Particulate nature of photon

1 **(a)** Describe the nature of a γ-ray photon.

(b) When a beam of γ-rays or X-rays passes through matter, it may interact with an electron and be scattered through an angle θ, as show in Fig. 1.1.

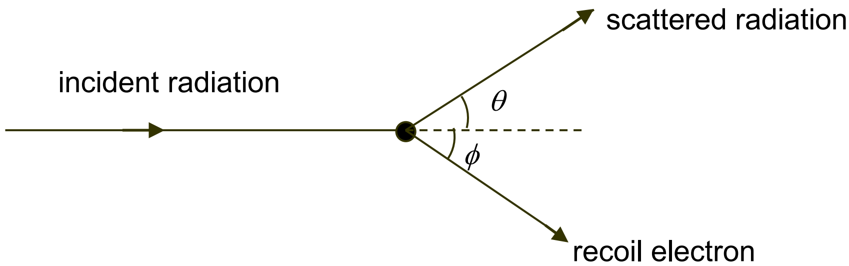


Fig. 1.1

According to a theory, the energy E' of the scattered radiation is given by

$$\frac{1}{E'} - \frac{1}{E} = \frac{1}{m_e c^2}(1 - \cos\theta),$$

where E is the energy of the incident radiation, m_e is the mass of the electron and c is the speed of light. The electron, originally at rest, recoils in a direction defined by the angle ϕ.

(i) A ^{60}Co source emits γ-ray of energy 1.33 MeV.

1. Find the largest possible energy loss this γ-ray can suffer in an interaction with a stationary electron.
2. In what direction does the recoil electron move after this interaction?

[6]

(ii) The reduction in energy of the γ-radiation can be detected as a change in wavelength.

1. Is this wavelength change an increase or a decrease?
2. Show that the magnitude $\Delta\lambda$ of the wavelength change corresponding to the energy reduction ($E - E'$) is given by
   $\Delta\lambda = A(1 - \cos\theta)$, where A is a constant.

   Find A in terms of m_e, c and the Planck constant h. [5]

(iii) In an experiment to measure $\Delta\lambda$ for X-rays of incident wavelength 7.09×10^{-11} m, scattered from graphite at various angles θ, the following results were obtained:

θ / °	45	75	90	120	135
$\Delta\lambda$ / 10^{-11} m	0.07	0.17	0.23	0.35	0.41

Each of the readings of θ was subjected to an uncertainty of ± 1°, and each of the value of $\Delta\lambda$ values to an uncertainty of $\pm\ 0.01 \times 10^{-11}$ m.

By plotting a suitable linear graph using graph paper, investigate the extent to which these results support the theoretical relationship. State your conclusion. [7]

[Special Paper Nov 1994 Q9]

Photoelectric effect

2 An evacuated tube contains two parallel metal electrodes, one of which is an emitter of electrons and the other a collector. When the emitter is illuminated with electromagnetic radiation of photon energy 4.7 eV at a power of 3.8 mW, photoelectrons are emitted. The potential difference V between collector and emitter is adjusted, and the photocurrent I is measured. Fig. 2.1 is a graph of the variation with V of I.

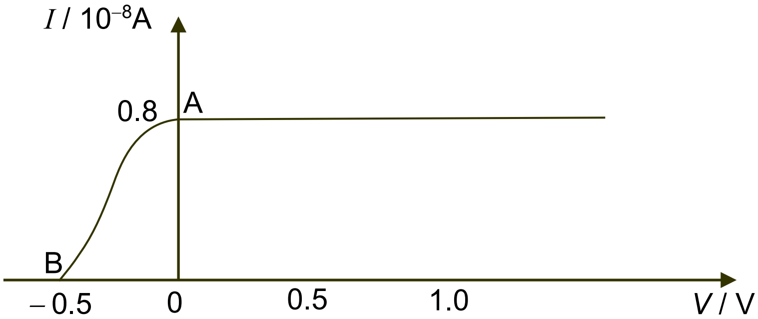


Fig. 2.1

(i) Calculate the rate at which photons are incident on the emitter. [2]

(ii) Calculate the maximum rate at which electrons leave the emitter. [1]

(iii) Explain the difference between your answers in **(i)** and **(ii)**. [2]

(iv) Calculate the maximum speed at which electrons leave the emitter. [3]

(v) Determine the work function of the material of the emitter. [1]

(vi) Suggest an explanation for the shape of the graph in region AB of Fig. 2.1[2]
[Special Paper Nov 1999 Q11]

