THE PR:IME! PACKAGE PART 6

Modern Physics (Quantum Physics, Lasers & Semiconductors and Nuclear Physics)

MCQ

1 An electron of mass *m* and charge *e* is accelerated from rest through a potential difference of *V*. What is the frequency of a photon whose wavelength is equal to the de Broglie wavelength of this electron? (*c* is the speed of light and *h* is the Planck constant.)

A $\dfrac{c\sqrt{2meV}}{h}$ **B** $\dfrac{h}{c\sqrt{2meV}}$ **C** $\dfrac{hc}{eV}$ **D** $\dfrac{eV}{h}$

A

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

$$eV = \frac{p^2}{2m}$$

$$p = \sqrt{2meV}$$

Using $\lambda = \dfrac{h}{p}$

$$= \frac{h}{\sqrt{2meV}}$$

Using $f = \dfrac{c}{\lambda}$

$$= \frac{c\sqrt{2meV}}{h}$$

[AJC 2013]

2 The accelerating voltage in a X-ray tube is increased while keeping the power supplied constant.
Which of the following statement is *incorrect*?

A The intensity of the X-ray spectrum produced is increased.

B The rate of emission of X-ray photon is increased.

C The cutoff wavelength is reduced.

D The wavelengths of characteristic lines remains unchanged.

[AJC 2012]

None of the above. Options A and B are correct. As voltage is increased, the kinetic energy of the incident electrons will increase, electrons will be hitting the metal target at a high speed and each electron may undergo several collisions before it comes to rest, emitting a few X-ray photons in the process. Option C, cutoff wavelength is reduced as f increases. Option D, The characteristic lines are dependent on the target metal and independent of the energy of the electron.

3 Which of the following statement about the production of laser is *false*?

A Population inversion enhances the chance of stimulated emission taking place.

B Meta stable state is needed for population inversion to take place.

C Meta stable state ensures that there is no spontaneous emission.

D Stimulated emission of photon can occur in a direction that is not in line with the direction of the laser beam.

C

A: True. Since there are more electrons in the excited state in population inversion, the chances of a photon causing stimulated emission is greater than that of it being absorbed.

B: True. Excited electrons stay in the metastable state for about 10^5 times longer than in a normal excited state ($\tau_{metastable}$ = 10^{-3} s & $\tau_{excited}$ = 10^{-8} s). This allows for more electrons to be in the excited state than ground state, hence creating a population inversion.

C: False. Electrons will not stay at the meta stable state forever, just about 10^5 times longer than the average lifetime in a normal excited state ($\tau_{metastable}$ = 10^{-3} s & $\tau_{excited}$ = 10^{-8} s). It will eventually de-excite spontaneously if no photon comes in to stimulate an emission.

D: True. The spontaneously emitted photon in option **C** can be in any direction and may therefore not be in line with the direction of the laser beam. If this photon is not in line with the direction of laser, and it goes on to stimulate an emission, then the emitted photon will also not be in line with the direction of laser.

Side note: All the stray photons in option **D** will move out of the system leaving only those that are in line with the direction of laser. These photons are reflected by the mirrors at the ends of the lasing material, thus making many passes in the material, each time generating many stimulated emission in the same direction.

[AJC 2012]

4 The nucleus Z has the notation ${}^{y}_{x}\mathrm{Z}$. The binding energy per nucleon of the nucleus is *E*. What is the mass defect of this nucleus?

A $\dfrac{E}{c^2}$ **B** $\dfrac{E}{yc^2}$ **C** $\dfrac{xE}{c^2}$ **D** $\dfrac{yE}{c^2}$

D

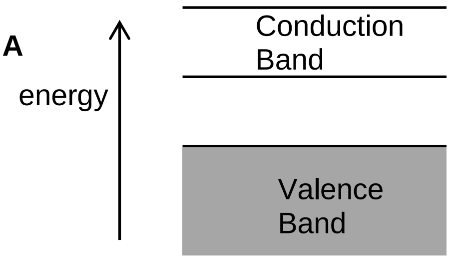
$\text{BE of nucleus} = yE = \Delta mc^2$

$\Delta m = \dfrac{yE}{c^2}$

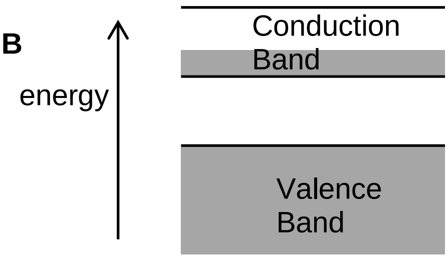
[AJC 2012]

5 The following diagrams show the upper energy bands of solids at absolute zero. The shaded areas represent occupied electron energy levels. Which one represents the intrinsic semiconductor?

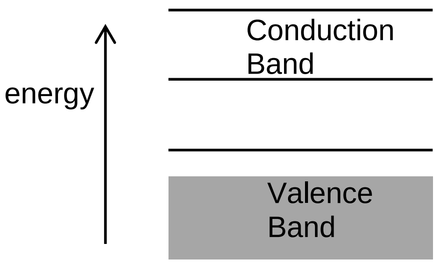
A



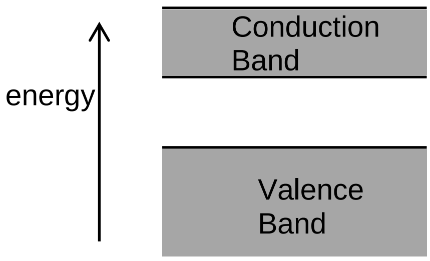
B



C



D



A
For an intrinsic semiconductor at absolute zero, there are no free electrons in the conduction band. Valence band is fully occupied.

Note: At room temperature, the thermal energy is enough to cause some free electrons to be liberated to the conduction band, creating some holes in the valence band in the process. These electron-hole pairs then contribute to the conduction of electricity in the conduction band and valence band respectively.

[AJC 2012]

6 Nuclide X decays with a half-life of 15 days to stable nuclide Y. At a particular time, *t*, the ratio of the number of nuclides X to the number of nuclides Y in a sample is 1:1.
How long after time *t* will the ratio in the sample be 1:3?

A 15 days **B** 30 days **C** 45 days **D** 60 days

A
1 half-life after time *t*, the number of nuclides of X will reduce by ½ and the number of nuclides of Y will increase by ½. The ratio will then become 1:3.

[AJC 2012]

7 Which statement about conduction of electricity of **extrinsic** semiconductors is wrong?

A The conductivity of extrinsic semiconductors increases with increasing temperature

B The resistivity of extrinsic semiconductors increases with decreasing impurities

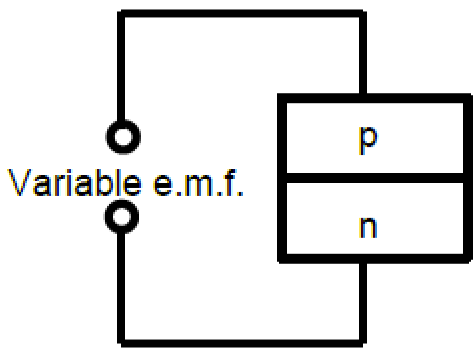
C Holes in the valence band accounts for the increase in conductivity of the semiconductor

D Donor electrons within the donor levels accounts for the increase in conductivity of the semiconductor

D
Donor electrons in the conduction band increases conductivity.

[DHS 2012]

8 The figure below shows a p-n junction connected to a variable e.m.f. source
Which of the following correctly predicts the current in the p-n junction as the potential at the p-type semiconductor varies with respect to the n-type semiconductor?



	Higher potential at p-type	**Lower potential at p-type**
A	no current	from p to n type
B	from p to n type	no current
C	from p to n type	from n to p type

D	from n to p type	from p to n type

B
Electrons will travel from the n-type to the p-type semiconductor when the p-type is at a higher potential and will be repelled when it is at a lower potential.

[DHS 2012]

9 A metal surface in an evacuated tube is illuminated with monochromatic light causing the emission of photoelectrons which are collected at an adjacent electrode. If the experiment were to be replaced with light of half the intensity but the same wavelength, how would the photocurrent I and stopping potential V be affected?

A I unchanged, V doubled
B I halved, V unchanged
C I halved, V halved
D I halved, V doubled

B
The photocurrent is directly proportional to light intensity, while the stopping potential is dependent on the wavelength of incident radiation (from Einstein's photoelectric equation).

[IJC 2012]

10 Which of the following statements is true?

A A beam of electrons directed at a vessel of cold gas can cause the formation of either an absorption or emission line spectrum.

B A beam of white light directed at a vessel of cold gas can only cause the formation of an absorption line spectrum.

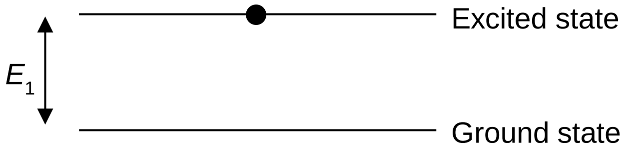
C A beam of electrons directed at a vessel of cold gas can only cause the formation of an absorption line spectrum.

D A beam of electrons directed at a vessel of cold gas can only cause the formation of an emission line spectrum.

B
For absorption spectrum, there must be a whole spectrum of light (white light) passing through the gas to provide photons of different wavelengths that are equivalent to the difference E levels of the cold gas atoms. When components of white light is absorbed by cold gas atoms and photons are reemitted by the gas atoms, they are emitted in all directions.

[IJC 2012]

11 In a stimulated emission of a photon, which of the following statements is true?



A The electron in the excited state de-excites to the ground state in a random process and produce a photon of energy E_1.

B An incident electron of energy E_1 moves pass the excited atom. The atom then de-excites to give off an electron of energy E_1. The incident electron is being absorbed by the atom.

C An incident photon of energy E_1 moves pass the excited atom. The atom then de-excites to give off a photon of energy E_1 which moves together with the incident photon with the same phase.

D An incident electron of energy E_1 moves pass the excited atom. The atom then de-excites to give off a photon of energy $E_1 - E$ which moves together with the incident electron with the same phase, where E is the kinetic energy of the incident electron.

C

In stimulated emission, the photon that is created by the transition of an electron from an excited state to a lower energy level must have the same energy and phase as the incoming photon

[IJC 2012]

12 Which of the following statements concerning nuclear reactions, the mass differences and energies released is true?

A The greater the binding energy of a nucleus, the more stable it is.

B If the total mass of the products of a reaction is greater, this reaction is impossible.

C When a stationary nucleus decays to produce a daughter nucleus and a γ-photon, the products always move off in opposite directions so as to conserve linear momentum.

D The half-life of a radioactive substance can be changed by allowing the substance to react chemically to produce a new radioactive compound.

C

A: False. The greater the binding energy **per nucleon** of a nucleus, the more stable it is.

B: False. If the total mass of the products of a reaction is greater, this reaction is still possible but effectively, the reaction absorbs energy.

C: True.

D: False. A chemical reaction produces a new radioactive compound but the nuclei are unchanged. Thus, half-life is unchanged.

[IJC 2012]

13 Which statement correctly describes how the scanning tunnelling microscope obtains atomic-scale images of surfaces?

A The voltage applied between the tip of the microscope and the surface ionises the air molecules and allows a current to flow.

B High speed electrons emitted from the tip of the microscope tunnel into the surface to allow a current to flow.

C Electrons on the surface repel electrons from the tip of the microscope and cause a current to flow.

D Electrons can tunnel through the small gap between the tip of the microscope and the surface and allows a current to flow.

D

Electrons can tunnel through the small gap between the tip of the microscope and the surface and allows a current to flow. This process is called quantum tunnelling.

[JJC 2012]

14 Two deuterium nuclei undergo fusion to produce a nucleus of helium plus a neutron and releases 3.27 MeV of energy as shown below.

$$^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{1}_{0}\text{n} + 3.27 \text{ MeV}$$

The mass of the two deuterium nuclei is

A 5.8×10^{-30} kg less than that of the products.

B 5.8×10^{-30} kg more than that of the products.

C 5.8×10^{-36} kg less than that of the products.

D 5.8×10^{-36} kg more than that of the products.

B

deuterium + deuterium $\rightarrow$ helium + neutron + energy release

Mass of LHS of equation is **more than** mass of RHS of equation.

For mass equivalent,

$$E = mc^2$$
$$3.27 \times 10^6 \times 1.6 \times 10^{-19} = m(3 \times 10^8)^2$$
$$m = 5.8 \times 10^{-30} \text{ kg}$$

[JJC 2012]

15 A potential barrier has a width *W* and potential height 6.0 MeV. The probability of a 3.0 MeV electron tunnelling through it is 0.025.
Suppose that the potential height of the barrier is now doubled, what must the width of the barrier be in order for a 3.0 MeV electron to have the same probability of transmission?

