.

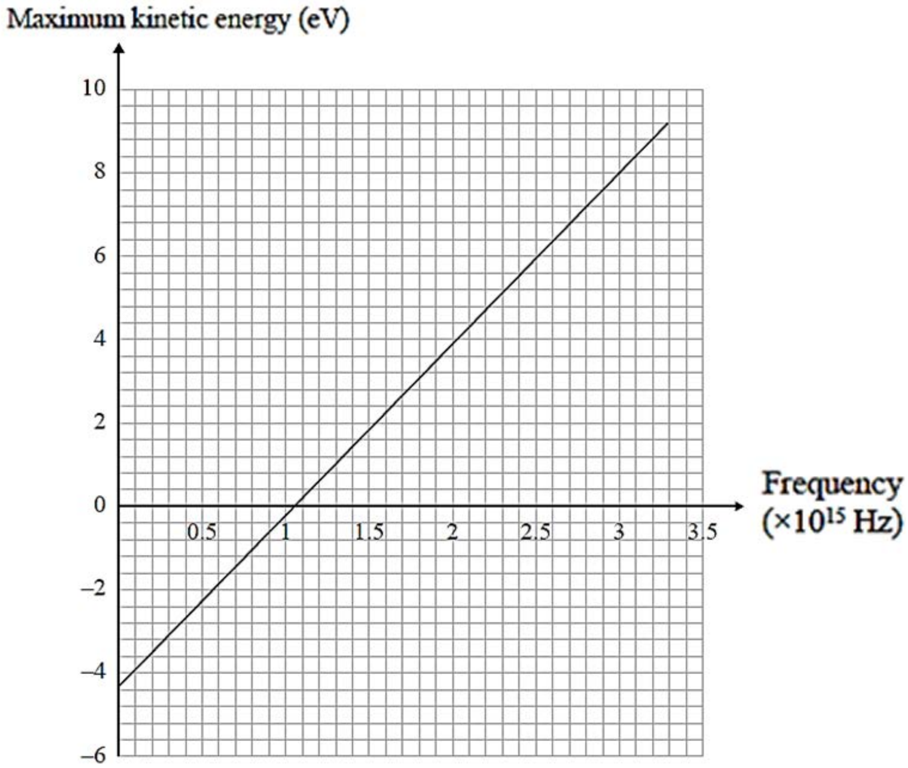


(a) Describe what causes a current in the circuit.
(b) Explain how changing the brightness of the light affects the size of the current in the circuit.

To investigate the properties of the photocell, a variable voltage supply is connected to the photocell, as shown in the circuit diagram. Using a colour filter makes the light hitting the zinc cathode monochromatic.



The voltage is changed until there is no current in the circuit. This voltage is a measure of the maximum kinetic energy of the released electrons, in electron volts.
By using different colour filters to change the frequency of the light hitting the zinc cathode, a graph of maximum electron kinetic energy, in electron volts, against frequency is drawn.



(c) From the graph, determine the threshold frequency of zinc.

(d) The equation for the maximum kinetic energy of the released electrons, in joules, is

$$E_K = hf - \phi .$$

Using information from the graph, calculate a value for Planck's constant. Show your working.

(e) Determine the threshold frequency for a metal that releases an electron with maximum kinetic energy of 3.94×10^{-20} J when light of wavelength 4.01×10^{-7} m shines on it.

NIGHT VISION CAMERA (2006;3)

Planck's constant = 6.63×10^{-34} Js

A night vision camera detects low levels of light on the photo-cathode, which releases a few electrons. A photomultiplier increases the number of electrons, which then hit the screen to produce an image.

(a) Name the effect that causes electrons to be released by the photo-cathode.
(b) The photo-cathode material of this night vision camera prevents it detecting infrared radiation. State why this is so.

The photo-cathode is made of a material that has a work function of 2.58×10^{-19} J.

(c) Calculate the lowest frequency of light that could release a photoelectron.
(d) Explain the effect on the number and energy of the electrons released when the frequency of the light is decreased.

The photo-cathode is replaced with a different material. When illuminated with light of wavelength 2.80×10^{-7} m, electrons with a maximum kinetic energy of 3.04×10^{-19} J are produced.

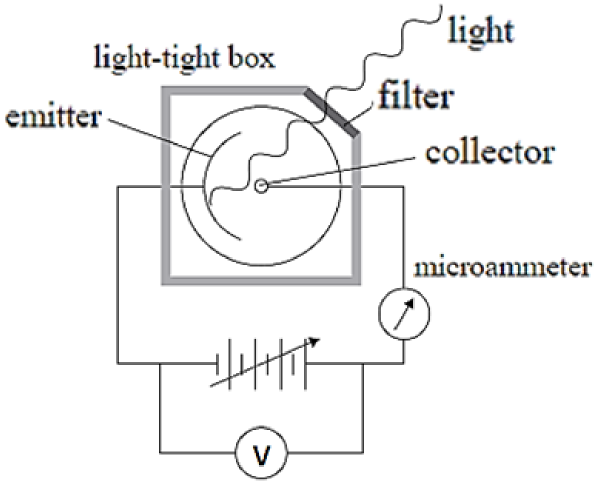
(e) Calculate the threshold frequency for the material.

