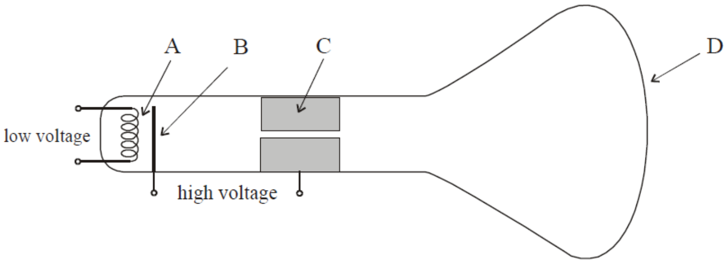
13. The Electron

Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier

Contents

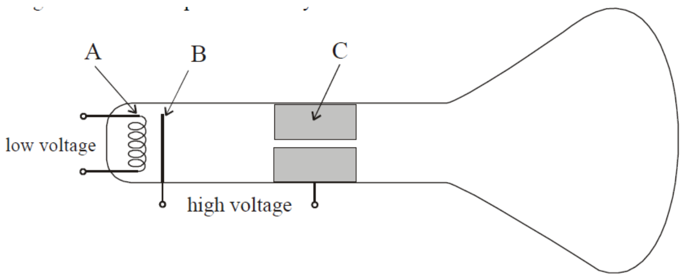
Cathode ray tube

2002 Question 6 [Ordinary Level]



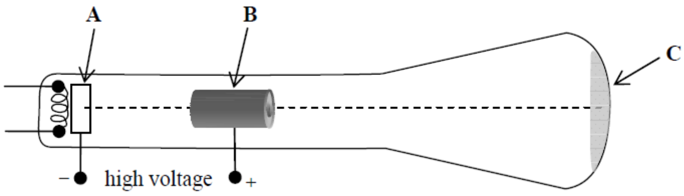
(i) What is thermionic emission?
(ii) The diagram shows a simple cathode ray tube.
(iii)Name the parts labelled A, B, C and D in the diagram.
(iv)Give the function of any two of these parts.
(v) How can the beam of electrons be deflected?
(vi)Give a use of a cathode ray tube.
(vii) In an X-ray tube, electrons are also produced by thermionic emission.
(viii) Draw a sketch of an X-ray tube.
(ix)Why is a lead-shield normally put around an X-ray tube?

2005 Question 10 [Ordinary Level]



(i) The electron is one of the three main subatomic particles.
Give two properties of the electron.
(ii) Name another subatomic particle.
(iii)The diagram shows a simple cathode ray tube.
Name the parts labelled A, B and C.
(iv)Electrons are emitted from A, accelerated across the tube and strike the screen.
Explain how the electrons are emitted from A.
(v) What causes the electrons to be accelerated across the tube?
(vi)What happens when the electrons hit the screen?
(vii) How can a beam of electrons be deflected?
(viii) Give one use of a cathode ray tube.

2009 Question 12 (d) [Ordinary Level]

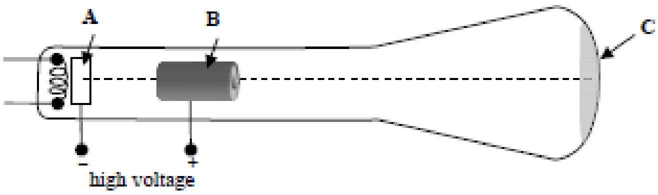


(i) The diagram shows a simple cathode ray tube.
Thermionic emission occurs at plate A.
(ii) What is thermionic emission?
(iii)What are cathode rays?
(iv)Why is there a high voltage between A and B?
(v) What happens to the cathode rays when they hit the screen C?
(vi)Give a use for a cathode ray tube.

2012 Question 10 [Ordinary Level]

A cathode ray tube and an X-ray tube are practical applications of thermionic emission.
In these tubes thermionic emission releases electrons, which are then accelerated into a beam.
An electron is a subatomic particle.

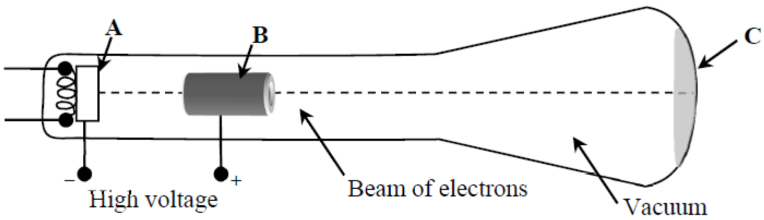
(i) Name another subatomic particle and give two of its properties.
(ii) The diagram shows a simple cathode ray tube.
Name the parts labelled **A**, **B**, **C**.



(iii) Give the function of any two of these labelled parts.
(iv) How can the beam of electrons be deflected?
(v) What happens at **C** when the electrons hit it?
(vi) Why is a vacuum needed in a cathode ray tube?
(vii) In an X-ray tube, a beam of electrons is used to produce X-rays.
Draw a sketch of an X-ray tube.
(viii) Give one safety precaution taken by a radiographer when using an X-ray machine.

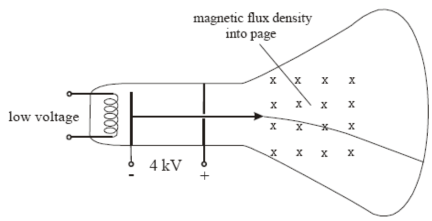
2016 Question 10 [Ordinary Level]

X-ray tubes and cathode ray tubes are practical applications of thermionic emission.
Thermionic emission causes the emission of electrons, which are sub-atomic particles.
The diagram shows a simple cathode ray tube, which produces a beam of electrons by thermionic emission.



(i) State two properties of the electron. Name another sub-atomic particle.
(ii) Name the parts labelled A, B, and C in the diagram.
(iii) State the function of any two of these parts.
(iv) How could the beam of electrons be deflected?
(v) Why is it important to have a vacuum inside a cathode ray tube?
(vi) State one use of a cathode ray tube.
(vii) Electrons are produced by thermionic emission in an X-ray tube also.
Draw a sketch of an X-ray tube.
(viii) Why are lead aprons often worn when using an X-ray tube?