3 Fig. 3.1 illustrates a device called an image intensifier.

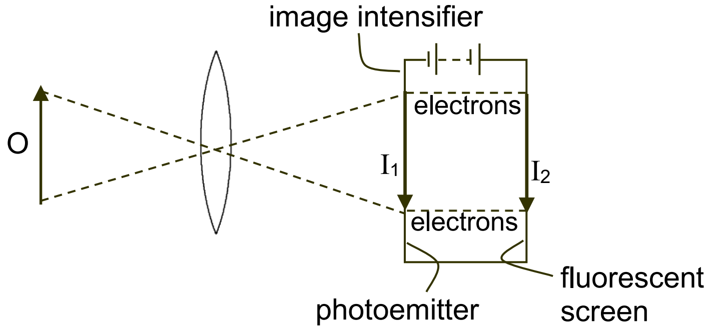


Fig. 3.1

A thin layer of photoemissive material is deposited on the inner side of a glass window in an evacuated tube. A fluorescent screen is mounted parallel to the photoemitter. An optical image I_1 of an object O is cast on the photoemitter. Electrons from the emitter are accelerated to the fluorescent screen, producing an image I_2 which is brighter than I_1.

In a particular image intensifier, the primary image I_1 is formed with light of wavelength 700 nm and power 5.0×10^{-9} W. For light of this wavelength, one photoelectron is emitted, on average, for every 85 photons incident on the emitter.

(a) **(i)** Calculate the number of photons incident on the emitter in one second.

(ii) Hence calculate the rate at which electrons are emitted.

(iii) Assume that all emitted electrons reach the fluorescent screen, calculate the corresponding current between emitter and screen. [5]

(b) **(i)** Because the final image is brighter than the primary image, light energy has been created. Given the principle of conservation of energy, how do you account for this? [2]

(ii) Image intensifier tubes may be coupled in series so that the final image of the first intensifier acts as the primary image of the second, and so on. An arrangement of three intensifiers is illustrated in Fig. 3.2.

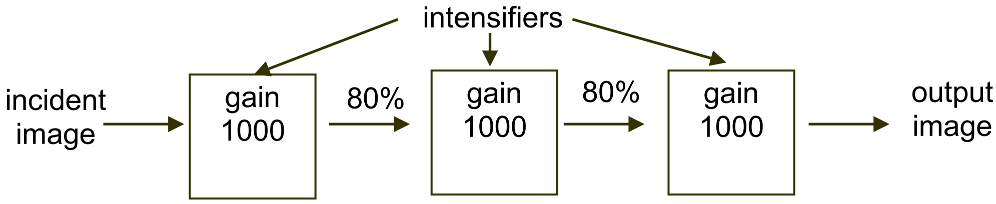


Fig. 3.2

The optical gain (the ratio of the brightness of the final image to that of the primary image) of each intensifier is 1000, and the efficiency of the optical coupling between each is 80 %.
Calculate the overall gain of this composite intensifier. [2]

(c) Perfect reproduction of the primary image is achieved only if electrons leaving the emitter travel in straight lines perpendicular to the emitter, directly to the screen. In fact, electrons leave the emitter with small initial speeds in all directions. This means that the electrons from one point on the primary image fall on a circular area on the fluorescent screen, called the disc of confusion. The diameter of this disc is proportional to the square root of the ratio of the initial kinetic energy to the final kinetic energy of the electrons.

(i) By means of a sketch showing electron trajectories, illustrate the formation of the disc of confusion. [1]

(ii) Explain how the size of the disc of confusion limits the quality of the secondary image. [1]

(iii) In a certain image intensifier, operating at an accelerating potential difference of 2.0 kV, the diameter of the disc of confusion is estimated to be about 1.0 mm.
Estimate the diameter of the disc if the accelerating potential were increased to 4.0 kV. Assume that the initial kinetic energy of the emitted electrons is 1.0 eV in both cases. [2]

[Special Paper Nov 2001 Q12]

Line spectrum

4 According to a theory of the atom, the frequencies f of the corresponding spectral lines of the elements are related to their proton numbers Z by the equation:

$$\sqrt{f} = a(Z - b)$$

where a and b are constants.

The wavelength λ of some of these spectral lines are tabulated below:

Element	sodium	potassium	manganese	zinc	strontium	rhodium
Z	11	19	25	30	38	45
λ / pm	1200	375	210	144	87.5	61.4

Use a graphical method to determine the values of the constants a and b. [11]

[Special Paper Nov 1997 Q5]

de Broglie wavelength

5 In a simple model of the hydrogen atom, the electron is allowed to move only along a straight line of length a. The associated wave motion must always show a standing wave pattern along this line, with nodes at the ends.

