AS Level Physics

Module 3 - Electromagnetic radiation and quantum phenomena

3.1.2 The Photoelectric Effect

Worked Examples

The Photoelectric Effect

Exam Style Question 1

An argon-laser emits electromagnetic radiation of wavelength $5.1 \times 10^{-7}\ m$. The radiation is directed onto the surface of a caesium plate. The work function energy for caesium is $1.9\ eV$.

(i) Name the region of the electromagnetic radiation emitted by the laser.

(ii) Show that the work function energy of caesium is $3.0\ \times\ 10^{-19}\ J$.

(iii) Calculate

1) the energy of a single photon.

2) the maximum kinetic energy of an electron emitted from the surface of caesium.

(iv) State and explain what change, if any, occurs to the maximum kinetic energy of an emitted electron if the intensity of the laser light is reduced.

(v) The power of the laser beam is $80\ mW$. Calculate the number of electrons emitted per second from the caesium plate assuming that only 7.0% of the incident photons interact with the surface electrons.

The Photoelectric Effect

Exam Style Question 1

(i) Name the region of the electromagnetic radiation emitted by the laser.

Visible Light.

(ii) Show that the work function energy of caesium is $3.0\ \times\ 10^{-19}\ J$.

Just convert $1.9\ eV$ to J

$$work\ function(\phi) = 1.9\ eV \times 1.6 \times 10^{-19}\ J$$
$$\phi = 3.04 \times 10^{-19}\ J$$

(iii) Calculate

1) the energy of a single photon

Use $E = \frac{hc}{\lambda}$

$$E = \frac{(6.63 \times 10^{-34}\ Js)(3.0 \times 10^{8}\ m\ s^{-1})}{(5.1 \times 10^{-7}\ m)}$$
$$E = 3.9 \times 10^{-19}\ J$$

2) the maximum kinetic energy of an electron emitted from the surface of caesium.

Use $hf = \phi + KE_{max}$

$$3.9 \times 10^{-19}\ J = 3.04 \times 10^{-19}\ J + KE_{max}$$
$$KE_{max} = (3.9 \times 10^{-19}\ J) - (3.04 \times 10^{-19}\ J)$$
$$KE_{max} = 8.6 \times 10^{-20}\ J$$

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 1

An argon-laser emits electromagnetic radiation of wavelength $5.1 \times 10^{-7}\ m$. The radiation is directed onto the surface of a caesium plate. The work function energy for caesium is $1.9\ eV$.

(i) Name the region of the electromagnetic radiation emitted by the laser.

(ii) Show that the work function energy of caesium is $3.0 \times 10^{-19}\ J$.

(iii) Calculate

1) the energy of a single photon.

2) the maximum kinetic energy of an electron emitted from the surface of caesium.

(iv) State and explain what change, if any, occurs to the maximum kinetic energy of an emitted electron if the intensity of the laser light is reduced.

(v) The power of the laser beam is $80\ mW$. Calculate the number of electrons emitted per second from the caesium plate assuming that only 7.0% of the incident photons interact with the surface electrons.

The Photoelectric Effect

Exam Style Question 1

(iv) State and explain what change, if any, occurs to the maximum kinetic energy of an emitted electron if the intensity of the laser light is reduced.
No change to maximum KE of electron and each photon has the same energy but there are fewer photons.

(v) The power of the laser beam is $80\ mW$. Calculate the number of electrons emitted per second from the caesium plate assuming that only 7.0% of the incident photons interact with the surface electrons.

$$no.of\ photons = \frac{80 \times 10^{-3}\ W}{3.9 \times 10^{-19}\ J} = 2.05 \times 10^{17}$$

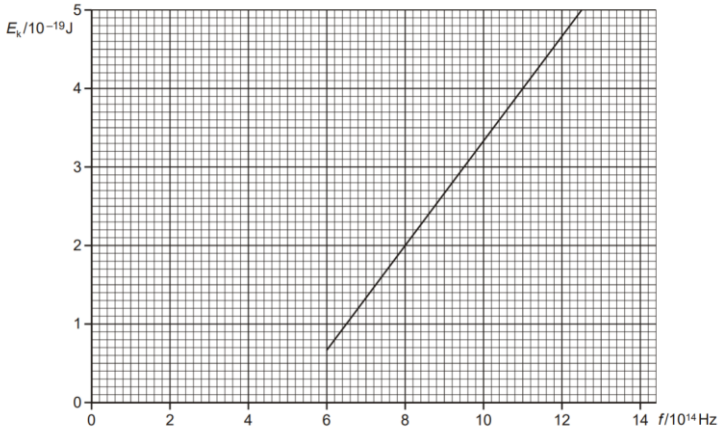
But only 7.0% of incident photons interact with the surface electrons therefore:

$$no.electrons = 0.07 \times 2.05 \times 10^{17} = 1.44 \times 10^{16}\ s^{-1}$$

The Photoelectric Effect

Exam Style Question 2

A negatively charged metal plate is exposed to electromagnetic radiation of frequency f. The figure below shows the variation with f of the maximum kinetic energy E_k of the photoelectrons emitted from the surface of the metal.



(i) Define the threshold frequency of a metal.

(ii) 1) Explain how the graph shows that the threshold frequency of this metal is $5.0 \times 10^{14}\ Hz$.

2) Calculate the work function energy of this metal in joules.

(iii) Electromagnetic radiation falls on the surface of a metal having work function energy greater than your answer in (ii).

1) State and explain the change, if any, to the gradient of the line shown in the figure above.

2) State and explain the change, if any, to the position of the line shown in the figure.

The Photoelectric Effect

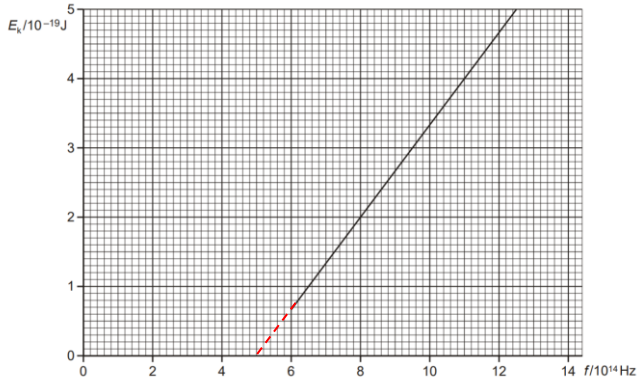
Exam Style Question 2

(i) Define the threshold frequency of a metal.

The minimum frequency needed to free an electron from the surface of a metal.

(ii) 1) Explain how the graph shows that the threshold frequency of this metal is $5.0 \times 10^{14}\ Hz$.

Extend the line until it intersects with the $x - axis$ and you will get $5.0 \times 10^{14}\ Hz$.



2) Calculate the work function energy of this metal in joules.

Use $\phi = hf_0$

$$\phi = (6.63 \times 10^{-34}\ Js)(5.0 \times 10^{14}\ Hz)$$

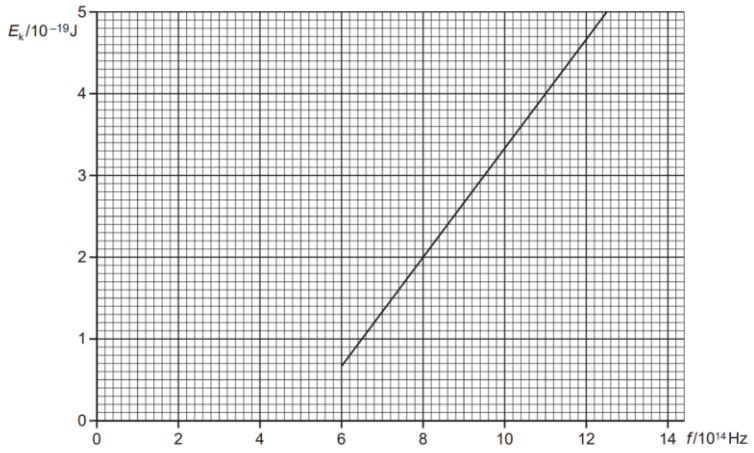
$$\phi = 3.3 \times 10^{-19}\ J$$

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 2

A negatively charged metal plate is exposed to electromagnetic radiation of frequency f. The figure below shows the variation with f of the maximum kinetic energy E_k of the photoelectrons emitted from the surface of the metal.



(i) Define the threshold frequency of a metal.

(ii) 1) Explain how the graph shows that the threshold frequency of this metal is $5.0 \times 10^{14}\ Hz$.

2) Calculate the work function energy of this metal in joules.

(iii) Electromagnetic radiation falls on the surface of a metal having work function energy greater than your answer in (ii).

1) State and explain the change, if any, to the gradient of the line shown in the figure above.