LIGHT ENERGY CHANGED TO ELECTRICAL ENERGY (2005;1)

$$\text{Charge on an electron} = 1.60 \times 10^{-19}\ \text{C}$$
$$\text{Speed of light} = 3.00 \times 10^{8}\ \text{m s}^{-1}$$
$$\text{Planck's constant} = 6.63 \times 10^{-34}\ \text{J s}$$
$$\text{Rydberg's constant} = 1.10 \times 10^{7}\ \text{m}^{-1}$$

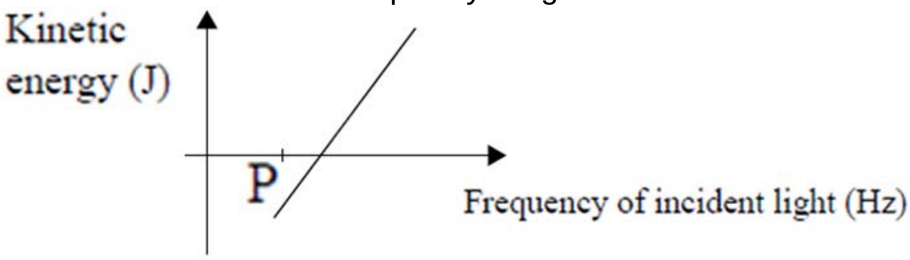
Year 13 photography students were taking photographs of Prince William on his recent visit to New Zealand. The camera they were using had a light meter that measured the brightness of the light. One of the students mentioned that the light meter was developed from the photoelectric cell. In a photoelectric cell, electrons are released to generate a current when light is incident on the metal surface of the cell. The circuit diagram of a cell is shown.

light meter



(a) Light of frequency 6.16 x 10^{14} Hz is incident on the photoelectric cell. Calculate the energy of the light photons.

Each photon will release an electron. The graph below shows the relationship between the kinetic energy of the released electrons and the frequency of light incident on the cell.



(b) Describe what would happen if light of frequency P were incident on the photoelectric cell.

(c) Each photon of frequency 6.16 x 10^{14} Hz will release an electron with a maximum kinetic energy of 0.35 eV. Calculate the threshold frequency of the metal surface of the cell.

(d) If the metal of the photoelectric cell is now changed to one with a greater work function, draw a line on the graph above to represent how its kinetic energy would depend on the frequency of the incident light.

(e) Explain what effect the brightness of the light will have on the current generated in the photoelectric cell.

If the battery is reversed, its voltage can be adjusted until the current stops.

(f) Explain how this cut-off (stopping) voltage, when the light is brighter, compares with the cut-off voltage when the light is less bright.

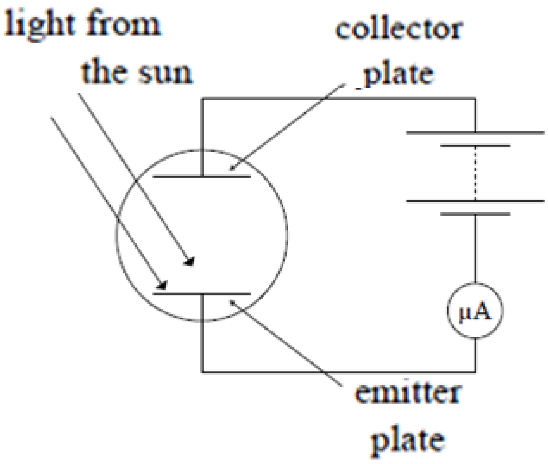
(g) State TWO different ways in which the wave model of light fails to explain the photoelectric effect. Explain ONE of the statements you make.

QUESTION THREE (2004;3)

Use the following information when answering this question:

$$\text{Speed of light} = 3.00 \times 10^{8} \text{ m s}^{-1}$$
$$\text{Planck's constant} = 6.63 \times 10^{-34} \text{ J s}$$

Light energy from the Sun can be changed into electrical energy by a photoelectric cell. The diagram shows an experimental set-up that can be used to investigate this energy change. The emitter plate has work function energy of 3.0×10^{-19} J.



(a) State why it is necessary to make the collector plate positive.
(b) Explain why the sun's light energy can cause a current in this circuit.
(c) Calculate the maximum wavelength of light that will cause a current.