(a) Sketch two possible modes of the standing waves. [2]

(b) From the condition that the standing waves must have nodes at the ends of the line of length a, find the allowed values of the momentum of the electrons. [2]

(c) Hence show that the allowed values E_n of the energy of the electron in this model of the hydrogen atom are given by

$$E_n = \frac{n^2 h^2}{8 m_e a^2}$$

where n = 1, 2, 3, …. [3]

(d) The approximate diameter of the hydrogen atom is 1.1×10^{-10} m. Take this as the value of a. Calculate the values of E_1, E_2 and E_3, and draw an energy level diagram showing the n = 1, 2 and 3 states of this model of the hydrogen atom. [3]

(e) A photon is emitted when the electron in the hydrogen atom makes a transition from a higher energy state to a lower energy state. Calculate the longest wavelength of radiation which could be emitted from the hydrogen atom, based on this model. [3]

(f) The emission spectrum of hydrogen shows several prominent lines in the visible region. Comment on your answers in **(e)** with reference to this observation. [2]

[Special Paper Nov 1998 Q12]

6 **(a)** Using the de Broglie's wavelength expression, find an expression for the kinetic energy E of an electron in terms of λ, h and the electron mass m. (assume electron is moving with a speed much lesser than the speed of light.) [3]

(b) In a simple model of the hydrogen atom, the electron moves in a circular orbit about the proton. The centripetal acceleration is provided by the electrostatic attraction between electron and proton.

Calculate the kinetic energy of an electron in an orbit of radius 5.3×10^{-11} m. [5]

(c) Calculate the number of electron wavelengths equivalent to the circumference of this orbit in **(b)**. [3]

[Special Paper Nov 1996 Q4]

Answers

1 (b)(i) 1.12 MeV **2 (i)** 5.1×10^{15} s^{-1} **(ii)** 5.0×10^{10} s^{-1} **(iv)** 4.2×10^{5} m s^{-1} **(v)** 6.7×10^{-19} J	**3(a) (i)** 1.8×10^{10} s^{-1} **(ii)** 2.1×10^{8} s^{-1} **(iii)** 3.3×10^{-11} A **(c)(iii)** 0.71 mm **5 (e)** 13 nm **6 (b)** 2.2×10^{-18} J

Particulate nature of photon

1 **(a)** Describe the nature of a γ-ray photon.

γ-ray photon is a quantum of electromagnetic radiation of energy E given by $E = hf$ where h: Planck constant and f : frequency.

The wavelength of γ is in the order of 10^{-12} m.

(b) When a beam of γ-rays or X-rays passes through matter, it may interact with an electron and be scattered through an angle θ, as show in Fig. 1.1.

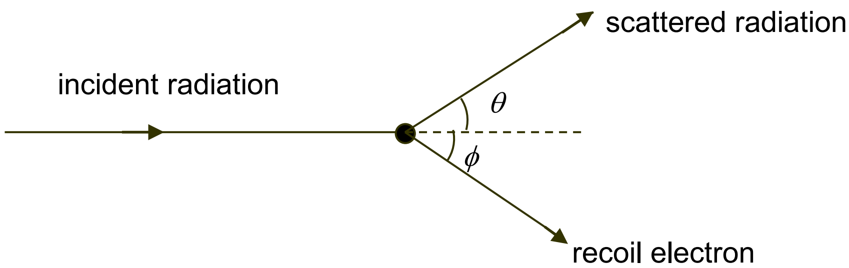


Fig. 1.1

According to a theory, the energy E ' of the scattered radiation is given by

$$\frac{1}{E'} - \frac{1}{E} = \frac{1}{m_e c^2}(1 - \cos\theta),$$

where E is the energy of the incident radiation, m_e is the mass of the electron and c is the speed of light. The electron, originally at rest, recoils in a direction defined by the angle ϕ.

(i) A ^{60}Co source emits γ-ray of energy 1.33 MeV.

1. Find the largest possible energy loss this γ-ray can suffer in an interaction with a stationary electron.

The largest energy loss occurs when *E'* is minimum.
or when $\frac{1}{E'} - \frac{1}{E}$ is a maximum, which means $(1-\cos\theta)$ is a maximum.
The maximum of $(1-\cos\theta)$ is 2 (when θ = 180°).
Hence $\frac{1}{E'} - \frac{1}{E} = \frac{2}{m_e c^2}$

$$\frac{1}{E'} - \frac{1}{1.33 \times 1.6 \times 10^{-13}} = \frac{2}{(9.11 \times 10^{-31})(3.00 \times 10^{8})^2}$$

$E' = 3.43 \times 10^{-14}$ J = 0.21483 MeV

Energy loss = 1.33 – 0.21483 = **1.12 MeV**

2. In what direction does the recoil electron move after this interaction?

Since θ = 180°, by conservation of momentum, the recoil electron has to move forward with $\phi = 0$.