A 0.577 *W* **B** 0.707 *W* **C** 1.41 *W* **D** 1.73 *W*

A

$$T = e^{-2kd}$$
$$k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$$

Since probability of transmission is the same,

$$T = T'$$
$$e^{-2kd} = e^{-2k'd'}$$
$$kd = k'd'$$
$$\left(\sqrt{U-E}\right)d = \left(\sqrt{U'-E}\right)d'$$
$$d' = \frac{\left(\sqrt{U-E}\right)d}{\sqrt{U'-E}}$$
$$= \frac{\left(\sqrt{(6.0-3.0)\times 10^6}\right)W}{\sqrt{(2\times 6.0-3.0)\times 10^6}}$$
$$= 0.577\ W$$

[MI 2012]

16 The rest masses of deuteron ${}^2_1\text{H}$, proton and neutron are 2.0150u, 1.0086u and 1.0097 u respectively.
Which of the following is true for a deuteron to disintegrate to a proton and a neutron?

A The deuteron emits a photon of energy 2 MeV.

B The deuteron emits a photon of energy 3 MeV.

C The deuteron captures a photon of energy 2 MeV.

D The deuteron captures a photon of energy 3 MeV.

D

$$\text{rest mass energy of reactant} = 2.0150uc^2$$

$$\begin{aligned}\text{rest mass energy of products} &= (1.0086 + 1.0097)uc^2 \\ &= 2.0183uc^2 \\ \Delta\text{rest mass energy} &= (2.0183 - 2.0150)uc^2 \\ &= 0.0033uc^2 \\ &= 0.0033(1.66\times10^{-27})(3.00\times10^{8})^2 \\ &= 4.9302\times10^{-13}\text{ J} \\ &= 3.08\text{ MeV}\end{aligned}$$

Since rest mass energy of products > rest mass energy of reactant, an input energy is required.

[MI 2012]

17 Which of the following statements about intrinsic semiconductors is true?

A At room temperature, the valence band is completely filled and the conduction band is partially filled.

B At absolute zero, the valence band is completely filled and the conduction band is partially filled.

C The total current flow is the sum of both 'hole' and 'electron' currents.

D Intrinsic semiconductors can be doped to increase its resistivity.

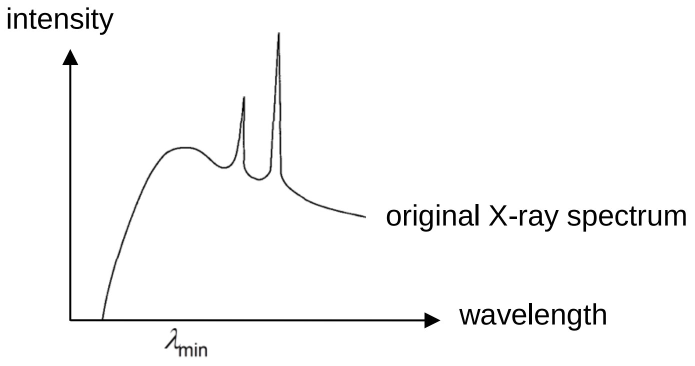
C

Both the **movement of electrons and holes** in the conduction band and valence band respectively are **responsible for electrical conduction** in intrinsic semiconductors

A: Incorrect because in intrinsic semiconductors, electrons from valence band move to the conductor band, hence, the valence band is not completely filled.
B: Incorrect. For an intrinsic semiconductor at absolute zero, there are no free electrons in the conduction band. Valence band is fully occupied.

[MJC 2012]

18 The following graph shows the spectrum of X-rays emitted from an X-ray tube.



If the potential difference between the target and cathode is increased, which one of the following represents a possible change in minimum wavelength and wavelengths of the peaks?

	minimum wavelength	wavelengths of peaks
A	Decrease	increase
B	Decrease	remain the same

C	Increase	increase
D	Increase	remain the same

B

The peaks will remain the same as these are characteristic of the target metal. If the p.d. is increased, the electrons are fired with greater kinetic energy at the target metal, which means that more energetic X-rays can be produced. The cutoff wavelength will decrease, because $eV_{AC} = \dfrac{hc}{\lambda_{min}}$.

[PJC 2012]

19 There is a possibility that visible light from a low power laser source can be harmful to the naked eye.
Which of the following explanations is the most suitable?

A The photon energy can be extremely high.

B The light from the source can contain very high energy radiation.

C The intensity of light received by the eye can be very high.

D The wavelength of the light can be very small.

C

Laser beams are collimated and even at long distances away from the source, power is concentrated over a small area, i.e. intensity remains high. This is the main reason for eye hazard.

[PJC 2012]

20 From the results of the Geiger-Marsden α particles scattering experiment, it can be deduced that

A an atom has electrons orbiting around the nucleus.

B the nucleus is made up of neutrons and protons.

C an atom has a positively charged core.

D an atom has equal number of protons and electrons.

C

[PJC 2012]

21 A stationary nucleus of thorium (A = 220, Z = 90) emits an α particle of kinetic energy E. What is the ratio of the kinetic energy of the daughter nucleus to the α particle?

A $\dfrac{1}{110}$ **B** $\dfrac{1}{108}$ **C** $\dfrac{1}{55}$ **D** $\dfrac{1}{54}$

D

By conservation of mass number, the daughter nucleus D should have mass number 216.

Applying conservation of momentum,

$$m_D v_D = m_\alpha v_\alpha$$

$$216u \times v_D = 4u \times v_\alpha$$

$$v_D = \frac{4}{216} \times v_\alpha$$

Therefore, ratio of kinetic energies

$$= \frac{\frac{1}{2}m_D v_D^{\ 2}}{\frac{1}{2}m_\alpha v_\alpha^{\ 2}}$$

$$= \frac{216u \times \left(\frac{4}{216}\right)^2 \times v_\alpha^{\ 2}}{4u \times v_\alpha^{\ 2}}$$

$$= \frac{1}{54}$$

[PJC 2012]

22 Light of wavelength 450 nm is incident on a metal surface. The most energetic electrons ejected from the metal surface are undeflected as they pass through a region of mutually perpendicular magnetic and electric fields of strength 2.0×10^{-3} T and 1400 V m^{-1}, respectively.
What is the work function energy of the metal?

A 2.2×10^{-19} J **B** 4.4×10^{-19} J **C** 6.6×10^{-19} J **D** 8.8×10^{-19} J

A

As electron passes through undeflected, net force acting on it is zero.

$$F_E = F_B$$

$$qE = Bqv$$

$$v = \frac{E}{B}$$

Considering energy of a photon,

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

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

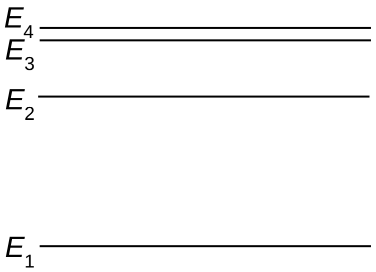
$$= \frac{hc}{\lambda} - \frac{1}{2}mv^2$$

$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{450\times10^{-9}} - \frac{1}{2}(9.11\times10^{-31})\left(\frac{1400}{2.0\times10^{-3}}\right)^2$$

$$= 2.2\times10^{-19} \text{ J}$$

[RI 2012]

23 The figure, drawn to scale, represents the energy levels for a certain atom.



Transitions from E_3 to E_1 give rise to the emission of green light.
Which transition could give rise to red light?

A E_4 to E_2 **B** E_4 to E_3 **C** E_3 to E_2 **D** E_2 to E_1

D

$\lambda_{red} > \lambda_{green}$

$f_{red} < f_{green} \quad (\because c = f\lambda)$

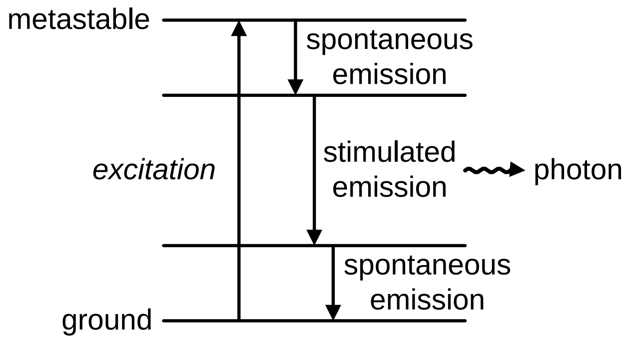
$E_{red} < E_{green} \quad (\because E = hf)$

Since wavelength of red light ≈ wavelength of green light, the difference in energy of a photon of red and green light will be small.

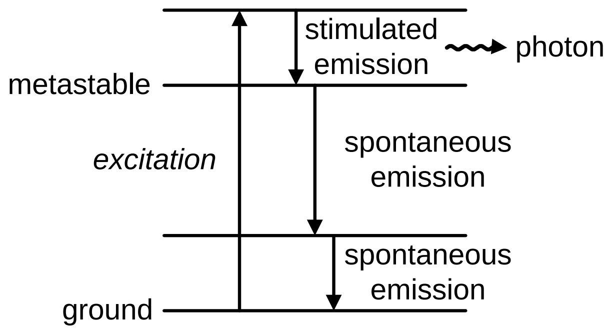
[RI 2012]

24 Which energy level diagram shows possible transitions in the production of laser light?

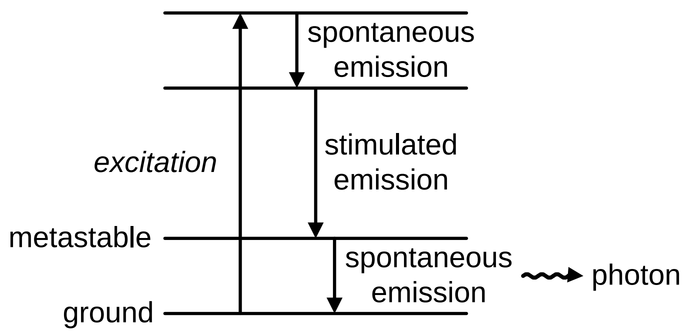
A



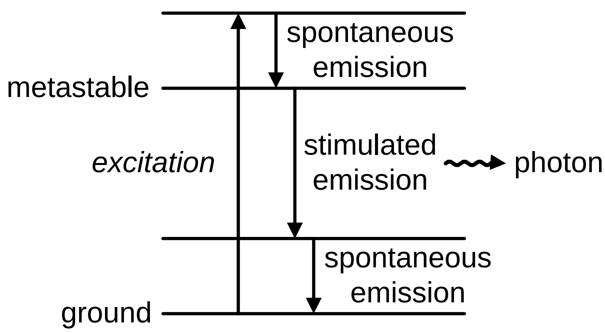
B



C



D



D
Electrons on the metastable state will most likely undergo stimulated emission.

[RI 2012]

25 An electron is incident on a rectangular potential barrier with a kinetic energy of 2.0 eV. The barrier height is 6.0 eV and its width is $d = 1.0 \times 10^{-10}$ m. If the width of the barrier is reduced to d' and the transmission coefficient is doubled, the ratio $\frac{d'}{d}$ is

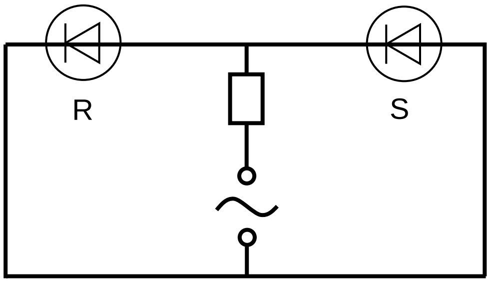
A 0.50 **B** 0.66 **C** 0.72 **D** 2.0

B

$$T = e^{-2kd}$$
$$T' = e^{-2kd'}$$
$$\frac{T'}{T} = \frac{e^{-2kd'}}{e^{-2kd}} = e^{2k(d-d')}$$
$$2k(d-d') = \ln\frac{T'}{T}$$
$$d - d' = \frac{1}{2k}\ln\frac{T'}{t}$$
$$1 - \frac{d'}{d} = \frac{1}{2kd}\ln\frac{T'}{T}$$
$$\frac{d'}{d} = 1 - \frac{1}{2kd}\ln\frac{T'}{T}$$
$$= 1 - \frac{6.63\times10^{-34}}{2\sqrt{8\pi^2(9.11\times10^{-31})(6.0-2.0)(1.60\times10^{-19})}}\ln 2$$
$$= 0.66$$

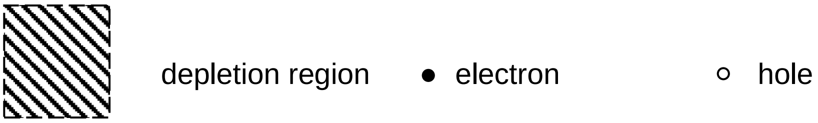
[RVHS 2012]

26 Two diodes, R and S, are connected to an alternating source as shown below.

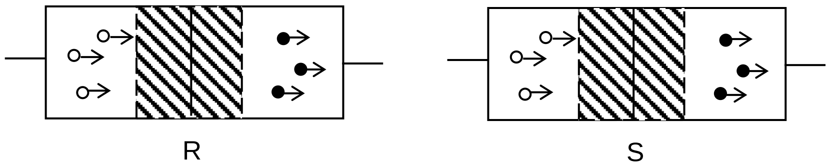


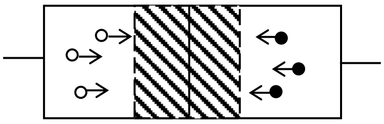
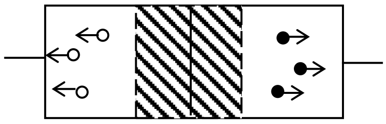
Which of the following shows a possible movement of charges in the two diodes at a particular instant in time?