2003 Question 9 [Higher Level]



(i) List two properties of the electron.
(ii) Name the Irishman who gave the electron its name in the nineteenth century.
(iii) Give an expression for the force acting on a charge q moving at a velocity v at right angles to a magnetic field of flux density B.
(iv) An electron is emitted from the cathode and accelerated through a potential difference of 4kV in a cathode ray tube (CRT) as shown in the diagram.
How much energy does the electron gain?
(v) What is the speed of the electron at the anode? (Assume that the speed of the electron leaving the cathode is negligible.)
(vi) After leaving the anode, the electron travels at a constant speed and enters a magnetic field at right angles, where it is deflected. The flux density of the magnetic field is 5×10^{-2} T.
Calculate the force acting on the electron.
(vii) Calculate the radius of the circular path followed by the electron, in the magnetic field.
(viii) What happens to the energy of the electron when it hits the screen of the CRT?
mass of electron = 9.1×10^{-31} kg; charge on electron = 1.6×10^{-19} C

The photoelectric effect / the photocell

2011 Question 11 [Ordinary Level]

Read this passage and answer the questions below.
Einstein explained the photoelectric effect by using Planck's quantum theory (*E*=*hf*).
The German physicist Heinrich Hertz in 1887 was the first to discover that when light shines on certain metals, they emit electrons.

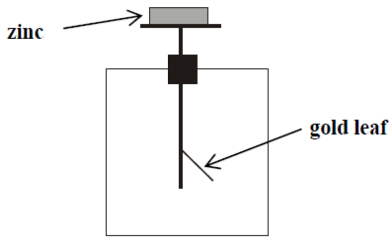
Metals have the property that some of their electrons are only loosely bound within atoms, which is why they are such good conductors of electricity. When light strikes a metallic surface it transfers its energy to the metal, in the same way as when light shines on your skin, causing you to feel warmer. This transfer of energy from the light can agitate electrons in the metal, and some of the loosely bound electrons can be knocked off the surface of the metal.

But the strange features of the photoelectric effect become apparent when one studies the more detailed properties of the released electrons. As the intensity of the light – its brightness – is increased the number of released electrons will also increase, but their speed stays the same. On the other hand, the speed of the released electrons will increase if the frequency of the light shining on the metal is increased.
(Adapted from '*Elegant Universe'* by Brian Greene, Vintage 2000)

a) Who discovered the photoelectric effect?
b) Who explained the photoelectric effect?
c) What happens when light shines on certain metals?
d) Why is a metal a good conductor of electricity?
e) Why does your skin feel warm when light shines on it?
f) In the photoelectric effect, what happens when the intensity of the light is increased?
g) How can the speed of electrons emitted in the photoelectric effect be controlled?
h) Give one application of the photoelectric effect.

2006 Question 12 (c) [Ordinary Level]

(i) In an experiment to demonstrate the photoelectric effect, a piece of zinc is placed on a gold leaf electroscope, as shown. The zinc is given a negative charge causing the gold leaf to deflect.
Explain why the gold leaf deflects when the zinc is given a negative charge.
(ii) Ultraviolet radiation is then shone on the charged zinc and the gold leaf falls.
Explain why.
(iii) What is observed when the experiment is repeated using infrared radiation?
(iv) Give one application of the photoelectric effect.



2005 Question 12 (d) [Higher Level]

(i) One hundred years ago, Albert Einstein explained the photoelectric effect.
What is the photoelectric effect?
(ii) Write down an expression for Einstein's photoelectric law.
(iii) Summarise Einstein's explanation of the photoelectric effect.
(iv) Give one application of the photoelectric effect.

2004 Question 9 [Higher Level]

(i) Distinguish between photoelectric emission and thermionic emission.

(ii) A freshly cleaned piece of zinc metal is placed on the cap of a negatively charged gold leaf electroscope and illuminated with ultraviolet radiation.
Explain why the leaves of the electroscope collapse.

(iii) Explain why the leaves do not collapse when the zinc is covered by a piece of ordinary glass.

(iv) Explain why the leaves do not collapse when the zinc is illuminated with green light.

(v) Explain why the leaves do not collapse when the electroscope is charged positively.

(vi) The zinc metal is illuminated with ultraviolet light of wavelength 240 nm. The work function of zinc is 4.3 eV.
Calculate the threshold frequency of zinc.

(vii) Calculate the maximum kinetic energy of an emitted electron.

Planck's constant = 6.6×10^{-34} J s; speed of light = 3.0×10^{8} m s^{-1}; 1 eV = 1.6×10^{-19} J

2004 Question 12 (d) [Higher Level]

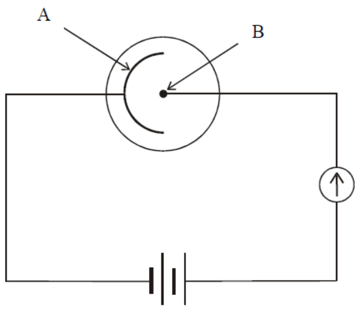
A typical solar panel consists of a sandwich made of a p-n junction surrounded by a pair of conductors. When light falls on the solar panel, the photoelectric effect occurs and a current flows.

(i) What is a p-n junction?

(ii) In 1921, Albert Einstein was awarded the Nobel Prize in Physics for his explanation of the photoelectric effect.
Outline his explanation.

(iii) The work function of iron is 4.7 eV.
Calculate the maximum kinetic energy of an emitted electron when ultraviolet radiation of wavelength 200 nm is incident on iron.

2003 Question 12 (d) [Ordinary Level]



(i) What is a photon?

(ii) The diagram shows a photocell connected in series with a sensitive galvanometer and a battery. Name the parts labelled A and B.

(iii) What happens at A when light falls on it?

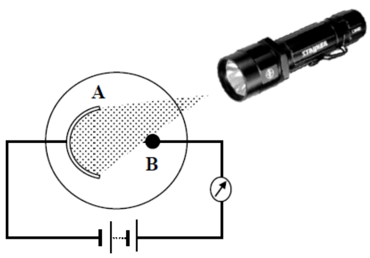
(iv) What happens in the circuit when the light falling on A gets brighter?

(v) Give an application of a photocell.

2008 Question 12 (c) [Ordinary Level]

(i) What is the photoelectric effect?

(ii) A photocell is connected to a sensitive galvanometer as shown in the diagram.



(iii) When light from the torch falls on the photocell, a current is detected by the galvanometer.

(iv) Name the parts of the photocell labelled A and B.

(v) How can you vary the brightness of the light falling on the photocell?

(vi) How does the brightness of the light effect the current?

(vii) Give a use for a photocell.