[6]

(ii) The reduction in energy of the γ-radiation can be detected as a change in wavelength.

1. Is this wavelength change an increase or a decrease?

Since $E = \frac{hc}{\lambda}$, decrease in *E* means an increase in wavelength.

2. Show that the magnitude $\Delta\lambda$ of the wavelength change corresponding to the energy reduction ($E - E'$) is given by
$\Delta\lambda = A(1 - \cos\theta)$, where *A* is a constant.

Find *A* in terms of m_e, *c* and the Planck constant *h*. [5]

$$\Delta\lambda = \lambda' - \lambda$$
$$= \frac{hc}{E'} - \frac{hc}{E}$$
$$= hc\left(\frac{1}{E'} - \frac{1}{E}\right)$$
$$= hc\frac{1}{m_e c^2}(1-\cos\theta)$$

Hence $A = \frac{h}{m_e c}$.

(iii) In an experiment to measure $\Delta\lambda$ for X-rays of incident wavelength 7.09×10^{-11} m, scattered from graphite at various angles θ, the following results were obtained:

θ / °	45	75	90	120	135
$\Delta\lambda$ / 10^{-11} m	0.07	0.17	0.23	0.35	0.41

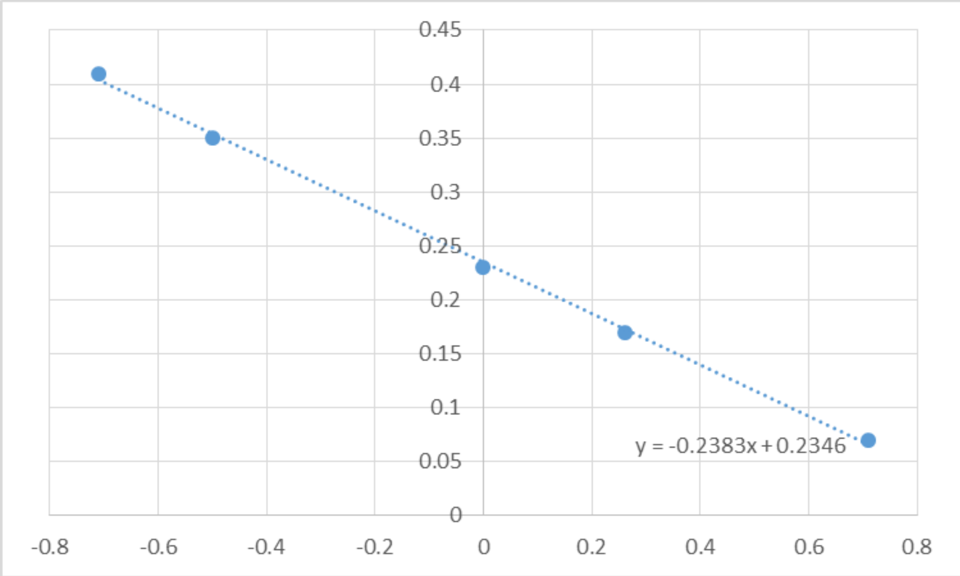
Each of the readings of θ was subjected to an uncertainty of $\pm$ 1°, and each of the value of $\Delta\lambda$ values to an uncertainty of $\pm\ 0.01 \times 10^{-11}$ m.

By plotting a suitable linear graph using graph paper, investigate the extent to which these results support the theoretical relationship. State your conclusion. [7]

[Special Paper Nov 1994 Q9]

θ / °	45	75	90	120	135
cos θ	0.71	0.26	0	–0.50	–0.71
$\Delta\lambda$ / 10^{-11} m	0.07	0.17	0.23	0.35	0.41

Plot $\Delta\lambda$ against cos θ. If straight line graph is obtained, gradient will be $-A$ and intercept is A.



Intercept = 2.346×10^{-12}; gradient = -2.383×10^{-12}.

$$A = \frac{h}{m_e c} = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(3.00 \times 10^{8})} = 2.43 \times 10^{-12} \text{ m}$$

The difference between actual A and intercept $\approx$ 3.5%;
The difference between actual A and gradient $\approx$ 1.9%;

Since $\Delta\lambda$ has uncertainty of $\pm\, 0.01 \times 10^{-11}$ m, for a value of 0.07×10^{-11} m, percentage uncertainty = 14 %.