Legend:

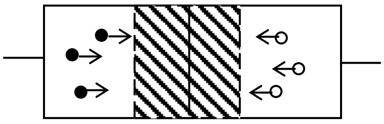
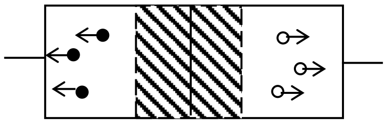


A

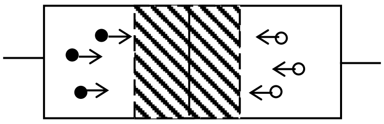
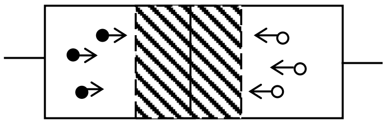


B  

R S

C  

R S

D  

R S

C
Electrons will move towards the region at a higher potential and holes will move towards the region at a lower potential.

[RVHS 2012]

27 In a cancer therapy unit, patients are given treatment from a certain radioactive source. This source has a half-life of 4 years. A particular treatment requires 10 minutes of irradiation when the source is first used.
How much time is required for this treatment, using the same source, 2 years later?

A 7 minutes **B** 10 minutes **C** 14 minutes **D** 20 minutes

C

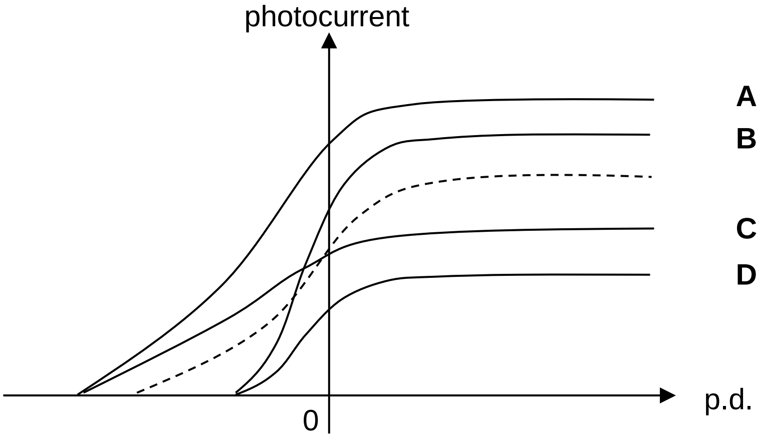
$$A = A_0 e^{-\lambda t}$$
$$= A_0 e^{-\left(\frac{\ln 2}{4}\right)(2)}$$
$$= \frac{A_0}{\sqrt{2}}$$

Time required, *t'*,

$$A_0 t = A t'$$
$$t' = \frac{A_0}{A} t$$
$$= \sqrt{2} t$$
$$= \sqrt{2}(10)$$
$$= 14 \text{ minutes}$$

[RVHS 2012]

28 A metal surface in an evacuated tube is illuminated with *orange* light, causing the emission of photo-electrons which are collected at an adjacent electrode. For a given intensity of light, the way in which the photocurrent depends on the p.d. between the electrodes is as shown by the dotted graph.
Which graph is obtained if the experiment is repeated with *green* light of the same intensity?



C

$\lambda_{green} < \lambda_{orange}$

$f_{green} > f_{orange}$ $(\because c = f\lambda)$

$E = \phi + eV_s$

$V_{s,green} > V_{s,orange}$

$I = \dfrac{P}{A}$

$= \dfrac{Nhf}{At}$

For the same intensity,

$N_{green} f_{green} = N_{orange} f_{orange}$

$N_{green} < N_{orange}$ $(\because f_{green} > f_{orange})$

$I_{green} < I_{orange}$

[SAJC 2012]

29 In order to trace the line of a water-pipe buried 0.4 m below the surface of a field, an engineer wishes to add a radioactive isotope to the water. Which sort of isotope should be chosen?

	emitter	half-life
A	β	a few hours
B	β	several years
C	γ	a few hours
D	γ	several years

C

γ ray can penetrate 0.4 m of field and the half life must be short such that there is measurable activity within a few hours.

[SAJC 2012]

30 A surface is bombarded normally by photons of frequency *f*. On average, *n* photons strike a unit area of the surface each second.
Assuming that the photons are absorbed by the surface, what is the pressure exerted on the

surface? (h is the Planck constant, c is the speed of light)

A $2nhf$ **B** $2nhf$ / c **C** nhf / c **D** nf

C

$$\text{pressure} = \frac{F}{A} = \frac{\Delta p}{At} = \frac{n(p-0)}{(1)(1)} = n\left(\frac{h}{\lambda}\right) = \frac{nhf}{c}$$

[TPJC 2012]

31 The probing tip of a Scanning Tunnelling Microscope is placed at a height x above a metal surface. The probability that an electron will tunnel through the gap between the tip and the surface is 8.5×10^{-15}.
What is the probability of the same electron **not** tunnelling through the barrier when the height of the gap is increased to 1.5x?
(Assume that the potential difference between the tip and surface remains constant)

A 0 **B** 4.2×10^{-10} **C** 7.8×10^{-22} **D** 1

D

$T = e^{-2kd}$

When the height gap is increased, the probability of tunnelling through will be smaller than 8.5×10^{-15} and the probability of not tunnelling through will be very close to 1.

[TPJC 2012]

32 Data for the α-decay of bismuth-212 ($^{212}_{83}\text{Bi}$) to form thallium-208 ($^{208}_{81}\text{Tl}$) are given in the table below.

Nucleus	mass of nucleus / u
bismuth-212	211.9459
thallium-208	207.9374
helium-4	4.0015

Which one of the following statements is true for this radioactive decay?

A There is 7.0×10^{-3} u of mass loss and 7.3×10^{-11} eV of energy is released.

B There is 7.0×10^{-3} u of mass loss and 7.3×10^{-11} eV of energy is absorbed.

C There is 7.0×10^{-3} u of mass loss and 6.5 MeV of energy is released.

D There is 7.0×10^{-3} u of mass loss and 6.5 MeV of energy is absorbed.

C

$^{212}_{83}\text{Bi} \rightarrow {}^{208}_{81}\text{Tl} + {}^{4}_{2}\text{He}$

$$\text{rest mass of product} = 211.9459 \text{ u}$$

$$\text{rest mass of reactant} = (207.9374 + 4.0015) \text{ u} = 211.9389 \text{ u}$$

$$\Delta\text{rest mass} = (211.9389 - 211.9459) \text{ u} = -0.007 \text{ u}$$

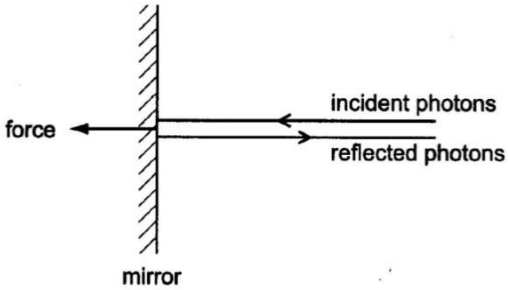
There is 7.0×10^{-3} u of mass loss.

$$\begin{aligned}\Delta\text{rest mass energy} &= -0.007\ \text{uc}^2 \\ &= -0.007\left(1.66\times10^{-27}\right)\left(3.00\times10^{8}\right)^2 \\ &= -1.0458\times10^{-12} \\ &= -6.5\ \text{MeV}\end{aligned}$$

6.5 MeV of energy is released.

[TPJC 2012]

33 Photons strike a mirror normally and are reflected back along their initial path. The change in momentum of the photons as they are reflected from the mirror causes a small force to act on the mirror, as shown in the diagram.



The wavelength of the photons is halved and the intensity of the photon beam remains the same. Which quantity is halved?

A The energy of each photon striking the mirror.

B The number of photons striking the mirror each second.

C The momentum of each photon striking the mirror.

D The force acting on the mirror.

B

The intensity of the beam is given by

$$\text{Intensity} = \frac{\text{total energy of all photons hitting mirror per unit time}}{\text{cross-sectional area of beam}}$$

$I = \dfrac{nhf}{A}$, where n = no. of photons hitting mirror per unit time.

$$I = \frac{nhc}{A\lambda}$$

Hence, if wavelength λ is halved while intensity I remains constant, the number of photons hitting the mirror per unit time (n) must also be halved. Hence, B is the correct statement.

The energy of each photon is given by $E = hf = \dfrac{hc}{\lambda}$. Hence, if the wavelength is halved, the energy per photon will be doubled. Hence, (A) is wrong.

The momentum of each photon is given by de Broglie's relation $p = \dfrac{h}{\lambda}$. Hence, if the wavelength is halved, the momentum of each photon will be doubled. Hence, C is wrong.

If p is the momentum of each photon, then the change in momentum of each photon as it rebounds from the mirror is $\Delta p = p_f - p_i = +p - (-p) = 2p$.

Since the momentum of each photon is doubled if its wavelength is halved, this means that the force exerted by each photon on the mirror will be doubled. However, from the first paragraph above, we concluded that the number of photons hitting the mirror per unit time, n, has halved. Hence, the force on the mirror will remain constant, since p has doubled but n has halved. Hence, D is wrong.

[VJC 2012]

34 In a X-ray tube, electrons of high energy E are incident on a target of tungsten.
Which of the following three statements are correct?

(i) All the energy of the electrons is converted into X-rays.

(ii) The maximum X-ray wavelength obtained is $\frac{hc}{E}$.

(iii) The wavelengths of the characteristic X-ray spectral lines are independent of the potential difference applied to accelerate the electrons.

A (ii) only **B** (iii) only **C** (i) and (ii) only **D** (ii) and (iii) only

B

Statement (i) is wrong. Most of the energy goes towards heating the metal target. Statement (ii) is wrong. "hc/E" is the **minimum** wavelength. Only statement (iii) is correct. The wavelengths of the characteristic X-ray spectral lines depend on the material used to make the target (and not the potential difference applied to accelerate the electrons).

[VJC 2012]

35 $^{232}_{90}Th$ decays via a series of α, β, and γ decays to the stable isotope $^{208}_{82}Pb$.
Which row describes what can be deduced about the numbers of each decay type?

	number of α decays	number of β decays	number of γ decays
A	6	4	cannot tell
B	6	cannot tell	4
C	cannot tell	6	6
D	cannot tell	cannot tell	cannot tell

A

The nucleon number drops by 24 from 232 to 208, which indicates that 6 α-particles must have been emitted.

The proton number would have dropped by 12 from 90 to 78. However, the final proton number is 82, which means 4 β particles must have been emitted also.

γ particles EM photons, and it is not possible to tell how many photons are emitted in the process.

[AJC 2013]

36 In an alpha-particle scattering experiment, which factors could be increased so as to increase the number of alpha-particles scattered through large angles by a thin metal foil?

1 alpha-particle energy
2 thickness of foil
3 the atomic number of the metal of the foil

A 1 and 2 **B** 1 and 3 **C** 2 only **D** 2 and 3

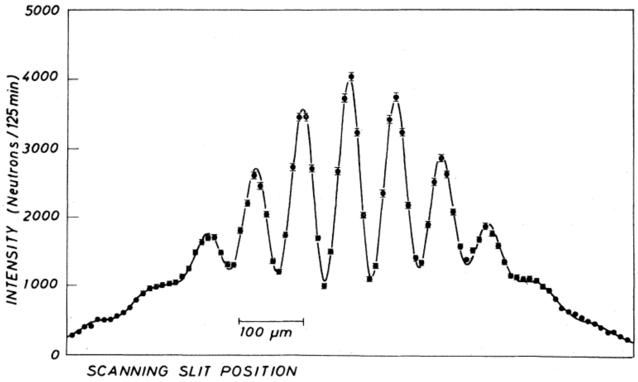
D

Large angle α-particle scattering is dependent on the target, and if the target nucleus has more protons (more positively charged) or if the target foil is thicker, more α-particles will be scattered at large angles.