2012 Question 12 (d) [Higher Level]

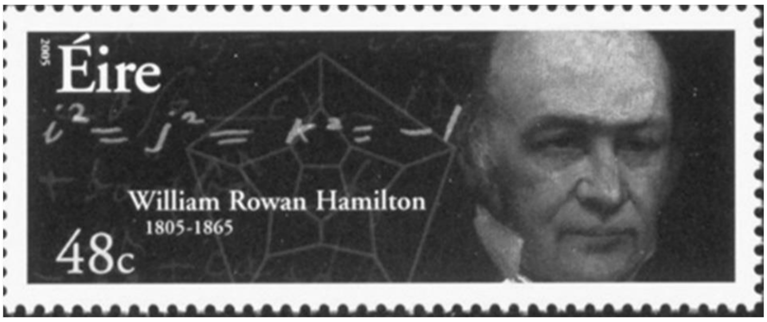
(i) Draw a diagram to show the structure of a photocell.

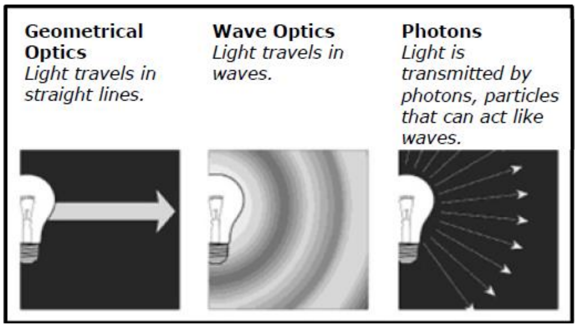
(ii) Describe an experiment to demonstrate how the current through a photocell can be increased.

(iii) Give an application of the photoelectric effect.

The dual nature of light

2016 Question 11 [Higher Level]
Read the following passage and answer the accompanying questions.





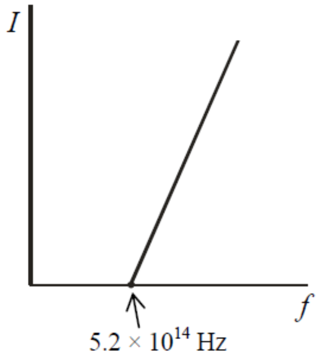
The story of theories of light nicely demonstrates the ways in which theories are used as science evolves. Some ideas are discarded while others are retained as approximations that are appropriate in certain circumstances.
Geometrical optics hit its heyday in the nineteenth century when the Irish mathematician William Rowan Hamilton made a mathematical prediction about conical refraction that was later verified by his friend and colleague Humphrey Lloyd.
Geometrical optics, though clearly an approximation, is nonetheless a good description for a wave with wavelengths small enough for interference effects to be irrelevant. Ray diagrams can be used to explain refraction and reflection as well as in the fields of photography, medicine and astronomy.
Isaac Newton had developed a 'corpuscular' theory that was inconsistent with the wave theory of light developed by his rival Robert Hooke and by Christian Huygens. Thomas Young measured light interference, providing a clear verification that light had the properties of a wave.
However, later developments in quantum theory demonstrated that Newton was also correct in some sense. Quantum mechanics now tells us that light is indeed composed of individual particles called photons that are responsible for communicating the electromagnetic force. Quantum mechanics gives us our most fundamental description of what light is and how it interacts with matter.

(Adapted from *Knocking on Heaven's Door: How Physics and Scientific Thinking Illuminate the Universe and the Modern World*, Lisa Randall, Random House, 2011)

(i) State the laws of refraction.
(ii) Draw a ray diagram to show the formation of a virtual image in a magnifying glass.
(iii) Explain what is meant by the term wavelength.
(iv) As part of his investigations into light, Newton dispersed light with a prism.
List the colours observed by Newton, in order, starting with the colour that was refracted the least.
(v) In Young's experiment to demonstrate the wave nature of light he needed two coherent sources of light.
How might he have produced these sources?
(vi) Calculate the energy of a photon of green light, which has a wavelength of 510 nm.
(vii) Quantum mechanics is used to explain how electrons in atoms produce line emission spectra.
Describe how these spectra are produced.
(viii) State two differences between photons and electrons.

2017 Question 9 {middle 2 parts} [Higher Level]
(iii) One of his students, Niels Bohr, further developed Rutherford's model of the atom.
The Bohr model helps us identify different elements using emission line spectra.
Explain, using the Bohr model, how line spectra are formed.
(iv) Draw a labelled diagram of a spectrometer and describe how a spectrometer and diffraction grating can be used to observe (*i*) a line spectrum and (*ii*) a continuous spectrum.

2009 Question 8 [Higher Level]



(i) An investigation was carried out to establish the relationship between the current flowing in a photocell and the frequency of the light incident on it. The graph illustrates the relationship.
Draw a labelled diagram of the structure of a photocell.

(ii) Using the graph, calculate the work function of the metal.

(iii) What is the maximum speed of an emitted electron when light of wavelength 550 nm is incident on the photocell?

(iv) Explain why a current does not flow in the photocell when the frequency of the light is less than 5.2×10^{14} Hz.

(v) The relationship between the current flowing in a photocell and the intensity of the light incident on the photocell was then investigated. Readings were taken and a graph was drawn to show the relationship.

(vi) Draw a sketch of the graph obtained.

(vii) How was the intensity of the light varied?

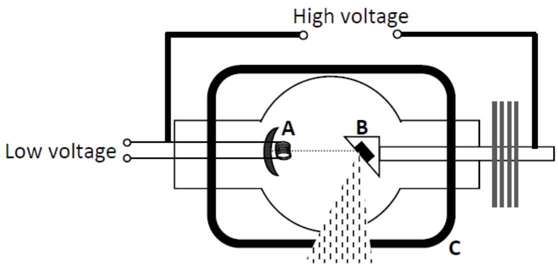
(viii) What conclusion about the nature of light can be drawn from these investigations?

(Planck constant = 6.6×10^{-34} J s; speed of light = 3.0×10^{8} m s^{-1};
charge on electron = 1.6×10^{-19} C; mass of electron = 9.1×10^{-31} kg)

X-Rays

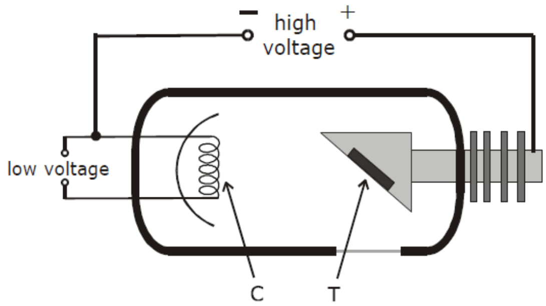
2018 Question 10 [Ordinary Level]

X-rays are produced when a beam of high speed electrons collides with a target in a tube like the one shown.