Hence we can say the results support the theoretical relationship.

Photoelectric effect

2 An evacuated tube contains two parallel metal electrodes, one of which is an emitter of electrons and the other a collector. When the emitter is illuminated with electromagnetic radiation of photon energy 4.7 eV at a power of 3.8 mW, photoelectrons are emitted. The potential difference V between collector and emitter is adjusted, and the photocurrent I is measured. Fig. 2.1 is a graph of the variation with V of I.

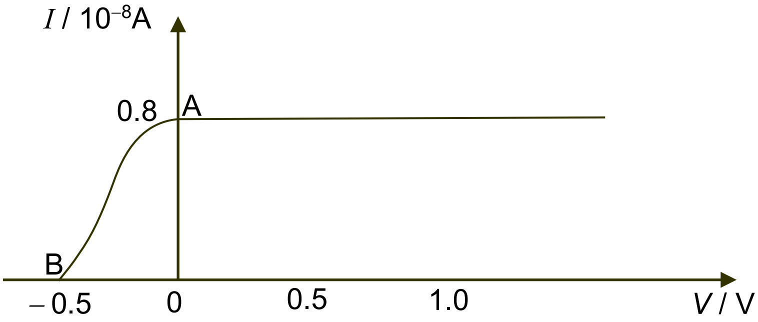


Fig. 2.1

(i) Calculate the rate at which photons are incident on the emitter. [2]

$$\text{Power} = \frac{NE}{t}$$

$$\frac{N}{t} = \frac{3.8 \times 10^{-3}}{4.7 \times 1.6 \times 10^{-19}}$$

$= 5.1 \times 10^{15}\ s^{-1}$

(ii) Calculate the maximum rate at which electrons leave the emitter. [1]

Maximum current = 0.8×10^{-8} A = nQ / t

$$\frac{n}{t} = \frac{0.8 \times 10^{-8}}{1.6 \times 10^{-19}}$$

$= 5.0 \times 10^{10}\ s^{-1}$

(iii) Explain the difference between your answers in **(i)** and **(ii)**. [2]

Most of the photons are reflected or scattered by the metal surface and do not have the opportunity to interact with the electrons in the metal to cause them to be emitted.

Electrons that are further away from the surface of the metal may also lose their energy during collisions with other electrons and hence they do not have enough energy to leave the surface of the metal.

(iv) Calculate the maximum speed at which electrons leave the emitter. [3]

$e V_S = 0.5 \text{ eV} = \frac{1}{2} mv^2$

$v = \ldots. = 4.2 \times 10^5 \text{ m s}^{-1}$

(v) Determine the work function of the material of the emitter. [1]

energy of photon = work function + $e V_S$

work function = 4.7 – 0.5 = 4.2 eV or 6.7×10^{-19} J

(vi) Suggest an explanation for the shape of the graph in region AB of Fig. 2.1. [2]

[Special Paper Nov 1999 Q11]

Photoelectrons are emitted with a range of kinetic energies. The energies range from 0 to 0.5 eV. As the potential of the collector becomes negative, electrons with smaller kinetic energy will not have sufficient energy to overcome the repulsive potential and hence not able to reach the collector, hence the current decreases as the collector potential becomes more negative.

When the collector potential reaches –0.5 eV (stopping potential), even the most energetic electrons are not able to reach the collector, hence current drops to zero.

When the potential becomes more positive, the (saturated) current does not increase anymore as the maximum number of electrons depends on the number of photons incident on the emitter, which is a constant unless intensity of radiation is increased.

3 Fig. 3.1 illustrates a device called an image intensifier.

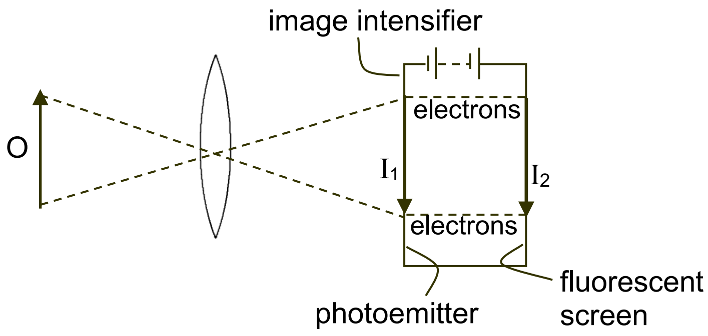


Fig. 3.1

A thin layer of photoemissive material is deposited on the inner side of a glass window in an evacuated tube. A fluorescent screen is mounted parallel to the photoemitter. An optical image I_1 of an object O is cast on the photoemitter. Electrons from the emitter are accelerated to the fluorescent screen, producing an image I_2 which is brighter than I_1.