If the energy of the α-particles is increased, less α-particles will be scattered at large angles

[AJC 2013]

37 Figure below shows the experimental results of a double-slit experiment done using neutrons.



Double-slit interference pattern made with neutrons.

If C_{60} molecules (each of mass 720 times that of a neutron) with the same kinetic energies of the neutrons are used to do the experiment in the same experimental condition, the fringe spacing will

A increase by 720 times.
B increase by $\sqrt{720}$ times.
C decrease by 720 times.
D decrease by $\sqrt{720}$ times.

D

From $E = \dfrac{p^2}{2m}$

$$p = \sqrt{2mE}$$

Using $\lambda = \dfrac{h}{p}$

$$= \frac{h}{\sqrt{2mE}}$$

$$\therefore \lambda \propto \frac{1}{\sqrt{m}}$$

The fringe spacing Δx for double-slit experiment is proportional to λ, thus

$$\Delta x \propto \frac{1}{\sqrt{m}}$$

$$\frac{(\Delta x)_{C_{60}}}{(\Delta x)_n} = \sqrt{\frac{m_n}{m_{C_{60}}}}$$

$$= \frac{1}{\sqrt{720}}$$

[HCI 2013]

38 An isotope of carbon, ^{14}C is unstable and decays by β-emission with a half-life of 5740 years. Two archeological samples of organic matter were found at a site. The number of ^{14}C in one sample is greater than the other by a factor of 16. The difference in age (in years) between the two samples is

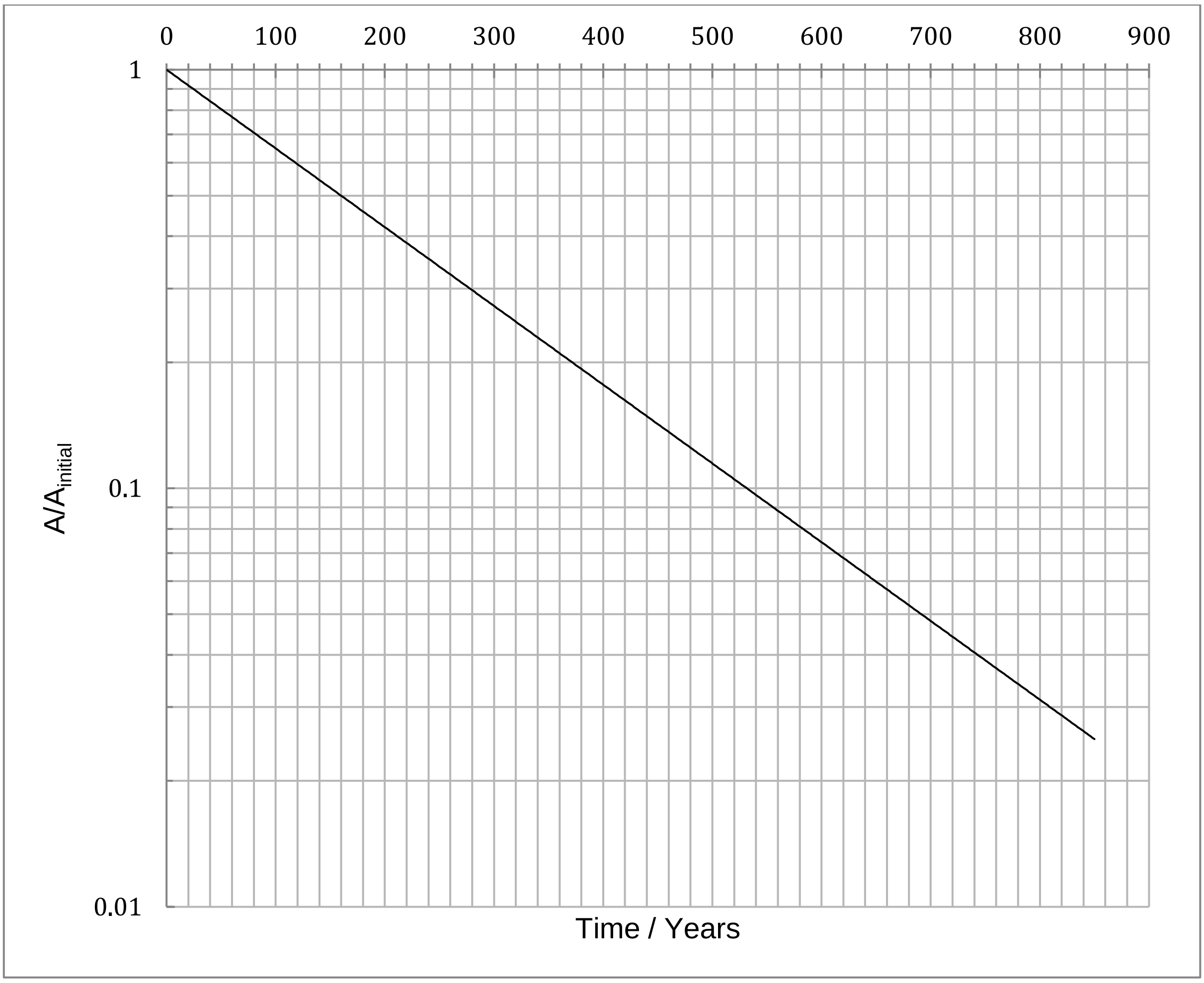
A 1 913 **B** 17 220 **C** 22 960 **D** 45 920

C

Ratio of one sample is greater than the other by a factor of 16 (i.e. 2^4). One sample has decayed 4 more half-lives. The difference in age between the two samples is 4×5740 = 22 960 years

[MJC 2013]

39 A radioactive source has activity, A, and initial activity $A_{initial}$. A graph of $\frac{A}{A_{initial}}$ against time for this radioactive source is plotted on a logarithmic scale as shown below.



What is the half- life of the source in years?

A 0.0017 **B** 160 **C** 280 **D** 420

B

From graph, when $\frac{A}{A_{initial}} = 0.5$, time $=$ 160 years.

[NJC 2013]

40 When electrons of energy E are incident on a pair of narrow slits 0.0600 μm apart, the bright bands in the interference pattern are separated by 0.400 mm on a screen 20.0 cm from the slits.
What is the value of E?

A 0.136 eV **B** 41.4 eV **C** 105 eV **D** 10400 eV

C

$$\lambda = \frac{ax}{D}$$
$$\frac{h}{p} = \frac{ax}{D}$$
$$\frac{h}{\sqrt{2mE}} = \frac{ax}{D}$$
$$E = \frac{1}{2m}\left(\frac{hD}{ax}\right)^2$$
$$= \frac{1}{2\left(9.11\times10^{-31}\right)}\left[\frac{\left(6.63\times10^{-34}\right)\left(20.0\times10^{-2}\right)}{\left(0.0600\times10^{-6}\right)\left(0.400\times10^{-3}\right)}\right]^2$$
$$= 1.68\times10^{-17}\text{ J}$$
$$= 105\text{ eV}$$

[RIJC 2013]

41 In 2010 the Japanese launched the world's first interplanetary solar sail spacecraft, called IKAROS. This works because photons reflected from the sail, of area *A*, undergo a change of momentum and, by Newton's third Law, exert a forward force on the sail.

A beam of light of intensity I is reflected at right angles to a solar sail. The momentum of a photon is given by the expression $\frac{hf}{c}$, where *f* is the frequency of the light, *h* is the Planck constant and *c* is the speed of light. What is the force exerted on the sail?

A $\frac{IA}{hf}$ **B** $\frac{2hf}{c}$ **C** $\frac{2IA}{c}$ **D** $\frac{I}{c}$

C

$$P = IA \rightarrow \frac{nhf}{t} = IA \rightarrow \frac{n}{t} = \frac{IA}{hf}$$
$$F = \frac{\Delta p}{t} = \frac{n\left[\frac{hf}{c} - \left(-\frac{hf}{c}\right)\right]}{t}$$
$$F = \frac{2n}{t}\frac{hf}{c} = \frac{2IA}{hf}\frac{hf}{c} = \frac{2IA}{c}$$

[AJC 2015]

42 The resistance of a piece of pure silicon falls as the temperature rises.

Which of the following statements is true?

A The ratio of the positive to negative charge carriers increases.

B The ratio of the positive to negative charge carriers decreases.

C The charge carriers can move more easily at a higher temperature.

D The total number of charge carriers increases with temperature.

D

For intrinsic semiconductors, the ratio of charge carriers is always 1 since electrons that are excited from the conduction band always leaves a hole in the valance band.

At higher temperatures, lattice ions vibrate more vigorously and may collide more often with the charge carriers, representing a rise in the resistance.

[AJC 2015]

43 In an experiment to learn more about the structure of the atom, Geiger and Marsden fired α-particles at a thin sheet of gold foil. They found that most of the α-particles passed through the gold foil with no significant deviation, although a very tiny minority were deflected through large angles, and some were even back-scattered (deflected by more than 90°).

The experiment is repeated with a foil made from a heavier isotope of gold.

How would the results be different?

A A much greater proportion of the α-particles would be back-scattered.

B A much greater proportion of the α-particles would deflect through a large angle.

C A greater proportion of the α-particles would pass through with no significant deviation.

D There would be no significant change.

D

Back scattering and large angle scattering is due to the positive charge in the gold nucleus. Since the charge of the nucleus is constant, the scattering will not change. Thus A, B & C is incorrect.

[AJC 2015]

44 The activity of a radioactive sample is monitored by using a GM detector. At 1:30 pm, a count-rate of 562 counts per min (cpm) is registered. The count-rate falls to 163 cpm half an hour later, at 2:00 pm. Background radiation contributes a count-rate of 30 cpm.

Calculate the count-rate at 1:00 pm.

A 2158 cpm **B** 2128 cpm **C** 1968 cpm **D** 1938 cpm

A

$C = C_0 e^{-\lambda t}$

$C_{2.00} = C_{1.00} e^{-\lambda(60)} = C_{1.30} e^{-\lambda(30)}$

After deducting background count, the following 2 equations are obtained.

$133 = C_{1.00}\, e^{-\lambda(60)}$ – (i)

$133 = 532\, e^{-\lambda(30)}$ – (ii)

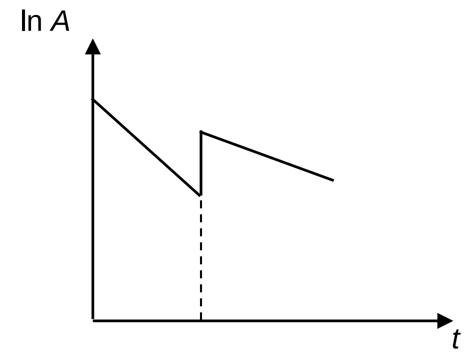
Solving (i) and (ii), $C_{1.00}$ = 2128 cpm

Adding background count, detected count-rate = 2158 cpm

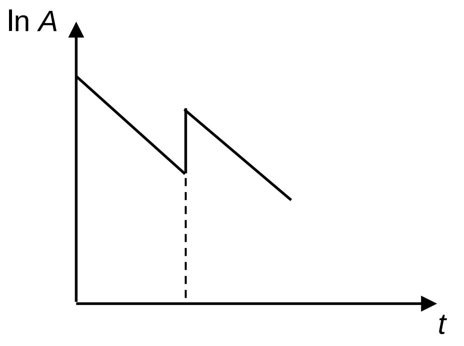
[HCI 2015]

45 At time t = 0, some radioactive gas is injected into a sealed vessel. At time T, a different radioactive gas with a half-life very much shorter than the first is injected into the same vessel.

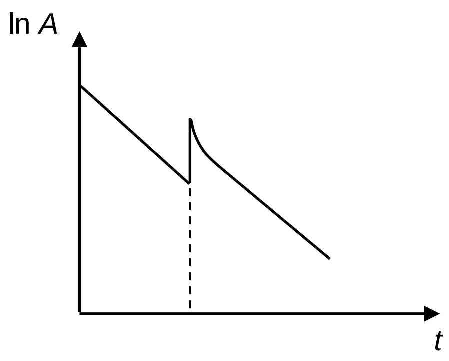
Which one of the following graphs best represents how activity A varies with t?



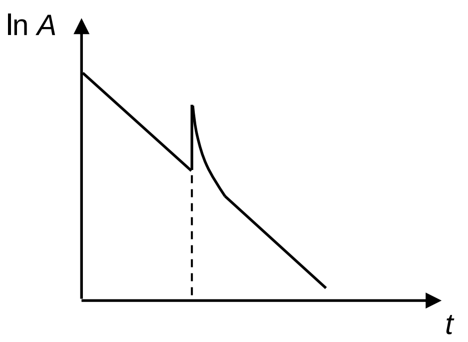
A



B



C

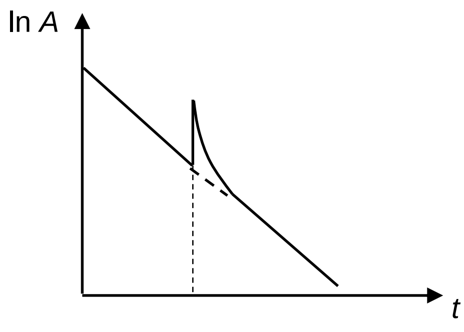


D

D $A = A_0 e^{-\lambda t}$

ln A = ln A_0 – λt

The curved part comes about because of two difference decay constants. Since the added gas has a much shorter half-life, the gradient of the graph should eventually return to the original gradient, and "continue" from where the original "left off".