2) State and explain the change, if any, to the position of the line shown in the figure.

The Photoelectric Effect

Exam Style Question 2

(iii) Electromagnetic radiation falls on the surface of a metal having work function energy greater than your answer in (ii).

1) State and explain the change, if any, to the gradient of the line shown in the figure above.

The gradient stays the same. The gradient is equal to h and therefore independent of the metal.

2) State and explain the change, if any, to the position of the line shown in the figure.

The line is shifted to the right because the threshold frequency is greater.

The Photoelectric Effect

Exam Style Question 3

Electromagnetic radiation incident on a metal plate releases energetic electrons from its surface. The metal plate is placed in an evacuated chamber. The energy of each photon is $2.8\ eV$. The metal has a work function energy of $1.1\ eV$.

(i) Explain what is meant by the work function energy of the metal.

(ii) State the speed of the photons.

(iii) For an electron emitted from the surface of the metal, calculate

1) its maximum kinetic energy in joules

2) its maximum speed.

(iv) State the change, if any, to your answer for the maximum speed of an electron emitted from the surface of the metal when the intensity of the incident electromagnetic radiation is doubled.

The Photoelectric Effect

Exam Style Question 3

(i) Explain what is meant by the work function energy of the metal.
Minimum energy needed to free an electron to escape from the metal surface.

(ii) State the speed of the photons.
Speed of light $(3.0 \times 10^8\ m\ s^{-1})$

(iii) For an electron emitted from the surface of the metal, calculate
1) its maximum kinetic energy in joules
Use $hf = \phi + KE_{max}$

$$2.8\ eV = 1.1\ eV + KE_{max}$$
$$KE_{max} = 2.8\ eV - 1.1\ eV = 1.7\ eV$$
$$KE_{max} = 1.7\ eV \times 1.6 \times 10^{-19}\ J$$
$$KE_{max} = 2.72 \times 10^{-19}\ J$$

2) its maximum speed.

$$KE_{max} = 2.72 \times 10^{-19}\ J$$
$$\frac{1}{2}mv^2 = 2.72 \times 10^{-19}\ J$$
$$v = \sqrt{\frac{2.72 \times 10^{-19}\ J}{\frac{1}{2}m}}$$
$$v = \sqrt{\frac{2.72 \times 10^{-19}\ J}{\frac{1}{2}(9.1 \times 10^{-31}\ kg)}}$$
$$v = 7.7 \times 10^5\ m\ s^{-1}$$

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 3

Electromagnetic radiation incident on a metal plate releases energetic electrons from its surface. The metal plate is placed in an evacuated chamber. The energy of each photon is $2.8\ eV$. The metal has a work function energy of $1.1\ eV$.

(i) Explain what is meant by the work function energy of the metal.

(ii) State the speed of the photons.

(iii) For an electron emitted from the surface of the metal, calculate

1) its maximum kinetic energy in joules

2) its maximum speed.

(iv) State the change, if any, to your answer for the maximum speed of an electron emitted from the surface of the metal when the intensity of the incident electromagnetic radiation is doubled.

The Photoelectric Effect

Exam Style Question 3

(iv) State the change, if any, to your answer for the maximum speed of an electron emitted from the surface of the metal when the intensity of the incident electromagnetic radiation is doubled.

No change because the energy of the photon remains the same.

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 4

In an experiment it is observed that when blue light is shone on a clean metal surface electrons are emitted, but with red light there is no electron emission.

(a) State and define the effect observed in this experiment.

(b) Describe Einstein's theory to explain these observations.

(c) The longest wavelength of light incident on the metal surface which causes electrons to be emitted is $480\ nm$.

(i) Show that the work function of the metal is about $4 \times 10^{-19}\ J$.

(ii) Calculate the maximum speed of an emitted electron when a photon of energy $5.2 \times 10^{-19}\ J$ is incident on the metal surface.

The Photoelectric Effect

Exam Style Question 4

(a)State and define the effect observed in this experiment.
Photoelectric effect: is the emission of electrons from a metal surface when photons (or light, UV, EM radiation) are incident on the surface.

(b) Describe Einstein's theory to explain these observations.