(i) What are X-rays? State two properties of X-rays.
(ii) What process occurs at part A?
(iii) Name a substance used in part B.
(iv) State the function of part C.
(v) State one use of X-rays.
(vi) Why is a vacuum needed inside an X-ray tube?
(vii) Name another device that uses a beam of high speed electrons.
(viii) State one use for the device you have named in part (vii).
(ix) State one difference between X-rays and gamma-rays.

2004 Question 12 (d) [Ordinary Level]

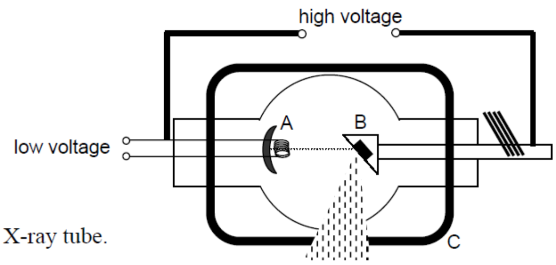


(i) The diagram shows an X-ray tube. What are X-rays?
(ii) How are electrons emitted from the cathode C?
(iii) What is the function of the high voltage across the X-ray tube?
(iv) Name a suitable material for the target T in the X-ray tube.
(v) Give one use of X-rays.

2007 Question 10 [Ordinary Level]

X-rays were discovered by Wilhelm Röntgen in 1895.

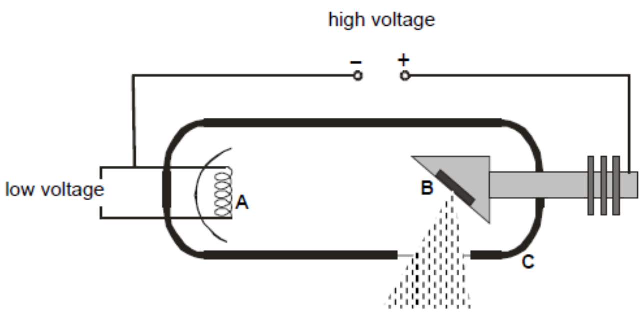
(i) What are X-rays?
(ii) Give one use for X-rays.
(iii) The diagram shows a simple X-ray tube. Name the parts labelled A, B and C.
(iv) Electrons are emitted from A, accelerated across the tube and strike B. Explain how the electrons are emitted from A.
(v) What is the purpose of the high voltage supply?
(vi) What happens when the electrons hit part B?
(vii) Name a suitable material to use for part B.
(viii) Give one safety precaution when using X-rays.



X-ray tube.

2010 Question 10 [Ordinary Level]

X-rays are produced when high speed electrons collide with a target in an X-ray tube as shown in the diagram.



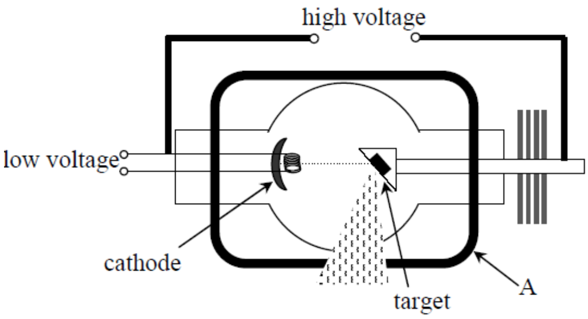
(i) What process occurs at the filament A?
(ii) Name a substance commonly used as the target B
(iii) Give three properties of X-rays
(iv) Give two uses of X-rays
(v) State the function of the part marked C
(vi) The photoelectric effect can be regarded as the inverse of X-ray production.
(vii) Describe an experiment to demonstrate the photoelectric effect
(viii) Give two applications of the photoelectric effect

2013 Question 10 [Ordinary Level]

(i) X-rays are used to diagnose and treat medical conditions.
The image shows an X-ray photograph.
What are X-rays?
(ii) State a property of X-rays that makes them suitable for medical use.
(iii) Give a use, other than medical, for X-rays.
(iv) In an X-ray tube a beam of electrons is used to produce X-rays.
Draw a labelled diagram showing the main parts of an X-ray tube.
(v) How are electrons produced in an X-ray tube?
(vi) What is the purpose of the high voltage in an X-ray tube?
(vii) What happens when the electrons hit the target in an X-ray tube?
(viii) Name a suitable material for use as the target.
(ix) Give one safety precaution required when using X-rays.

2015 Question 10 [Ordinary Level]

X-rays are produced when a beam of high speed electrons collides with a target in an X-ray tube, as shown below.



(i) What are X-rays?
(ii) State two properties of X-rays.
(iii) What process occurs at the cathode?
(iv) Name a substance commonly used as the target.
(v) State the function of the part marked A.
(vi) State one use of X-rays.
(vii) A cathode ray tube, like the one used in the cathode ray oscilloscope, also uses a beam of high speed electrons.
Draw a sketch of a cathode ray tube suitable for use in an oscilloscope.
(viii) Why is a vacuum needed in both the X-ray tube and the cathode ray tube?
(ix) State one use of a cathode ray oscilloscope.

2010 Question 9 [Higher Level]

(i) What is thermionic emission?
(ii) X-rays are produced when high-energy electrons collide with a target.
Draw a labelled diagram of an X-ray tube.
(iii) What are X-rays?
(iv) How do they differ from light rays?
(v) Give two uses of X-rays.
(vi) When electrons hit the target in an X-ray tube, only a small percentage of their energy is converted into X-rays. What happens to the rest of their energy.
(vii) How does this influence the type of target used?
(viii) A potential difference (voltage) of 40 kV is applied across an X-ray tube.
Calculate the maximum energy of an electron as it hits the target.
(ix) Calculate the frequency of the most energetic X-ray produced.

2006 Question 12 (d) [Higher Level]
The first Nobel Prize in Physics was awarded in 1901 for the discovery of X-rays.
(i) What are X-rays?
(ii) Who discovered them?
(iii) In an X-ray tube electrons are emitted from a metal cathode and accelerated across the tube to hit a metal anode.
How are the electrons emitted from the cathode?
(iv) How are the electrons accelerated?
(v) Calculate the kinetic energy gained by an electron when it is accelerated through a potential difference of 50 kV in an X-ray tube.
(vi) Calculate the minimum wavelength of an X-ray emitted from the anode.