[HCI 2015]

46 The work function of a metal is 2.7 eV. Electromagnetic radiation of frequencies ranging from 1.0×10^{14} Hz to 9.0×10^{14} Hz is incident on the surface of the metal.

What is the maximum kinetic energy of the electrons ejected from the surface of the metal?

A 1.0 eV **B** 2.3 eV **C** 3.1 eV **D** 6.4 eV

MCQ 37: A

Most energetic photon = $(6.63 \times 10^{-34})(9.0 \times 10^{14}) = 5.967 \times 10^{-19}$ J = 3.73 eV

$hf = \Phi + E_{Kmax}$
$E_{Kmax} = 3.73 - 2.7 = 1.0$ eV

[MJC 2015]

47 A radioactive source contains two species. One has a half-life of 4 days and decays by the emission of alpha particles whilst the other has a half-life of 3 days and emits beta particles. The initial count-rate is 352 min^{-1}, but when a sheet of paper is placed between the source and the detector this becomes 256 min^{-1}. The background count-rate is 16 min^{-1}. What will be the count-rate after 12 days, without the paper present?

A 27 min^{-1} **B** 28 min^{-1} **C** 43 min^{-1} **D** 44 min^{-1}

C
Paper stops alpha particles, so
$\alpha + \beta + background = 352\text{min}^{-1}$
$\beta + background = 256\text{min}^{-1}$
Initial count of beta particle source = 256-16=240min^{-1}
Initial count of alpha particle source = 352-256=96min^{-1}
After 12 days, alpha particle source undergo 3 half-lives and beta particle source undergo 4 half-lives
Final count of alpha particle source=$\frac{96}{2^3} = 12min^{-1}$
Final count of beta particle source=$\frac{240}{2^4} = 15min^{-1}$
Total count = 12+15+16=43min^{-1}

[NJC 2015]

Short structured questions

1 **(a)** In a fission process a neutron collides with a uranium-235 nucleus and causes a nuclear reaction summarised by the following equation.

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \rightarrow ^{P}_{Q}\text{X} \rightarrow ^{R}_{54}\text{Xe} + ^{90}_{38}\text{Sr} + 3^{1}_{0}\text{n} + \text{energy}$$

(i) Determine the numerical values of P, Q and R.

$P = 1 + 235$ $Q = 0 + 92$ $R + 90 + 3(1) = 236$
$= 236$ $= 92$ $R = 143$

P = ……………………………
Q = ……………………………
R = …………………………… [2]

(ii) State the feature of this equation that indicates that a chain reaction may be possible. [1]
More neutrons are produced than are required to cause the reaction

(b) In a laboratory source of strontium-90, the number of atoms present in the year 2013 is 2.36×10^{13}. Strontium-90 decays by emission of a β particle and this decay has a half-life of 28 years.
Calculate the activity of the source in the year 2113.

$$
\begin{aligned}
A &= \lambda N \\
&= \lambda N_0 e^{-\lambda t} \\
&= \frac{\ln 2}{t_{1/2}} N_0 e^{-\lambda t} \\
&= \frac{\ln 2}{28(365 \times 24 \times 60 \times 60)} \left(2.36 \times 10^{13}\right) e^{-\left(\frac{\ln 2}{28}\right)(100)} \\
&= 1.56 \times 10^{3} \text{ s}^{-1}
\end{aligned}
$$

activity = ... s^{-1} [2]

[AJC 2013]

2 Strontium-90 decays with the emission of a β-particle to form Yttrium-90. The reaction is represented by the equation

$$ {}^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\text{e} + 0.55 \text{ MeV} $$

The half-life of Strontium-90 is 27.7 years

(a) Suggest, with a reason, which nucleus ${}^{90}_{38}\text{Sr}$ or ${}^{90}_{39}\text{Y}$ has a greater binding energy. [2]

${}^{90}_{39}\text{Y}$ has a greater binding energy. The nuclide with greater binding energy gives rise to release of energy.

(b) Define *half-life.* [1]

The average time taken for the number of nuclei of that particular radioactive nuclide to decay to half of its original value.

(c) At the time of purchase of a Strontium-90 source, the activity is 3.7 × 10^6 Bq.

(i) Calculate, for this sample of strontium,

1. the initial number of atoms,

$$
\begin{aligned}
A &= \lambda N \\
N &= \frac{A}{\lambda} \\
&= \frac{A t_{1/2}}{0.693} \\
&= \frac{\left(3.7 \times 10^{6}\right)\left(27.7 \times 365 \times 24 \times 60 \times 60\right)}{0.693} \\
&= 4.66 \times 10^{15}
\end{aligned}
$$

initial number = ... [2]

2. the initial mass.

$$
\begin{aligned}
m_0 &= \left(\frac{4.66 \times 10^{15}}{6.02 \times 10^{23}}\right)\left(90 \times 10^{-3}\right) \\
&= 6.97 \times 10^{-10} \text{ kg}
\end{aligned}
$$

initial mass = ...kg [2]

(ii) Determine $\frac{A}{A_o}$, where A is the activity of the sample 5.0 years after purchase and A_o is the initial activity.

$$A = A_0 e^{-\lambda t}$$

$$\frac{A}{A_0} = e^{-\lambda t}$$

$$= e^{-\left(\frac{0.693}{27.7}\right)(5.0)}$$

$$= 0.882$$

$\frac{A}{A_o}$ = ... [2]

[DHS 2013]

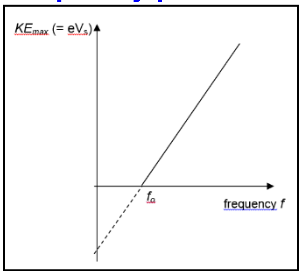
3 **(a)** **(i)** Explain what is meant by the photoelectric effect. [1]

A phenomenon in which electrons are emitted from a metal surface when electromagnetic radiation of sufficiently high frequency is incident on the metal surface.

(ii) Discuss one piece of evidence that photoelectric effect provides for the particulate nature of light. Draw a relevant sketched graph if necessary to illustrate your answer. [3]

Answer to address how particulate theory of light manages to address the following problems:

Frequency problem

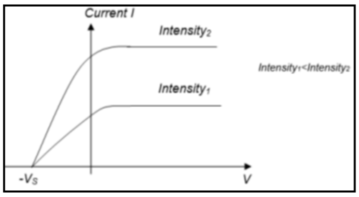


Observation: As frequency of light is varied, it is found that no electrons emitted below the threshold frequency f_o, which cannot be explained by wave theory.

Explanation: Particulate theory of light suggests that light exists in packets of energy called photons and the energy carried by each photon is E = Planck's constant $\times$ frequency(hf).

If the energy of the photon is below the work function of metal (hf_o), no photoelectric effect can take place.

Intensity problem



Observation: Increasing intensity of light did not change the stopping potential, or the maximum KE of the photoelectrons emitted.

Explanation: Increasing intensity while using light of the same frequency, f merely increases the rate of arrival of photons; without increasing the energy carried by each photon (E = hf). Therefore the maximum KE that a photoelectron can acquire will not change with intensity.

Time delay problem
Observation: At very low intensity of incident light, there is no time delay in the emission of photoelectrons, which was expected by the wave theory for the metal surface to absorb sufficient energy before photoelectrons would be emitted.
Explanation: Low light intensity simply means less photons bombard the metal surface per unit time, photoelectrons will still be emitted immediately when each absorbed a photon of a frequency higher than the threshold frequency.

(b) In an experiment, a monochromatic point source of electromagnetic radiation with power 22.0 W emits radiation of wavelength 480 nm uniformly in all directions. A metal plate with a small surface area of 4.00 mm^2 faces the source directly and is placed 25.0 cm away from the source. Electrons are emitted from the metal surface.

At this wavelength, only a fraction of the incident photons succeeds in ejecting a photoelectron from the metal. All the photoelectrons are collected and the current detected is 4.50 μA.

(i) Show that the power of the radiation incident on the metal plate is 1.12×10^{-4} W.

$$\text{Intensity at the plate} = \frac{\text{power of source}}{\text{spherical surface at 25 cm away from source}}$$

$$= \frac{22.0}{4\pi\left(25.0\times10^{-2}\right)^2}\ \text{W m}^{-2}$$

$$\text{Power at the plate} = \text{Area of plate} \times \text{intensity}$$

$$= 4.00\left[\frac{22.0}{4\pi\left(25.0\times10^{-2}\right)^2}\right]$$

$$= 1.12\times10^{-4}\ \text{W}\ \text{(shown)}$$

[2]

(ii) The quantum efficiency, η, is defined as the fraction of photons that results in successful emission of photoelectrons:

$$\eta = \frac{\text{Rate at which photo-electrons are emitted}}{\text{Rate at which photons arrived at metal surface}} \times 100\%$$

Estimate the quantum efficiency for this photoelectric experiment.

$$\text{Energy of a photon} = \frac{hc}{\lambda}$$

$$= \frac{\left(6.63\times10^{-34}\right)\left(3.00\times10^{8}\right)}{480\times10^{-9}}$$

$$= 4.14\times10^{-19}\ \text{J}$$

$$\text{Number of photons incident per unit time} = \frac{P}{E}$$

$$= \frac{1.12\times10^{-4}}{4.14\times10^{-19}}$$

$$= 2.70\times10^{14}\ \text{s}^{-1}$$

$$\text{Number of photoelectrons emitted per unit time} = \frac{\text{photocurrent}}{\text{elementary charge}}$$
$$= \frac{4.50\times10^{-6}}{1.60\times10^{-19}}$$
$$= 2.81\times10^{13}\ \text{s}^{-1}$$

$$\eta = \frac{2.81\times10^{13}}{2.70\times10^{14}}\times100\%$$
$$= 0.104$$
$$= 10.4\%$$

$\eta =$ .... % [4]

[HCI 2013]

4 **(a)** In a nuclear reaction, a Uranium-235 ($^{235}_{92}\text{U}$) nuclide is transformed into an unstable Uranium-236 ($^{236}_{92}\text{U}$) nuclide through bombardment by a slow moving neutron. The unstable Uranium-236 nuclide undergoes nuclear fission to form stable products of a Lathium-139 ($^{139}_{57}\text{La}$) nuclide and a Bromine-94 ($^{94}_{35}\text{Br}$) nuclide

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{236}_{92}\text{U} \rightarrow {}^{139}_{57}\text{La} + {}^{94}_{35}\text{Br} + 3\,{}^{1}_{0}\text{n} + \gamma$$

Rest mass of $^{235}_{92}\text{U}$ nuclide $= 235.044\ u$,
Rest mass of proton $= 1.00728\ u$,
Rest mass of neutron $= 1.00866\ u$

(i) Calculate the binding energy of $^{235}_{92}\text{U}$.