In a particular image intensifier, the primary image I_1 is formed with light of wavelength 700 nm and power 5.0×10^{-9} W. For light of this wavelength, one photoelectron is emitted, on average, for every 85 photons incident on the emitter.

(a) **(i)** Calculate the number of photons incident on the emitter in one second.

$$P = \frac{Nhc}{\lambda t}$$

$$\frac{N}{t} = \frac{P\lambda}{hc}$$

$= (5.0 \times 10^{-9})(700 \times 10^{-9}) / (6.63 \times 10^{-34})(3.0 \times 10^{8})$
$=$ **$\underline{1.8 \times 10^{10}\ s^{-1}}$**

(ii) Hence calculate the rate at which electrons are emitted.

$\frac{n}{t} = 1.8 \times 10^{10}\ s^{-1} / 85 =$ **$\underline{2.1 \times 10^{8}\ s^{-1}}$**

(iii) Assume that all emitted electrons reach the fluorescent screen, calculate the corresponding current between emitter and screen. [5]

Current $= \frac{ne}{t} = (2.1 \times 10^{8})(1.6 \times 10^{-19}) =$ **$\underline{3.3 \times 10^{-11}\ A}$**

(b) **(i)** Because the final image is brighter than the primary image, light energy has been created. Given the principle of conservation of energy, how do you account for this? [2]

The “additional” energy comes from the battery in the circuit. The electric field provided by the battery accelerates the electrons towards the fluorescent screen. The kinetic energy of the electrons are then converted to enhanced light given out by the fluorescent materials on the screen to produce a brighter image.

(ii) Image intensifier tubes may be coupled in series so that the final image of the first intensifier acts as the primary image of the second, and so on. An arrangement of three intensifiers is illustrated in Fig. 3.2.

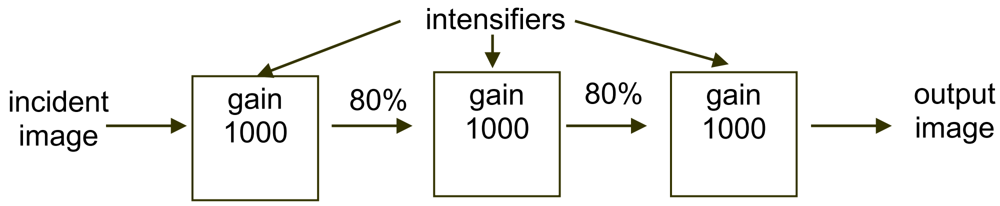


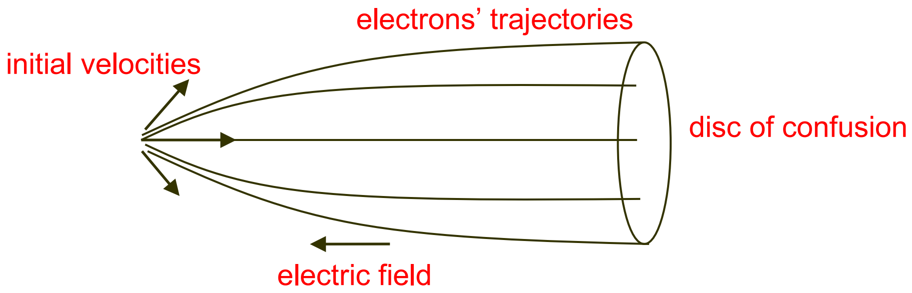
Fig. 3.2

The optical gain (the ratio of the brightness of the final image to that of the primary image) of each intensifier is 1000, and the efficiency of the optical coupling between each is 80 %.
Calculate the overall gain of this composite intensifier. [2]

Overall gain $= 1000 \times 0.8 \times 1000 \times 0.8 \times 1000 = 6.4 \times 10^{8}$

(c) Perfect reproduction of the primary image is achieved only if electrons leaving the emitter travel in straight lines perpendicular to the emitter, directly to the screen. In fact, electrons leave the emitter with small initial speeds in all directions. This means that the electrons from one point on the primary image fall on a circular area on the fluorescent screen, called the disc of confusion. The diameter of this disc is proportional to the square root of the ratio of the initial kinetic energy to the final kinetic energy of the electrons.

(i) By means of a sketch showing electron trajectories, illustrate the formation of the disc of confusion. [1]



The curved parabolic path is due to the electric field exerting a horizontal force on the electrons, causing them to curve.

(ii) Explain how the size of the disc of confusion limits the quality of the secondary image. [1]

The larger the disc, the greater is the overlap between electrons from adjacent pixels from the primary image and the lower is the resolution of the image.