Planck constant = 6.6×10^{-34} J s; speed of light = 3.0×10^{8} m s^{-1}; charge on electron = 1.6×10^{-19} C

2002 Question 9 [Higher Level]
(i) Explain with the aid of a labelled diagram how X-rays are produced.
(ii) Justify the statement “X-ray production may be considered as the inverse of the photoelectric effect.”
(iii) Describe an experiment to demonstrate the photoelectric effect.
(iv) Outline Einstein’s explanation of the photoelectric effect.
(v) Give two applications of a photocell.

2015 Question 7 [Higher Level]
X-rays have two important uses in medicine: imaging and radiation therapy.

(i) Describe, with the aid of a labelled diagram of an X-ray tube, how X-rays are produced.

A potential difference of 50 kV is applied across an X-ray tube.
(ii) Calculate the maximum velocity of an electron in the tube.
(iii) Calculate the minimum wavelength of the X-rays produced by the tube.

The large atoms found in bones (e.g. calcium and phosphorus) absorb X-ray photons.
The small atoms found in soft tissue (e.g. carbon and hydrogen) do not absorb X-ray photons. This is why bones cast shadows on an X-ray film.
The X-ray photons absorbed by large atoms can cause the photoelectric effect to occur.

(iv) What is the photoelectric effect?
(v) Describe a laboratory experiment to demonstrate the photoelectric effect.

(vi) Albert Einstein received a Nobel Prize in 1921 for his explanation of the photoelectric effect.
Outline Einstein’s explanation of the photoelectric effect.

2017 Question 10 [Higher Level]

(i) What are X-rays?

Electrons are produced and used in an X-ray tube.

(ii) How are the electrons produced?

(iii) Where in the tube does this take place?

A certain X-ray tube is designed to emit X-rays with wavelengths as small as 0.02 nm.

(iv) Calculate the energy of an X-ray photon of wavelength 0.02 nm

(v) Calculate the maximum velocity of an electron in the tube

(vi) Calculate the voltage applied to the electrons.

Electrons are also produced and used in a photocell.

(vii) Draw a labelled diagram of a photocell.

(viii) Describe how a photocell conducts current.

(ix) A current of 2 μA is flowing in a photocell.
How many electrons are generated in the photocell during each minute?

2018 Question 12 (d)

(i) **What is a p-n junction?**
It is where a p–type semiconductor and an n-type semiconductor meet

(ii) **Outline his explanation.**

- Light energy coming travels in packets called ‘photons’.
- If the photons contain enough energy they can get absorbed by an electron on the surface of the metal.
- Each photon gives all its energy to one electron
- A certain amount of this energy (known as *the work function*) goes to *liberating* (releasing) the electron. The remainder appears as kinetic energy of the liberated electron.
- The equation relating these variables is: $hf = \phi + \frac{1}{2}mv^2$

(iii)The work function of iron is 4.7 eV.
Calculate the maximum kinetic energy of an emitted electron when ultraviolet radiation of wavelength 200 nm is incident on iron.

$c = f\lambda$

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{200 \times 10^{-9}}$$

$f = 1.5\times10^{15}$ Hz

$hf = \phi + \frac{1}{2}mv^2$

$\frac{1}{2}mv^2 = hf - \phi$ $\qquad$ $\frac{1}{2}mv^2 = (6.67\times10^{-34})(1.5\times10^{15}) - (4.7)(1.6\times10^{-19})$

$\frac{1}{2}mv^2 = 2.4\times10^{-19}$ J

2017 Question 10

(i) What are X-rays?
photons / electromagnetic radiation with high energy / short wavelength / high frequency

(ii) How are the electrons produced?
thermionic emission

(iii) Where in the tube does this take place?
cathode/filament

(iv) Calculate the energy of an X-ray photon of wavelength 0.02 nm

$E = hf$ $\quad c = f\lambda$ $\quad E = h\frac{c}{\lambda}$ $\quad E = [6.6 \times 10^{-34}][\frac{3.0 \times 10^{8}}{0.02 \times 10^{-9}}]$

$E = 9.9 \times 10^{-15}$ J

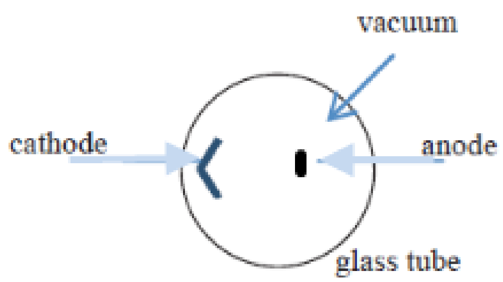
(v) Calculate the maximum velocity of an electron in the tube
$E = ½mv^2$
$9.9 \times 10^{-15} = ½ (9.1 \times 10^{-31})(v)^2$

$v = 1.48 \times 10^{8}$ m s^{-1}

(vi) Calculate the voltage applied to the electrons.

$W = VQ$ $\quad V = \frac{W}{q}$ $\quad V = \frac{9.9 \times 10^{-15}}{1.6 \times 10^{-19}}$ $\quad V = 62000$V

(vii) Draw a labelled diagram of a photocell.
Anode
Semi-cylindrical cathode
Case and vacuum



(viii) Describe how a photocell conducts current.
Light (of suitable frequency) falls on cathode.
Electrons are emitted

(ix) How many electrons are generated in the photocell during each minute?

$Q = It$ $\quad = (2 \times 10^{-6})(60)$ $\quad = 1.2 \times 10^{-4}$ coulombs

1 electron = 1.6×10^{-19} coulombs

Number of electrons = $\frac{total\ charge}{charge\ of\ 1\ electron} = \frac{1.2 \times 10^{-4}}{1.6 \times 10^{-19}} = 7.5 \times 10^{14}$ electrons

2017 Question 9 {middle 2 parts}

(iii)**Explain, using the Bohr model, how line spectra are formed.**

Energy supplied in the form of heat or light.

Electrons move to a higher/excited energy level

Electrons fall down via specific levels emitting light of specific frequencies/wavelengths.