Binding energy of $^{235}_{92}\text{U}$

$= (\text{mass defect})c^2$

$= [92(1.00728) + (235-92)(1.00866) - 235.044](1.66\times10^{-27})(3.00\times10^{8})^2$

$= 2.79\times10^{-10}\ \text{J}$

$= 1740\ \text{MeV}$

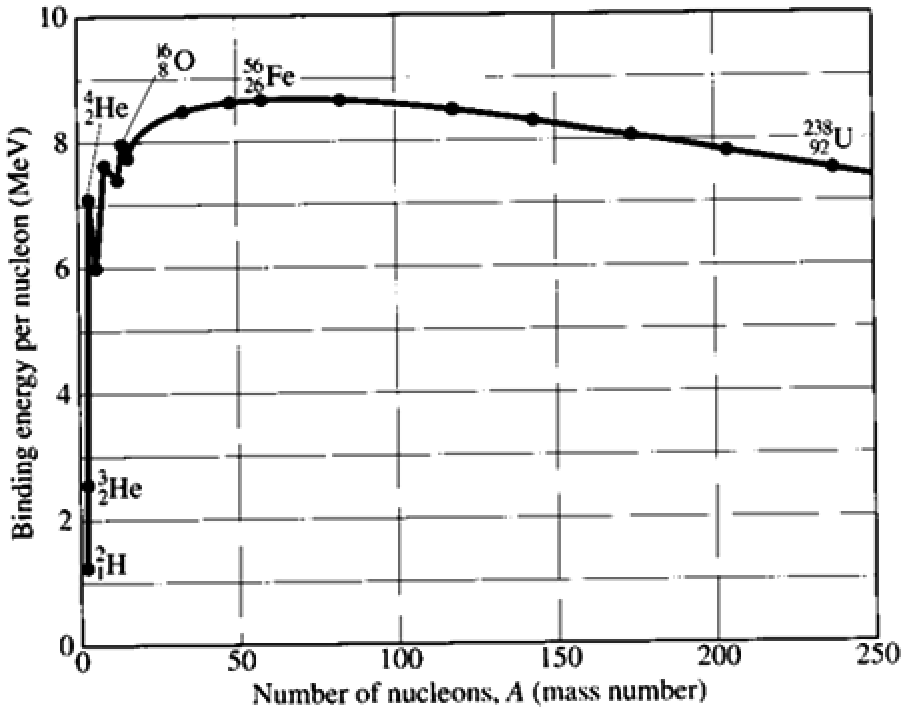
binding energy = ... MeV [2]

(ii) Given that the binding energy per nucleon of $^{139}_{57}\text{La}$ is 8.1893 MeV and the energy released in the above reaction is 197 MeV, determine the mass of $^{94}_{35}\text{Br}$, in terms of *u*.

$$\text{Energy released in reaction} = \text{BE}_{\text{La}} + \text{BE}_{\text{Br}} - \text{BE}_{\text{U}}$$
$$\text{BE}_{\text{Br}} = 197 - 8.1893(139) + 1740$$
$$= 799.7\ \text{MeV}$$
$$\text{BE}_{\text{Br}} = (\text{mass defect})c^2$$
$$(799.7\times10^{6})(1.60\times10^{-19}) = [35(1.00728) + (94-35)(1.00866) - m](1.66\times10^{-27})(3.00\times10^{8})^2$$
$$m = 93.9\ \text{u}$$

mass = ... *u* [3]

(b) **(i)** Sketch the graph showing the variation of binding energy per nucleon with nucleon number.



[2]

(ii) The $^{235}_{92}\text{U}$ nuclide can also decay by emitting an α-particle and a neutron to form an isotope of thorium, $^{230}_{90}\text{Th}$. Explain how the graph sketched in **(b)(i)** can help to deduce which nuclear process releases more energy. [1]

Multiply the binding energy per nucleon of each product nuclei with the nucleon number. Process with higher total binding energy of product nuclei releases more energy.

[DHS 2013]

5 X-rays are produced when electrons are accelerated through a potential difference towards a metal target such as tungsten. Fig. 5.1 shows a typical X-ray intensity spectrum that can be produced from an X-ray tube.

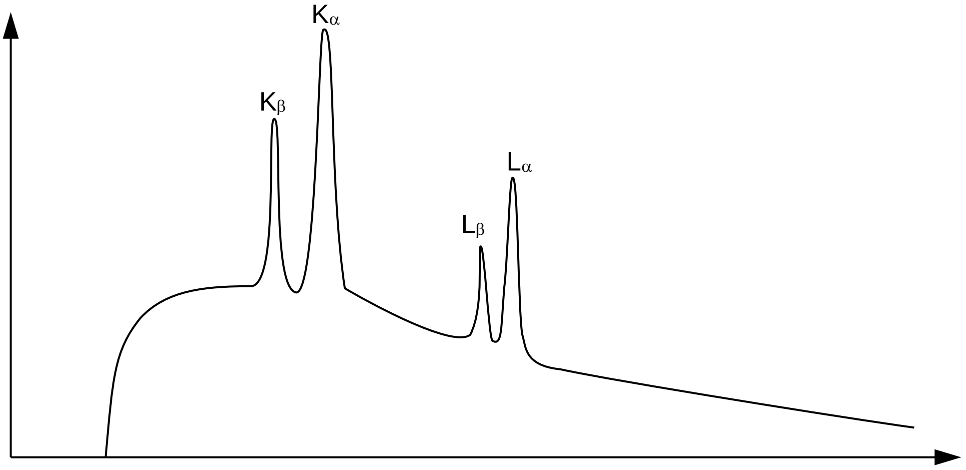


Fig. 5.1

Explain the following features of Fig. 5.1.

(a) characteristic lines [3]

The accelerated electrons first knock out/eject electrons out of one of the innermost shells of the target atom, leaving a vacancy/hole. An electron from a higher energy shell falls to fill the vacancy, hence emitting an x-ray photon of specific energy/frequency/wavelength. Since energy of photon is specific, it gives rise to the characteristic line.

The energy transitions are dependent on the set of discrete energy levels in a particular material. Since different materials have unique sets of discrete energy levels between the shells, the sharp peaks are therefore characteristic of the material.

(b) cutoff wavelength [1]
The cut-off wavelength corresponds to the most energetic photon that can be produced. That happens when all the kinetic energy of an accelerated electron is lost in a single collision/interaction with the target atom in producing one photon.

[AJC 2013]

6 Explain why population inversion and stimulated emission are necessary in the production of laser light. [4]
LASER is produced by stimulated emission. In stimulated emission, a photon incident on an excited atom emits two photons that are in phase and travel in the same direction with identical energy.
In order for the incident photons to result in stimulated emission, more atoms have to be in the higher energy state than in the lower one. This is called population inversion.
Incident photons can cause either stimulated absorption or stimulated emission. If there is no population inversion, incoming photons will be more likely absorbed to cause excitation rather than to result in stimulated emission.
The electrons need to remain in the metastable state (longer lifetime compared to usually short lifetime of excited states) so that stimulated emission is likely to occur before spontaneous emission.

[AJC 2013]

7 **(a)** The first four energy levels of a fictitious element X are shown in Fig. 7.1.

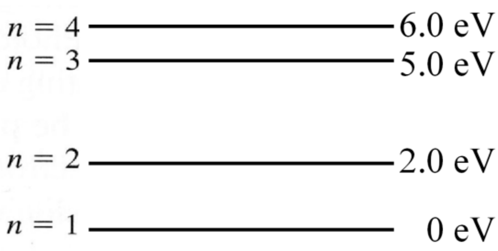


Fig. 7.1

Calculate the shortest wavelength observed in the absorption spectrum of cool atoms of element X.

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

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

For $n = 1 \rightarrow 4$,

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

$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{6.0(1.60 \times 10^{-19})}$$

$$= 2.1 \times 10^{-7} \text{ m}$$

shortest wavelength = ………………………….m [2]

(b) Spectra A and B in Fig. 7.2 below are both due to the fictitious element X.

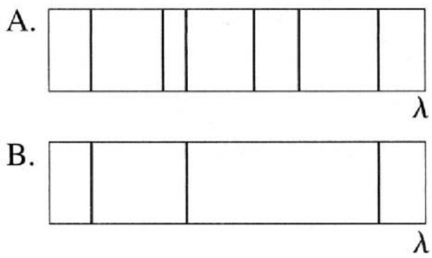


Fig. 7.2

(i) Identify which spectrum is an emission spectrum and which is an absorption spectrum. [1]

Spectrum A is the emission spectrum and B is the absorption spectrum.

(ii) Explain why the two spectra are different. [2]

Almost all the time, absorption transitions will start from the ground state, so the number of absorption lines are more limited and fewer than emission lines. On the other hand, there are many possible transitions for an excited atom to de-excite. So the emission lines are more numerous.

(iii) Explain how spectrum A shows that the energy levels in X are quantized. [2]

Line spectrum A has unique/discrete/quantized wavelengths.
These quantized wavelengths must come from quantized energy levels.

[IJC 2013]

8 Fig. 8.1 shows the current-voltage characteristic graph for an intrinsic semiconductor X.

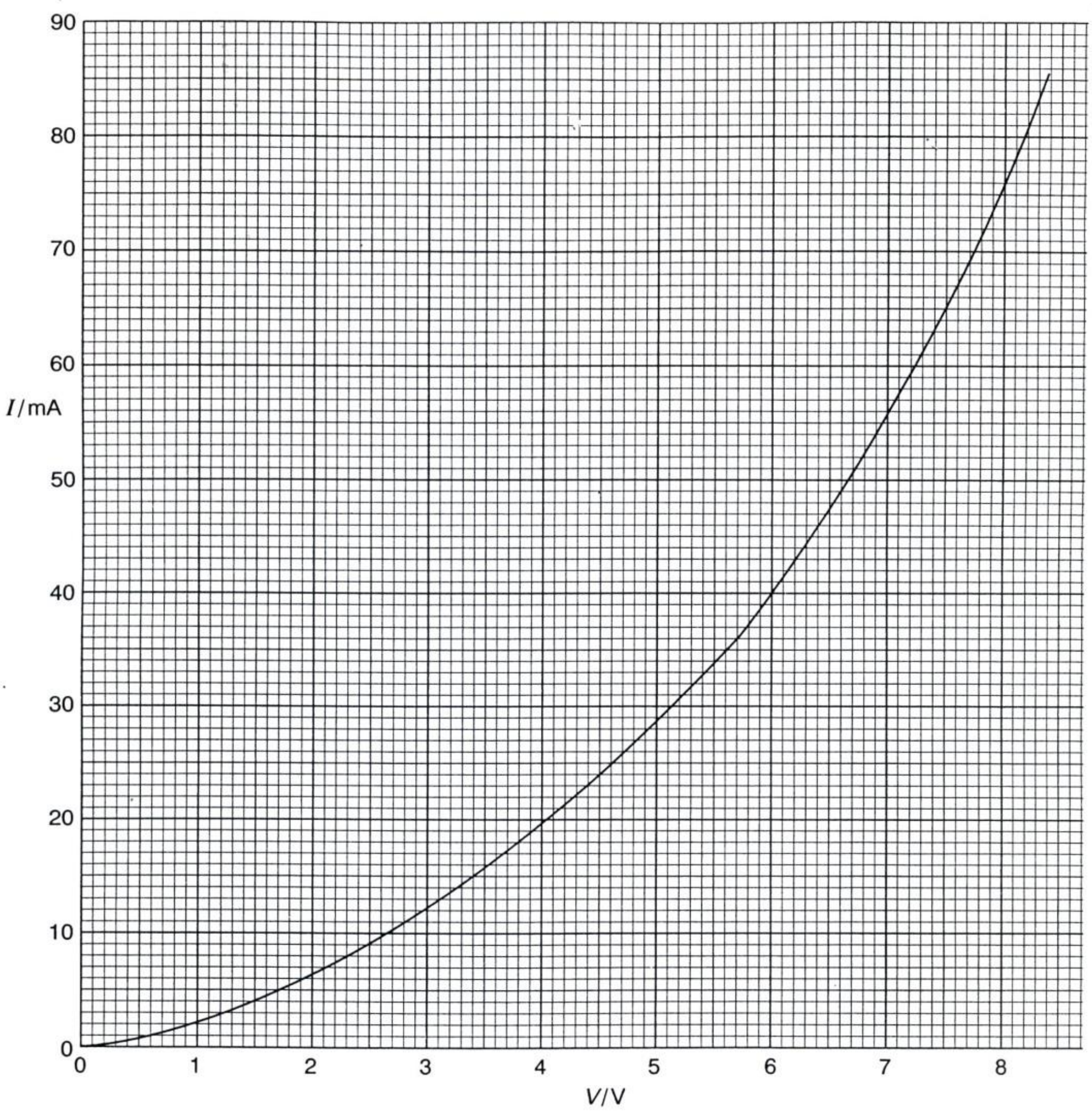


Fig. 8.1

(a) Using relevant features of the graph in Fig. 8.1, explain how it can be deduced that the resistance of the intrinsic semiconductor X decreases with voltage. [2]

The graph in Fig. 3.1 <u>curves towards the current axis</u>. Hence the <u>ratio of *V* to *I* will decreases</u> with increasing voltage.

OR the line drawn from origin to a point on the curve becomes gentler as voltage increases. Hence the ratio of *V* to *I*, which is the inverse of the gradient of this line, decreases

(b) Using band theory, explain why the resistance decreases with voltage for intrinsic semiconductors like X. [3]

The semiconductor has a band structure with a small band gap between the fully-filled valence band and the totally-unfilled conduction band at zero kelvin.

With an increase in temperature, some electrons from the valence band can easily gain enough thermal energy to promote to the conduction band via the small gap.

The electrons in the conduction band and holes in valence band behave as mobile charge carriers, increasing the number of <u>mobile positive and negative charge carriers</u>.

(c) The intrinsic semiconductor X is included in a circuit as shown in Fig. 8.2.