1) Individual photons are absorbed by individual electrons in the metal surface and so one to one interaction takes place.
2) Only photon with energy above the work function energy will cause photoelectron emission. Also for a given metal, no photoelectrons are emitted if the radiation has a frequency below a certain value – called the **threshold frequency** $(\boldsymbol{f_0})$.
3) Photon energy is proportional to frequency.
4) Therefore blue photons with higher frequency and shorter wavelength will cause photoemission but red photons will not.
5) If a photon of energy = hf is captured by an electron in the metal, some of its energy is used to overcome the work function (ϕ), and the remainder is used as the electron's kinetic energy. This is expressed as $hf - \phi = KE_{max}$.

(c) The longest wavelength of light incident on the metal surface which causes electrons to be emitted is $480\ nm$.

(i) Show that the work function of the metal is about $4 \times 10^{-19}\ J$.

Use $\phi = \frac{hc}{\lambda}$

$$\phi = \frac{(6.63 \times 10^{-34}\ Js)(3.0 \times 10^{8}\ m\ s^{-1})}{(480 \times 10^{-9}\ m)}$$

$$\phi = 4.1(4) \times 10^{-19}\ J$$

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 4

In an experiment it is observed that when blue light is shone on a clean metal surface electrons are emitted, but with red light there is no electron emission.

(a) State and define the effect observed in this experiment.

(b) Describe Einstein's theory to explain these observations.

(c) The longest wavelength of light incident on the metal surface which causes electrons to be emitted is $480\ nm$.

(i) Show that the work function of the metal is about $4 \times 10^{-19}\ J$.

(ii) Calculate the maximum speed of an emitted electron when a photon of energy $5.2 \times 10^{-19}\ J$ is incident on the metal surface.

The Photoelectric Effect

Exam Style Question 4

(ii) Calculate the maximum speed of an emitted electron when a photon of energy $5.2 \times 10^{-19}\ J$ is incident on the metal surface.

Use $E = \phi + KE_{max}$

$$KE_{max} = E - \phi$$

$$KE_{max} = (5.2 \times 10^{-19}\ J) - (4.14 \times 10^{-19}\ J)$$

$$KE_{max} = 1.1 \times 10^{-19}\ J$$

$$\frac{1}{2}mv^2 = 1.1 \times 10^{-19}\ J$$

$$v = \sqrt{\frac{1 \times 10^{-19}\ J}{\left(\frac{1}{2}\right)(9.1 \times 10^{-31}\ kg)}}$$

$$v = 4.9 \times 10^{5}\ m\ s^{-1}$$

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 5

A photoelectric cell is an electronic device that can detect photons.

(a) Fig. 4.1 shows a cross-section through a simple photocell.

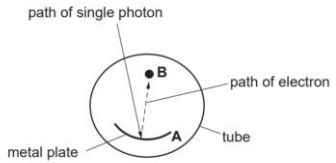


Fig. 4.1

A metal plate A is coated with potassium in an evacuated transparent tube. A photon entering the tube is absorbed by the plate, causing one electron to be released from the surface towards the collector rod B.

(i) State the name of this process.

(ii) Potassium has a work function of $3.5 \times 10^{-19}\ J$.

1) Define the term work function.

2) Calculate the threshold frequency of potassium.

(iii) The photon incident on plate A has a wavelength of $4.2 \times 10^{-7}\ m$. Show that its energy is about $5 \times 10^{-19}\ J$.

(iv) Calculate the maximum kinetic energy of the electron emitted from the potassium surface of plate A.

(b) An electron is released with zero speed from plate A. It is accelerated from plate A through a potential difference of $12\ V$ to the metal rod B in Fig. 4.1.

(i) 1) State the increase in kinetic energy of the electron in electronvolts (eV).

2) Show that this increase is about $2 \times 10^{-18}\ J$.

(ii) Calculate the speed of the electron as it hits rod B.

(c) The photocell is connected to a $12\ V\ d.c.$ supply through a very sensitive ammeter. Light of wavelength $4.2 \times 10^{-7}\ m$ shines on plate A. The plate absorbs $1.2 \times 10^{-6}\ J$ of light energy every second. One per cent of the absorbed photons cause electrons to be emitted from the plate. Estimate the current in the circuit.

The Photoelectric Effect

Exam Style Question 5

(a) (i) State the name of this process.

Photoelectric effect.

(a) (ii) Potassium has a work function of $3.5 \times 10^{-19}\ J$.

1)Define the term work function.

The minimum energy required to release an electron from the surface of the metal.