(iii) In a certain image intensifier, operating at an accelerating potential difference of 2.0 kV, the diameter of the disc of confusion is estimated to be about 1.0 mm.
Estimate the diameter of the disc if the accelerating potential were increased to 4.0 kV. Assume that the initial kinetic energy of the emitted electrons is 1.0 eV in both cases. [2]

[Special Paper Nov 2001 Q12]

The gain in KE of electron = loss in electric PE
When accelerating potential is 2.0 kV, the gain in KE = 2.0 keV, hence the final KE = 1.0 eV + 2.0 keV = 2.001 keV

When accelerating potential is 4.0 kV, the gain in KE = 4 keV, hence the final KE = 1.0 eV + 4.0 keV = 4.001 keV

Given diameter of disc is proportional to square root of ratio of initial to final KE,

$$\frac{D'}{D} = \sqrt{\left(\frac{0.001}{4.001} \times \frac{2.001}{0.001}\right)}$$

D' = 0.707 = **<u>0.71 mm</u>**

Line spectrum

4 According to a theory of the atom, the frequencies f of the corresponding spectral lines of the elements are related to their proton numbers Z by the equation:

$$\sqrt{f} = a(Z - b)$$

where a and b are constants.

The wavelength λ of some of these spectral lines are tabulated below:

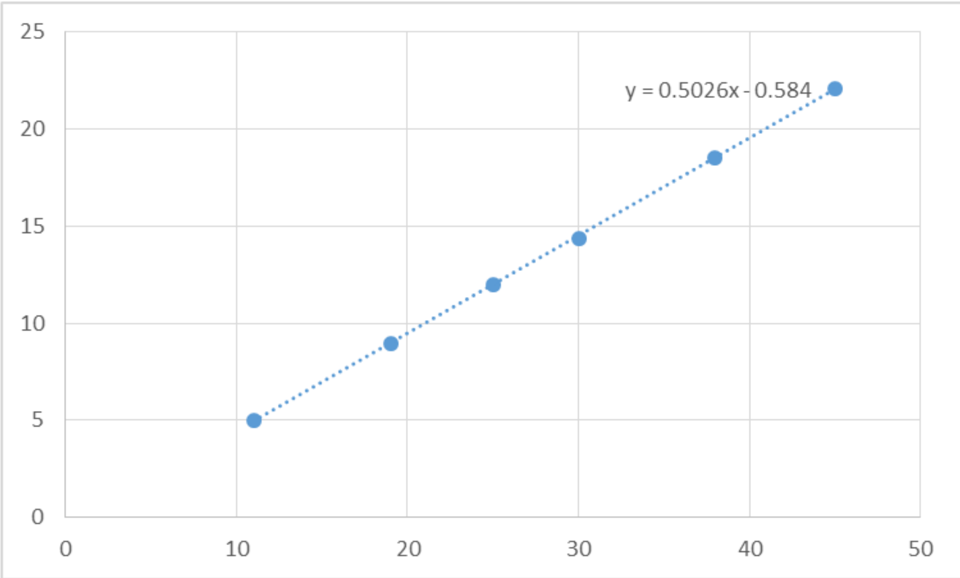
Element	sodium	potassium	manganese	zinc	strontium	rhodium
Z	11	19	25	30	38	45
λ / pm	1200	375	210	144	87.5	61.4

Use a graphical method to determine the values of the constants a and b. [11]

[Special Paper Nov 1997 Q5]

Plot $\sqrt{f}$ against Z. If straight line is obtained, gradient is a and intercept is $-ab$.

Element	sodium	potassium	manganese	zinc	strontium	rhodium
Z	11	19	25	30	38	45
λ / pm	1200	375	210	144	87.5	61.4
$\sqrt{f}$ /10^8 Hz	5.00	8.94	12.0	14.4	18.5	22.1

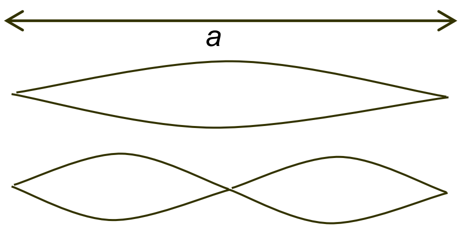


Gradient = 0.5026×10^8 and intercept = -0.584×10^8
Hence **a = 5.03×10^7 Hz$^{1/2}$** and ab = 5.84×10^7
Hence **b = 1.16**

de Broglie wavelength

5 In a simple model of the hydrogen atom, the electron is allowed to move only along a straight line of length *a*. The associated wave motion must always show a standing wave pattern along this line, with nodes at the ends.