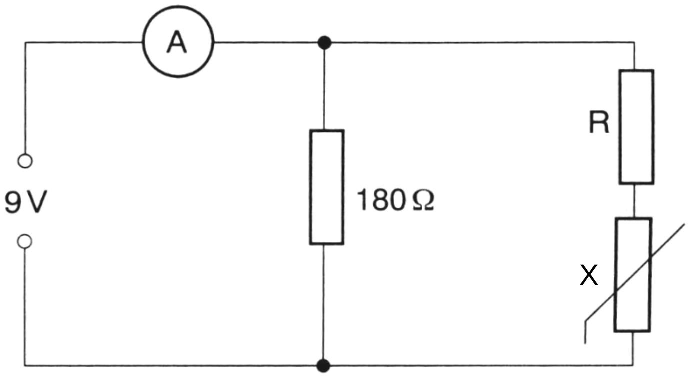


Fig. 8.2

It was found that the ammeter gave a reading of 90 mA and a current of 47 mA passes through the 180 Ω resistor.

(i) Determine the p.d. across X.

Current through X = 90 – 47 = 43 mA

From Fig. 8.1, p.d. across X = 6.2 V

p.d. across X = ... V [2]

(ii) Calculate the value of the resistance of resistor *R*.

$$\begin{aligned} V_{R\text{ and }X} &= V_{180\Omega} \\ &= IR \\ &= \left(47\times10^{-3}\right)(180) \\ &= 8.46\text{ V} \end{aligned}$$

$$\begin{aligned} V_R &= V_{R\text{ and }X} - V_X \\ &= 8.46 - 6.20 \\ &= 2.26\text{ V} \end{aligned}$$

$$V = IR$$

$$\begin{aligned} R &= \frac{V}{I} \\ &= \frac{2.26}{43\times10^{-3}} \\ &= 52.6\ \Omega \end{aligned}$$

value of *R* = ... Ω

(iii) Explain what can be deduced about the 9 V cell in Fig. 8.2. [1]

Since the voltage across the 180 Ω resistor is less than 9 V (8.46V), this means that there is internal resistance in the cell.

[IJC 2013]

9 An X-ray spectrum is shown in Fig. 9.1. The current of electrons *I* is accelerated through a potential difference of *V* as measured in volts before striking the metal target *M* inside the X-ray tube. λ_0 is the minimum wavelength detected in the spectrum.

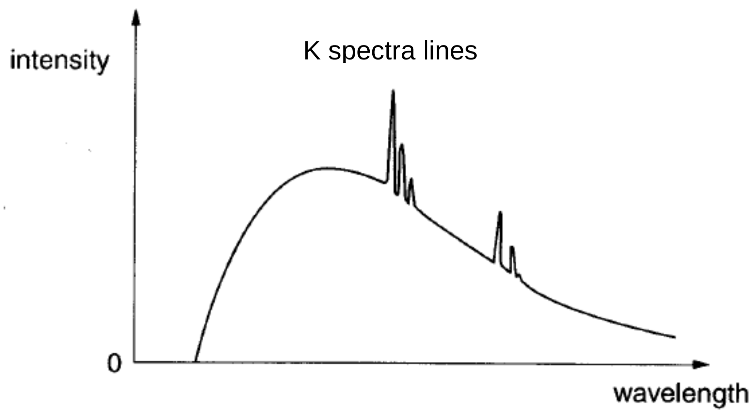


Fig. 9.1

(a) Complete the table below to indicate the change (if any) in Fig. 9.1 with the new adjustments made independently to the experiment.
Use one of the following terms for each answer; "increase", "unchanged" or "decrease".

A single change made to the experiment	Minimum wavelength, λ_0	Wavelengths of K spectra lines
V is increased	Decrease	Unchanged
I is decreased	Unchanged	unchanged
M is replaced with another metal of a lower mass number	Unchanged	increase

[3]

(b) **(i)** Show that λ_o is given by

$$\lambda_0 = \frac{1240}{V} \text{ nm}$$

The minimum wavelength is emitted as a photon in a single collision by the electron which is all its kinetic energy.

$$eV = \frac{hc}{\lambda_0}$$

$$\lambda_0 = \frac{hc}{eV}$$

$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.60 \times 10^{-19})V}$$

$$= \frac{1.24 \times 10^{-6}}{V}$$

$$= \frac{1240}{V} \text{ nm}$$

[3]

(ii) Determine the value of λ_0 in the X-ray spectrum for electrons accelerating across a p.d. of 50 kV.

$$\lambda_0 = \frac{1240}{V} = \frac{1240}{50 \times 10^3} = 0.0249 \text{ nm}$$

λ_0 = ... nm [1]

[IJC 2013]

10 (a) A student is provided with a freshly prepared sample of a radioactive material and the count rate C from the source is found to vary with time t as shown in Fig. 10.1(a).

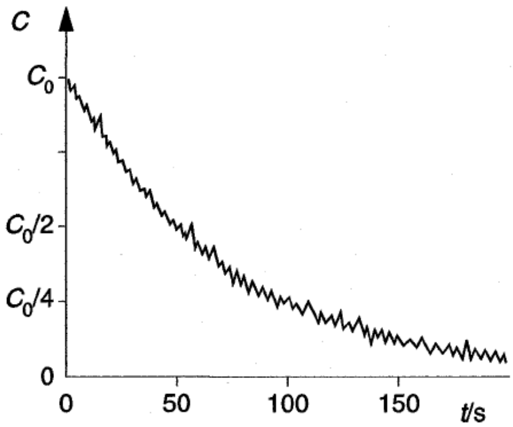


Fig. 10.1(a)

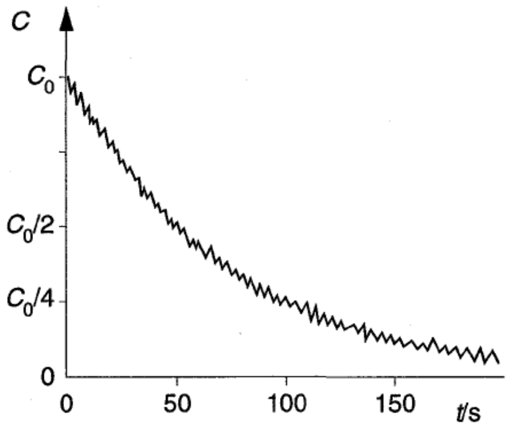


Fig. 10.1(b)

A second similar sample of the radioactive material is then prepared and the student repeats the experiment, but with the sample at a higher temperature. The variation with time of the count rate C for the second sample is shown in Fig. 10.1(b).

State the evidence that is provided by these two experiments for

(i) the *random* nature of radioactive decay, [1]

curve is not smooth, fluctutations, etc

(ii) the *spontaneous* nature of radioactive decay. [1]

Curve is same shape or same half life, not affected by temperature etc.

(b) Radium-224 has a half-life of 3.6 days.

(i) Show that the decay constant of Radium-224 is 2.23 × 10^{-6} s^{-1}.

$$\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3.6 \times 24 \times 60 \times 60} = 2.23 \times 10^{-6} \text{ s}^{-1} \text{ (shown)}$$

[1]

(ii) Hence, determine the activity of a sample of Radium-224 of mass 2.24 mg.

$$A = \lambda N$$
$$= \lambda\left(\frac{m}{M}N_A\right)$$
$$= \left(2.23\times10^{-6}\right)\left(\frac{2.24\times10^{-6}}{224\times10^{-3}}\right)\left(6.02\times10^{23}\right)$$
$$= 1.3\times10^{13}\ \text{Bq}$$

activity = ... s^{-1} [3]

(iii) Calculate the number of half-lives that must elapse before the activity of a sample of a radioactive isotope is reduced to one tenth of its initial value.

$$A = A_0 e^{-\lambda t}$$
$$\frac{1}{10}A_0 = A_0 e^{-\frac{\ln 2}{t_{1/2}}t}$$
$$e^{-\frac{\ln 2}{t_{1/2}}t} = \frac{1}{10}$$
$$-\frac{\ln 2}{t_{1/2}}t = \ln\frac{1}{10}$$
$$t = \frac{\ln 10}{\ln 2}t_{1/2}$$
$$= 3.32t_{1/2}$$

number of half-lives = ... [2]

[IJC 2013]

11 **(a)** A scanning tunnelling microscope (STM) is able to map out atomic-scale images of surfaces by using the "tunnelling" effect of electrons across an energy barrier.

(i) State what constitutes the energy barrier when using the STM. [1]

Vacuum gap between STM probe and surface.

(ii) Hence, describe briefly how the STM is able to map out atomic-scale images of surfaces. [2]

The tunnelling current between the STM probe and the surface is sensitive to small variations of the width of the energy barrier, or vacuum gap.

By moving the probe along the surface, the varying currents at each point is mapped out as varying depth/height of each point on the surface. By combining these points, an atomic-scale image of the surface is obtained.

OR By using a feedback mechanism, the probe is moved up or down to maintain constant current. The vertical motion is then plotted to obtain an atomic-scale image of the surface

(b) Distinguish between conduction band and valence band. [2]

Valence band is the highest occupied energy band whereas conduction band is the lowest unoccupied energy band.

(c) A junction is formed between slices of p-type and of n-type semiconductor material, as shown in Fig. 11.

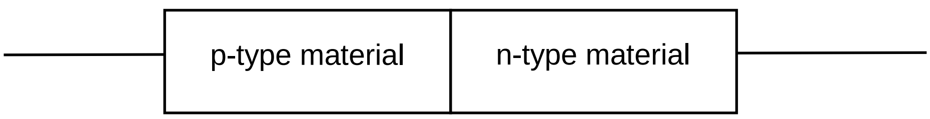


Fig. 11

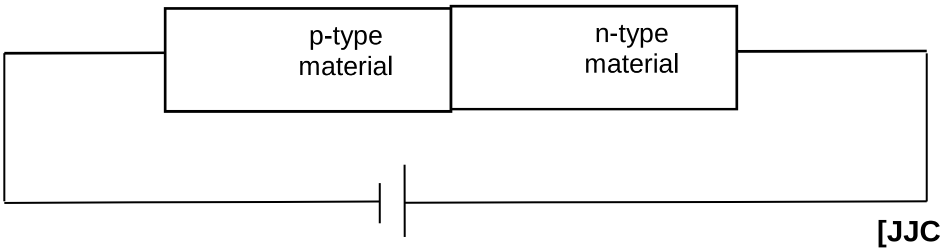
(i) Describe the origin of the depletion region at the junction. [4]

In the p-type region, the majority charge carriers are holes and in the n-type region, the majority charge carriers are electrons.

Diffusion of the mobile charge carriers occurs. Holes at the p-type region diffuse across the junction to the n-type region and electrons at the n-type region diffuse across the junction to the p-type region.

As holes and electrons diffuse across in opposite directions, most of them meet and recombine near the junction.
This resulted in the junction being depleted of mobile charge carriers hence forming the depletion region.

(ii) On Fig. 11, draw the symbol for a battery, connected so as to increase the width of the depletion region. [1]



[JJC 2013]

12 **(a)** Explain what is meant by half-life. [1]

The half-life of a radioactive nuclide is the average time taken for the activity to fall to half (its original value).

(b) The thickness of a sheet of aluminium foil is to be monitored using β-radiation as illustrated in Fig. 12.

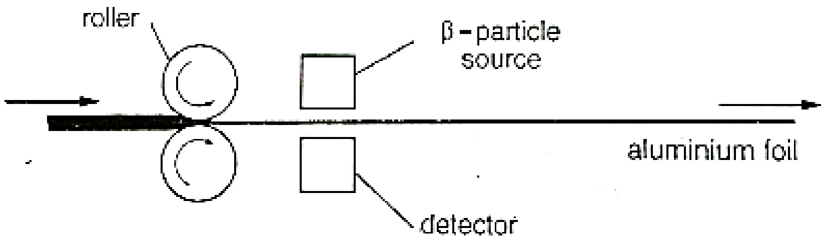


Fig. 12

(i) State and explain what would happen to the separation of the rollers if the output from the detector were to decrease. [2]

The decrease in output from the detector results from an increase in the foil thickness.

Hence, the separation of the rollers would decrease

(ii) A β-particle source of half-life 14 days is installed in the monitor and then used for a working day of 8.0 hours.

Calculate the ratio $\dfrac{\text{activity of source at end of working day}}{\text{activity of source at start of working day}}$.

$$A = A_0\left(\frac{1}{2}\right)^N$$

$$\frac{A}{A_0} = \left(\frac{1}{2}\right)^{\frac{8.0}{14\times24}}$$

$$= 0.98$$

ratio = ………………………… [2]

(iii) Suggest one advantage and one disadvantage of using a β-source which has a short half-life. [2]

Advantage:

1. High activity which reduces inaccuracies/errors due to background radiation
2. Takes only a short time for activity to reach a safe level for disposal

Disadvantage:

1. May cause the output from detector to vary (drop) rapidly without variation in the thickness of the aluminium sheet.
2. Frequent replacement of radioactive source

(iv) Suggest why a γ-radiation source would not be satisfactory for monitoring changes in thickness of the foil. [1]

γ-radiation could <u>penetrate the aluminium foil with little loss in output</u> (from the detector) and this loss may be <u>too small to be detected easily</u> or measured accurately

[JJC 2013]

13 A fluorescent tube is filled with mercury vapour at low pressure. In order to emit light, the mercury atoms must first be excited.