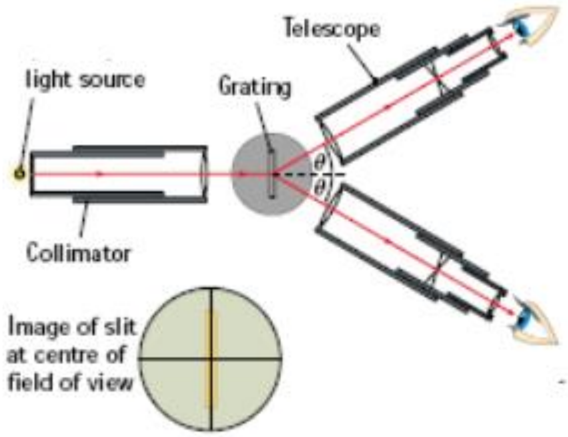
(iv)**Draw a labelled diagram of a spectrometer and describe how a spectrometer and diffraction grating can be used to observe (*i*) a line spectrum and (*ii*) a continuous spectrum.**

collimator (labelled)

table

telescope (labelled)

correct arrangement

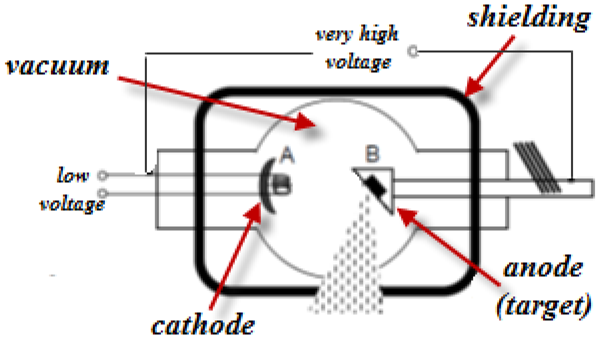


Line spectrum: light source is a vapour lamp

Continuous spectrum: light source is a filament bulb / white light

2015 Question 7

(i) **Describe, with the aid of a labelled diagram of an X-ray tube, how X-rays are produced.**



1. The low voltage supplies power to a filament which in turn heats the cathode at A.
2. Electrons are emitted from the hot cathode due to thermionic emission.
3. They get accelerated across the vacuum due to the very high voltage and smash into the high-density anode (usually tungsten) at B.
4. Most of the kinetic energy gets converted to heat, which must be removed with a coolant.
5. Some inner electrons in the tungsten get bumped up to a high orbital, then quickly fall back down to a lower lever, emitting X-rays in the process.
6. These X-rays are emitted in all directions.
7. Most of these get absorbed by the lead shielding, but some exit through a narrow window, where they are then used for the required purpose.

(ii) **A potential difference of 50 kV is applied across an X-ray tube.**
Calculate the maximum velocity of an electron in the tube.
Charge on electron = 1.6×10^{-19} C; mass of an electron = 9.1×10^{-31} Kg

Kinetic energy at the end = Potential energy at the beginning
$\frac{1}{2} mv_{el}^2$ = QV

$$v^2 = \frac{2QV}{m}$$

$$v^2 = \frac{(1.6 \times 10^{-19})(50000)}{9.1 \times 10^{-31}}$$

$$v^2 = 1.69 \times 10^{16}$$

$v = 1.3 \times 10^8$ m s^{-1}

(iii)**Calculate the minimum wavelength of the X-rays produced by the tube.**
In this case we assume that the potential energy at the beginning gets converted into X-rays which are electromagnetic radiation.
The energy associated with electromagnetic radiation is given by the equation E = hf
Electromagnetic energy at the end = Potential energy at the beginning
hf = QV

Now we don't know the frequency, but we do know the relationship between frequency and wavelength: c = fλ

$$f = \frac{c}{\lambda}$$

So we have $h\frac{c}{\lambda} = QV$ $\lambda = \frac{ch}{QV}$

c = speed of light h = Planck's constant Q = charge on an electron V = potential difference

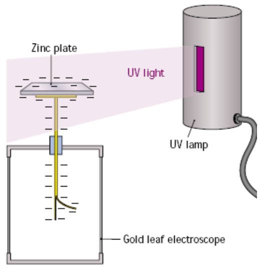
$$\lambda = \frac{(3.0 \times 10^8)(6.6 \times 10^{-34})}{(1.6 \times 10^{-19})(50000)}$$

$\lambda = 2.5 \times 10^{-11}$ m

(iv) **What is the photoelectric effect?**

The photoelectric effect is the emission of electrons from a metal due to electromagnetic radiation of a suitable frequency falling upon it.

(v) **Describe a laboratory experiment to demonstrate the photoelectric effect.**



Apparatus: Gold leaf electroscope with zinc plate on top.

Procedure:

Charge the electroscope negatively.

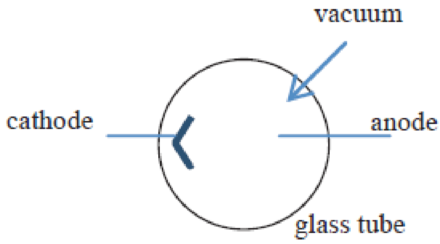
Shine ultraviolet light on the zinc plate.

Result: The leaves fall together

(vi) **Outline Einstein's explanation of the photoelectric effect.**

- The energy coming from the UV lamp travels in packets called 'photons'.
- If the photons contain enough energy they can get absorbed by an electron on the surface of the zinc metal.
- Each photon gives all its energy to one electron
- A certain amount of this energy (known as *the work function*) goes to *liberating* (releasing) the electron. The remainder appears as kinetic energy of the liberated electron.

2012 Question 12 (d)

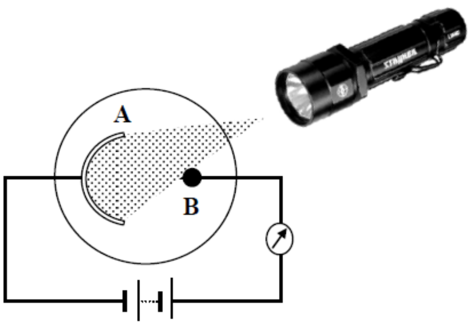


(i) **Draw a diagram to show the structure of a photocell.**

See diagram

(ii) **Describe an experiment to demonstrate how the current through a photocell can be increased.**

1. Set us as shown in diagram.
2. Bring the light source closer to the photocell.
3. A greater deflection in the galvanometer (or ammeter) indicates that the current in the circuit has increased.