(a) Sketch two possible modes of the standing waves. [2]



(b) From the condition that the standing waves must have nodes at the ends of the line of length *a*, find the allowed values of the momentum of the electrons. [2]

Since $a = n\dfrac{\lambda}{2}$ where *n* is a positive integer

and $p = \dfrac{h}{\lambda} = \dfrac{nh}{2a}$

(c) Hence show that the allowed values E_n of the energy of the electron in this model of the hydrogen atom are given by

$$E_n = \frac{n^2h^2}{8m_e a^2}$$

where n = 1, 2, 3,….

[3]

$$KE = \frac{p^2}{2m_e}$$

$$= (\frac{nh}{2a})^2 \frac{1}{2m_e}$$

$$= \frac{n^2h^2}{8m_e a^2}$$

(d) The approximate diameter of the hydrogen atom is 1.1×10^{-10} m. Take this as the value of a. Calculate the values of E_1, E_2 and E_3, and draw an energy level diagram showing the n = 1, 2 and 3 states of this model of the hydrogen atom. [3]

$$E_1 = \frac{1^2h^2}{8m_e a^2} = 5.0 \times 10^{-18} \text{ J}$$

$$E_2 = \frac{2^2h^2}{8m_e a^2} = 20 \times 10^{-18} \text{ J}$$

$$E_3 = \frac{3^2h^2}{8m_e a^2} = 45 \times 10^{-18} \text{ J}$$

$E_3 = 45 \times 10^{-18}$ J

$E_2 = 20 \times 10^{-18}$ J

$E_1 = 5.0 \times 10^{-18}$ J

(e) A photon is emitted when the electron in the hydrogen atom makes a transition from a higher energy state to a lower energy state. Calculate the longest wavelength of radiation which could be emitted from the hydrogen atom, based on this model. [3]

$$E_2 - E_1 = \; = \frac{hc}{\lambda}$$

$\lambda = \ldots = 1.3 \times 10^{-8}$ m = 13 nm (ultra-violet)

(f) The emission spectrum of hydrogen shows several prominent lines in the visible region. Comment on your answers in **(e)** with reference to this observation. [2]

[Special Paper Nov 1998 Q12]

Since the longest wavelength in (e), or smallest energy is in the UV range, this means that if the model is correct, then emission of visible light is not possible. Thus the model is incomplete as it does not account for the observation of visible light in the emission spectrum of hydrogen.

This is because it only takes into consideration the KE of the electron in the hydrogen atom, and does not include the electric potential energy of the atom.

If electric potential energy is included, the total energy is negative at all levels, and increases towards zero as n approaches infinity.

There are much closer spaced energy levels at the higher states which are responsible in producing photons of much lower energy values which fall within the visible region.

6 **(a)** Using the de Broglie's wavelength expression, find an expression for the kinetic energy E of an electron in terms of λ, h and the electron mass m. (assume electron is moving with a speed much lesser than the speed of light.) [3]

$$KE = \frac{p^2}{2m}$$
$$= \frac{h^2}{2m\lambda^2}$$

(b) In a simple model of the hydrogen atom, the electron moves in a circular orbit about the proton. The centripetal acceleration is provided by the electrostatic attraction between electron and proton.

Calculate the kinetic energy of an electron in an orbit of radius 5.3×10^{-11} m. [5]

Electrostatic force provides for the centripetal force

$$\frac{e^2}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r} = \frac{2\,\text{KE}}{r}$$

KE = ….. = **$\underline{2.2 \times 10^{-18}\ \text{J}}$**

(c) Calculate the number of electron wavelengths equivalent to the circumference of this orbit in **(b)**. [3]

$$KE = \frac{h^2}{2m\lambda^2} = 2.2 \times 10^{-18}\ \text{J}$$

Hence λ = … = 3.3×10^{-10} m

Circumference = $2\pi r$ = … = 3.3×10^{-10} m

Hence 1 electron wavelength is equivalent to the circumference of the orbit.

Answers

1 **(b)(i)** 1.12 MeV

2 **(i)** 5.1×10^{15} s^{-1}
(ii) 5.0×10^{10} s^{-1}
(iv) 4.2×10^{5} m s^{-1}
(v) 6.7×10^{-19} J

3 **(a) (i)** 1.8×10^{10} s^{-1}
(ii) 2.1×10^{8} s^{-1}
(iii) 3.3×10^{-11} A
(c)(iii) 0.71 mm

5 **(e)** 13 nm

6 **(b)** 2.2×10^{-18} J