2) Calculate the threshold frequency of potassium.

$$\phi = hf_0$$
$$3.5 \times 10^{-19}\ J = (6.6 \times 10^{-34}\ J\ s) f_0$$
$$f_0 = \frac{3.5 \times 10^{-19}\ J}{6.6 \times 10^{-34}\ J\ s} = 5.3 \times 10^{14}\ Hz$$

(a) (iii) The photon incident on plate A has a wavelength of $4.2 \times 10^{-7}\ m$. Show that its energy is about $5 \times 10^{-19}\ J$.

Use $E = \frac{hc}{\lambda}$

$$E = \frac{(6.6 \times 10^{-34}\ Js)(3.0 \times 10^{8}\ m\ s^{-1})}{(4.2 \times 10^{-7}\ m)}$$
$$E = 4.7 \times 10^{-19}\ J$$

(a) (iv) Calculate the maximum kinetic energy of the electron emitted from the potassium surface of plate A.

Use $\frac{hc}{\lambda} = \phi + KE_{max}$

$$4.7 \times 10^{-19}\ J = 3.5 \times 10^{-19}\ J + KE_{max}$$
$$KE_{max} = (4.7 \times 10^{-19}\ J) - (3.5 \times 10^{-19}\ J)$$
$$KE_{max} = 1.2 \times 10^{-19}\ J$$

tutorpacks.co.uk

The Photoelectric Effect

Exam Style Question 5

A photoelectric cell is an electronic device that can detect photons.

(a) Fig. 4.1 shows a cross-section through a simple photocell.

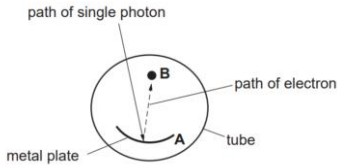


Fig. 4.1

A metal plate A is coated with potassium in an evacuated transparent tube. A photon entering the tube is absorbed by the plate, causing one electron to be released from the surface towards the collector rod B.

(i) State the name of this process.

(ii) Potassium has a work function of $3.5 \times 10^{-19}\ J$.

1) Define the term work function.

2) Calculate the threshold frequency of potassium.

(iii) The photon incident on plate A has a wavelength of $4.2 \times 10^{-7}\ m$. Show that its energy is about $5 \times 10^{-19}\ J$.

(iv) Calculate the maximum kinetic energy of the electron emitted from the potassium surface of plate A.

(b) An electron is released with zero speed from plate A. It is accelerated from plate A through a potential difference of $12\ V$ to the metal rod B in Fig. 4.1.

(i) 1) State the increase in kinetic energy of the electron in electronvolts (eV).

2) Show that this increase is about $2 \times 10^{-18}\ J$.

(ii) Calculate the speed of the electron as it hits rod B.

(c) The photocell is connected to a $12\ V\ d.c.$ supply through a very sensitive ammeter. Light of wavelength $4.2 \times 10^{-7}\ m$ shines on plate A. The plate absorbs $1.2 \times 10^{-6}\ J$ of light energy every second. One per cent of the absorbed photons cause electrons to be emitted from the plate. Estimate the current in the circuit.

The Photoelectric Effect

Exam Style Question 5

(b) An electron is released with zero speed from plate A. It is accelerated from plate A through a potential difference of $12\ V$ to the metal rod B in Fig. 4.1.

(i) 1) State the increase in kinetic energy of the electron in electronvolts (eV).

$$12\ eV$$

2) Show that this increase is about $2 \times 10^{-18}\ J$.

$$E = eV = 12\ eV \times 1.6 \times 10^{-19}\ J = 1.92 \times 10^{-18}\ J$$

(ii) Calculate the speed of the electron as it hits rod B.

$$\frac{1}{2}mv^2 = 2.0 \times 10^{-18}\ J$$

$$v = \sqrt{\frac{1.92 \times 10^{-18}\ J}{\left(\frac{1}{2}\right)(9.1 \times 10^{-31}\ kg)}}$$

$$v = 2.1 \times 10^{6}\ m\ s^{-1}$$

(c) One per cent of the absorbed photons cause electrons to be emitted from the plate. Estimate the current in the circuit.

$$electrons\ emitted\ per\ second = \frac{1.2 \times 10^{-6}\ J \times 1\%}{4.7 \times 10^{-19}\ J} = 2.55 \times 10^{10}$$

Now use $I = Ne$

$$I = (2.55 \times 10^{10})(1.6 \times 10^{-19}\ C)$$

$$I = 3.8 \times 10^{-9}\ A$$

tutorpacks.co.uk

Please see ‘3.1.1 The Photoelectric Effect notes’ pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.

tutorpacks.co.uk