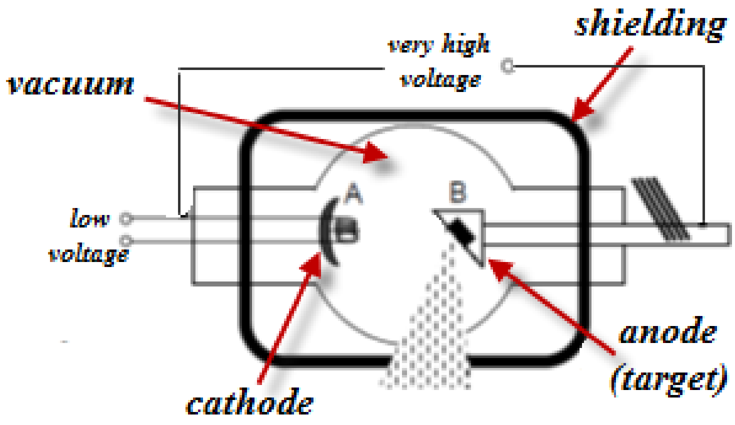
(iii) **Give an application of the photoelectric effect.**

Controlling the flame in central heating boilers / automatic doors / fire alarms / photocells / photocopiers / light meters, etc.

2010 Question 9

(i) **What is thermionic emission?**
It is the emission of electrons from the surface of a hot metal due to electromagnetic radiation of a suitable frequency falling upon it.

(ii) **Draw a labelled diagram of an X-ray tube.**



(iii) **What are X-rays?**
X-rays are electromagnetic radiation of high frequency / short wavelength

(iv) **How do they differ from light rays?**
X-rays have a higher frequency / penetrate matter / cause ionization.

(v) **Give two uses of X-rays.**
(Medical) analysis of bone structure/ luggage scanners (at airports) / any ***specific*** medical, industrial or security use, etc.

(vi) **When electrons hit the target in an X-ray tube, only a small percentage of their energy is converted into X-rays. What happens to the rest of their energy.**
The energy gets converted to heat.

(vii) **How does this influence the type of target used?**
The target material must have very high melting point.

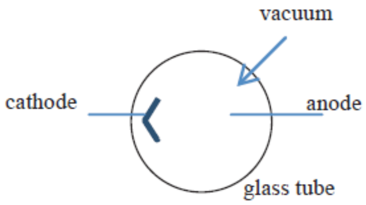
(viii) **Calculate the maximum energy of an electron as it hits the target.**
$W = QV$
$W = (1.6 \times 10^{-19})(40 \times 10^{3})$
$W = 6.4 \times 10^{-15}$ J

(ix) **Calculate the frequency of the most energetic X-ray produced.**
$E = hf$ $\quad f = \frac{E}{h} = \frac{6.4 \times 10^{-15}}{6.6 \times 10^{-34}}$ $\quad f = 9.7 \times 10^{18}$ Hz

2009 Question 8

(i) **What is a photon?**
A photon consists of a discrete (specific) amount of energy/electromagnetic radiation.

(ii) **Draw a labelled diagram of the structure of a photocell.**
See diagram



(iii) **Using the graph, calculate the work function of the metal.**
The graph indicates that current only flows when the frequency of the radiation reached 5.2×10^{14} Hz, so this corresponds to the threshold frequency (f_0).
$\phi = hf_0 = (6.6 \times 10^{-34})(5.2 \times 10^{14}) = 3.432 \times 10^{-19}$ J

(iv) **What is the maximum speed of an emitted electron when light of wavelength 550 nm is incident on the photocell?**
$hf = \phi + \frac{1}{2}mv^2$

We don't know f but we can work it out using $f = \frac{c}{\lambda} = \frac{3\times10^8}{550\times10^{-9}} = 5.45 \times 10^{14}$ Hz

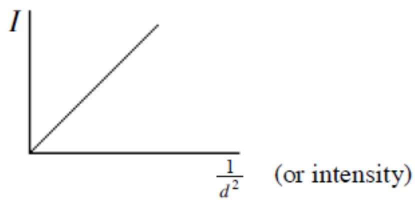
$hf = \phi + \frac{1}{2}mv^2$

$(6.6 \times 10^{-34})(5.45 \times 10^{14}) = 3.432 \times 10^{-19} + \frac{1}{2}(9.1\times 10^{-31})(v)^2$

$v = 1.922 \times 10^5$ m s^{-1}

(v) **Explain why a current does not flow in the photocell when the frequency of the light is less than 5.2×10^{14} Hz.**
Because the frequency is less than the threshold frequency so the individual photons do not contain enough energy to cause an electron to be released from an atom.

(vi) **Draw a sketch of the graph obtained.**
Current is directly proportional to Intensity *{each photon releases an electron, so if you have twice as many photons you will have twice as many electrons}*, so a straight line graph with the line going through the origin is required.



(vii) **How was the intensity of the light varied?**
Vary the distance between the light source and the photocell.

(viii) **What conclusion about the nature of light can be drawn from these investigations?**
Light is made up of discrete amounts of energy called photons.

2006 Question 12 (d)

(i) What are X-rays?
High frequency electromagnetic radiation.

(ii) Who discovered them?
Rontgen

(iii) How are the electrons emitted from the cathode?
By thermionic emission.

(iv) How are the electrons accelerated?
By the high voltage between the anode and cathode.

(v) Calculate the kinetic energy gained by an electron when it is accelerated through a potential difference of 50 kV in an X-ray tube.
Kinetic energy at the end = Potential energy at the beginning
$= (1.6 \times 10^{-19})(50 \times 10^{3})$
$= 8.0 \times 10^{-15}$ J

(vi) Calculate the minimum wavelength of an X-ray emitted from the anode.
$E = hf$ $\quad E = h\frac{c}{\lambda}$ $\quad \lambda = \frac{hc}{E}$ $\quad \lambda = \frac{(6.6 \times 10^{-34})(3.0 \times 10^{8})}{8.0 \times 10^{-15}}$ $\quad \lambda = 2.475 \times 10^{-11}$ m

2005 Question 12 (d)

(i) What is the photoelectric effect?
The photoelectric effect is the emission of electrons from the surface of a metal when light of suitable frequency shines on it.

(ii) Write down an expression for Einstein's photoelectric law.
$hf = \phi + \frac{1}{2}mv^2$

(iii) Summarise Einstein's explanation of the photoelectric effect.
Light is composed of packets (or bundles) of energy which he called photons.
All of energy from one photon is given to one electron.
Energy of the photon must be equal to or greater than the work function of the metal for the photoelectric effect to occur.
Any excess energy appears as kinetic energy of the electron.

(iv) Give one application of the photoelectric effect.
Sound track in film, photography, counters, photocell, burglar alarm, automatic doors, etc.

2004 Question 9

(i) Distinguish between photoelectric emission and thermionic emission.
The photoelectric effect is the emission of electrons when light of suitable frequency falls on a metal.
Thermionic emission is the emission of electrons from the surface of a hot metal.

(ii) Explain why the leaves of the electroscope collapse.
Photoelectric emission occurs (electrons get emitted from the surface of the metal).
The leaves lose their excess charge and therefore collapse.

(iii) Explain why the leaves do not collapse when the zinc is covered by a piece of ordinary glass.
Ordinary glass absorbs UV light (does not allow UV light to pass through)

(iv) Explain why the leaves do not collapse when the zinc is illuminated with green light.
The energy associated with photons of green light is too low for the photoelectric effect to occur, so no electrons are emitted from the electroscope.

(v) Explain why the leaves do not collapse when the electroscope is charged positively.
Any electrons emitted are attracted back to the positive electroscope.

(vi) Calculate the threshold frequency of zinc.
{First we need to convert the energy from eV to Joules, using 1eV = 1.6×10^{-19} Joules}
The symbol for work function is ϕ, so $\phi = 4.3$ eV = $(4.3)(1.6 \times 10^{-19})$ Joules = 6.88×10^{-19} Joules

Next we use ***$E = hf_0$*** *to calculate the threshold frequency*
$E = \phi = hf_0$ $\Rightarrow f_0 = \frac{E}{h}$ $f_0 = \frac{E}{h}$ $f_0 = \frac{6.88 \times 10^{-19}}{6.6 \times 10^{-34}}$ $f_0 = 1.04 \times 10^{15}$ Hz

(vii) Calulate the maximum kinetic energy of an emitted electron.
Energy of incident photon = Energy required to free an electron + kinetic energy of photo-electron.
$$hf = \phi + E_k$$

Remember that ϕ (the work function) = 6.88×10^{-19} Joules
{We don't know the frequency of the incident ultraviolet light, but we can know that the wavelength is 240 nm, so we can work out the frequency using $c = f\lambda$ or $f = \frac{c}{\lambda}$ }
$f = \frac{3.0 \times 10^{8}}{240 \times 10^{-9}}$ $= 1.25 \times 10^{15}$ Hz

$hf = \phi + E_k$ $\Rightarrow$ $E_k = hf - \phi$

$E_k = hf - \phi$
$E_k = [(6.6 \times 10^{-34})(1.25 \times 10^{15})] - (6.88 \times 10^{-19})$

$\Rightarrow E_k = 1.37 \times 10^{-19}$ Joules

2003 Question 9

(i) **List two properties of the electron.**
Negative charge, negligible mass, orbits nucleus, deflected by electric / magnetic field etc.

(ii) **Name the Irishman who gave the electron its name in the nineteenth century.**
George Stoney

(iii) **Give an expression for the force acting on a charge *q* moving at a velocity *v* at right angles to a magnetic field of flux density *B*.**
F = Bqv

(iv) **How much energy does the electron gain?**
{the final kinetic energy gained by the electron is equal to the initial (electrical) potential energy. The potential energy is given by the equation W = QV}
$W = (1.6 \times 10^{-19})(4000)$ $W = 6.4\times10^{-16}$ J

(v) **What is the speed of the electron at the anode?**
Kinetic energy = $\frac{1}{2} mv^2$ $\Rightarrow 6.4 \times10^{-16} = \frac{1}{2} (9.1 \times 10^{-31})(v^2)$ $\Rightarrow$ $v = 3.75 \times 10^7$ m s^{-1}

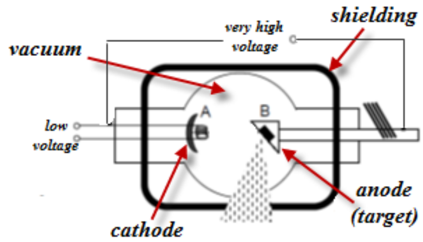
(vi) **Calculate the force acting on the electron.**
$F = Bev = (5 \times 10^{-2})(1.6 \times 10^{-19})(3.75 \times 10^7)$ $F = 3.0 \times10^{-13}$ N

(vii) **Calculate the radius of the circular path followed by the electron, in the magnetic field.**
$F = \frac{mv^2}{r}$ $r = \frac{mv^2}{F}$ $r = \frac{(9.1 \times 10^{-31})(3.75 \times 10^7)^2}{3.0 \times 10^{-13}}$ $\Rightarrow$ $r = 4.3\times10^{-3}$ m

(viii) **What happens to the energy of the electron when it hits the screen of the CRT?**
It gets converted to light.

2002 Question 9

(i) **Explain with the aid of a labelled diagram how X-rays are produced.**



1. Electrons are emitted from the hot cathode due to thermionic emission.
2. They get accelerated across the vacuum due to the very high voltage and smash into the high-density anode (usually tungsten) at B.
3. Some inner electrons in the tungsten get bumped up to a high orbital, then quickly fall back down to a lower lever, emitting X-rays in the process.

(ii) **Justify the statement "X-ray production may be considered as the inverse of the photoelectric effect."**

X-ray production: electrons are used to produce electromagnetic radiation

The photoelectric effect: electromagnetic radiation is used to release electrons

(iii)**Describe an experiment to demonstrate the photoelectric effect.**

Apparatus: gold leaf electroscope with zinc plate on top, ultraviolet light source

Procedure: Charge the electroscope negatively.

Shine ultraviolet light on the zinc plate.

Observation: The leaves collapse

(iv)**Outline Einstein's explanation of the photoelectric effect.**

Electromagnetic radiation consists of packets of energy which he called quanta.

The amount of energy in each quantum could be calculated using the formula $E = hf$

The incoming radiation needs to have sufficient energy to release an electron from the surface of a metal or it won't be absorbed at all.

If the incoming energy has more energy than an electron needs to be released (called its work function) then the excess energy appears as kinetic energy of the electron.

(v) **Give two applications of a photocell.**

Burglar alarm, smoke alarms, safety switch. light meters, automatic lights, counters, automatic doors, control of central heating burners, sound track in films, scanner reading bar codes, stopping conveyer belt