Fig. 13.1 shows some of the energy levels of the mercury atom, with Level 1 representing the ground state.

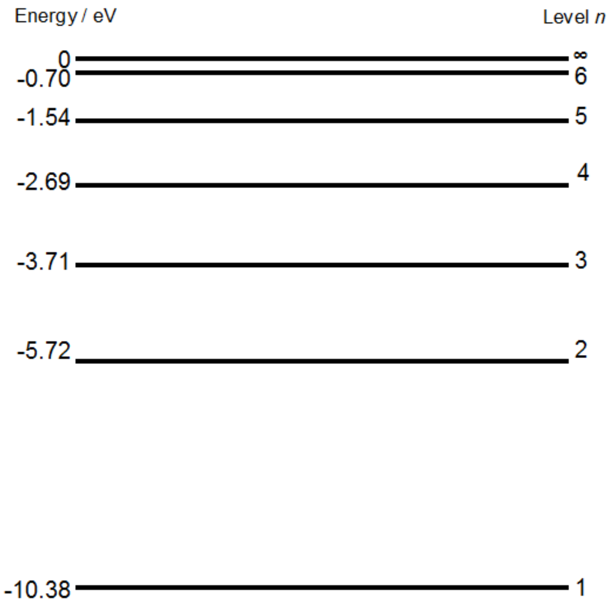


Fig. 13.1

(a) Explain with the aid of Fig. 13.1 why an emission spectrum can be observed. [3]

The diagram shows that atoms have <u>discrete energy levels</u>. When an atom in a particular excited state falls to a lower energy state, it emits a photon of energy that is exactly <u>equal to the difference in energy between the two states</u>. Hence <u>only photons of specific energies that are equal to the difference between two energy levels of the</u>

atom will be emitted. Since $E_p = hc/\lambda$, the wavelengths (or frequencies) corresponding to these photon energies give rise to an emission line spectrum.

(b) In order to cause the emission of photons, cool mercury vapour is placed in a discharge tube before being bombarded by a stream of electrons.

The electrons have been accelerated from rest through a potential difference of 7.3 V.

(i) State and explain how many different frequencies of electromagnetic radiation will be emitted by the mercury vapour. [2]
(Note: There is no requirement to calculate the exact frequencies of the electromagnetic radiation.)
Energy of electrons = 7.3 eV

Possible transitions are:

– 5.72 eV to – 10.38 eV **2 to 1**

– 3.71 eV to – 10.38 eV **3 to 1**

– 3.71 eV to – 5.72 eV **3 to 2**

Therefore, the number of possible transitions (or frequencies) is **3**.

(ii) Calculate the longest wavelength of the electromagnetic radiation produced and suggest the type of electromagnetic radiation.
The longest wavelength **is** produced from the smallest energy transition i.e. from – 3.71 eV to – 5.72 eV.

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

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

$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(5.72-3.71)(1.60\times10^{-19})}$$

$$= 6.17\times10^{-7}\ \text{m}$$

Visible spectrum

Longest wavelength = ... m

Type of electromagnetic radiation = ... [2]
[MI 2013]

14 Fig. 14.1 shows the graph shows the variation with wavelength λ of the relative intensity of an X-ray spectrum produced when the electrons strike a metal target.

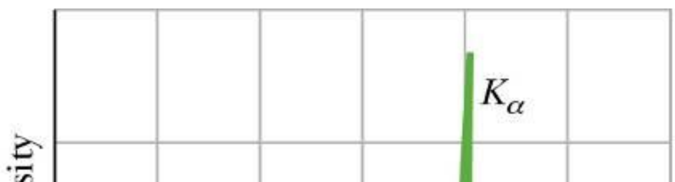


Fig. 14.1

The spectrum consists of a continuous spectrum and a characteristic line spectrum.

(a) **(i)** Estimate the maximum momentum of the incoming electrons striking the target.

From graph, $\lambda_{min} \approx 35$ pm

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

$$\frac{p^2}{2m_e} = \frac{hc}{\lambda}$$

$$p = \sqrt{\frac{2m_e hc}{\lambda}}$$

$$= \sqrt{\frac{2\left(9.11\times10^{-31}\right)\left(6.63\times10^{-34}\right)\left(3.00\times10^{8}\right)}{35\times10^{-12}}}$$

$$= 1.02\times10^{-22} \text{ N s}$$

maximum momentum of incoming electrons = ... N s [3]

(ii) State and explain how one can increase the relative intensity of the X-ray without causing a change in λ_{min}. [2]

The rate of emission of the electrons from the cathode can be increased (by increasing the temperature of the heating element) while keeping the accelerating potential constant.

This will increase the number of electrons incident on the target per unit time, which will in turn increase the rate of production of the X-ray photons.

(b) The metal target is now replaced by a new one. The X-ray spectrum produced is shown below in Fig. 14.2.

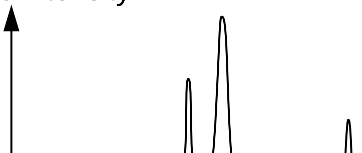


Fig. 14.2

(i) With reference to the presence of additional characteristic wavelengths, discuss whether the new metal target is made of atoms of a larger or smaller atomic mass than that of the old target. [3]

Existence of the *L* lines suggest that the photons emitted during the de-excitation of the electrons to the *L* shell are of higher energy (hence they are X-rays), compared to those emitted by the old target atoms.

This indicates that the energy gaps between the levels are greater due to the stronger attraction of the nucleus.

Hence, the new target has a larger atomic mass

(ii) Suggest a reason why the characteristic wavelengths emitted have small variations, instead of being a well-defined value. [1]

The variations in the wavelengths of the photons are due to the variations in the energies of the photons emitted.

OR This is due to the uncertainty in the energy levels of the atom (Heisenberg Uncertainty Principle)

[MJC 2013]

15 **(a)** Stimulated emission and spontaneous emission are two processes in which photon emissions can take place.

Compare the main difference between how these processes can happen. [1]

Stimulated emission is triggered by an external photon whereas spontaneous emission happens on its own accord.

(b) When a filament bulb is connected to a power supply, the filament in the bulb is heated up to produce a glow.

State the main type of photon emission process in a laser and a filament bulb.

Laser: Stimulated emission

Filament bulb: Spontaneous emission [1]

(c) Light from the laser is coherent whereas light from the filament bulb is not coherent.

Explain why. [2]

In laser, the emitted photons from stimulated emission have the same frequency and phase as incident photons. These emitted photons will trigger further stimulated emission causing a cascading effect, producing photons that have constant phase difference, i.e. coherent light.

In the candescent bulbs, the randomly emitted photons from spontaneous emission will have different direction and phase independent of each other. Hence the photons will have different phase, i.e. incoherent light.

(d) Light from the laser is directed through a diffraction grating onto a screen. It is then replaced with light from the filament bulb. Predict the observations. [1]
When light from the laser is directed through a diffraction grating onto a screen, an interference pattern is obtained on the screen. However no such pattern is seen when a filament bulb is used.

(e) State one other unique characteristic of light from laser. [1]
Any one of the following:
Light from laser is monochromatic.
Light from laser is highly directional.
Light from laser has high intensity

[MJC 2013]

16 (a) The energy of the sun is produced by the thermonuclear fusion reaction represented by

$$4\,{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2\,{}^{0}_{1}\text{e}$$

You may use the following masses in answering this question:

Mass of ${}^{1}_{1}\text{H} = 1.007825$ u
Mass of ${}^{4}_{2}\text{He} = 4.002603$ u
Mass of ${}^{0}_{1}\text{e} = 0.000549$ u

(i) Determine the energy released per nuclear reaction.

$$E = \left[4(1.007825) - 4.002603 - 2(0.000549)\right]uc^2$$
$$= 0.027599uc^2$$
$$= 0.027599\left(1.66\times10^{-27}\right)\left(3.00\times10^{8}\right)^2$$
$$= 4.12\times10^{-12}\ \text{J}$$
$$= 25.8\ \text{MeV}$$

energy released per reaction = ... MeV [2]

(ii) Given the Earth is at a distance 1.5×10^{11} m away from the Sun, and 1.35 kW m^{-2} of the Sun's energy is incident on Earth per second per unit area, determine the rate at which hydrogen nuclei are reacting in the Sun.
Let the energy emitted out by the sun per unit time be E,

$$I = \frac{E}{A}$$
$$E = IA$$
$$= \left(1.35\times10^{3}\right)(4\pi)\left(1.5\times10^{11}\right)^2$$
$$= 3.82\times10^{26}\ \text{W}$$

Rate at which a hydrogen is converted $= \dfrac{4\left(3.82\times10^{26}\right)}{4.12\times10^{-12}}$
$$= 3.70\times10^{38}\ \text{s}^{-1}$$

rate = ... s^{-1} [3]

(b) Fig. 16.1 shows the variation with nucleon number *A* of the binding energy per nucleon *E* of nuclei.

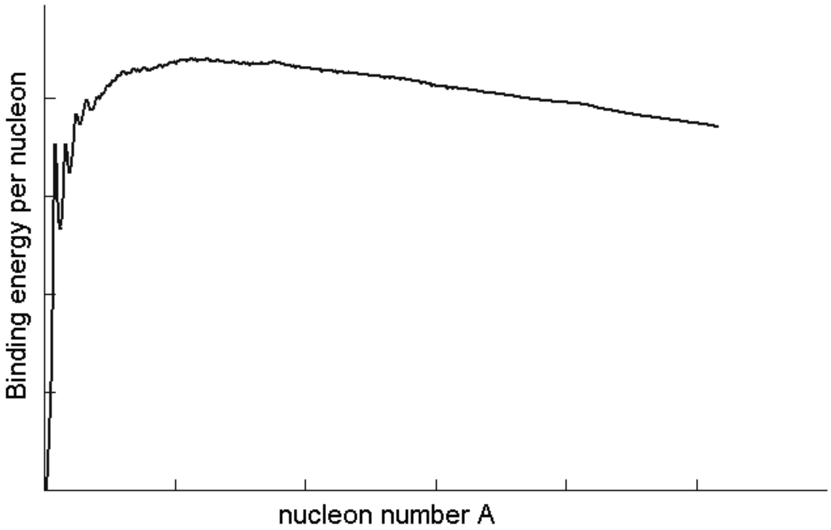


Fig. 16.1

(i) With the aid of Fig. 16.1, explain why more energy per nucleon is released in fusion than in fission. [2]

Energy released in a nuclear reaction is equal to the difference in binding energies between the products and the original reactants. From graph, the steeper slope of the binding energy curve for lighter nuclei indicates that the change in binding energy in fusion is larger, compared to that for fission reactions.

(ii) Even though fusion generates more energy per nucleon than a fission reaction, suggest why it is not viable to build a fusion reactor to simulate the fusion reactions happening in the sun. [1]

A very high temperature is required to enable fusion to occur and high pressure to overcome electrostatic repulsion. They must be within 1×10^{-15} meters of each other to fuse

[MJC 2013]

17 (a) In order to investigate the photo-electric effect, a student set up the apparatus as shown in Fig. 17.1.

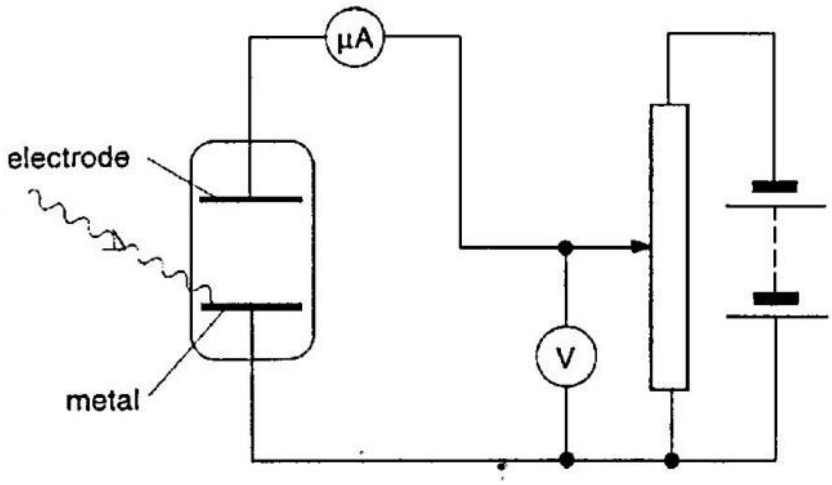


Fig. 17.1

The wavelength of the radiation incident on the metal surface was varied. For two values of wavelength λ, the stopping voltage V_s required just to prevent electrons from reaching the electrode was measured. The results are shown in Fig. 17.2.

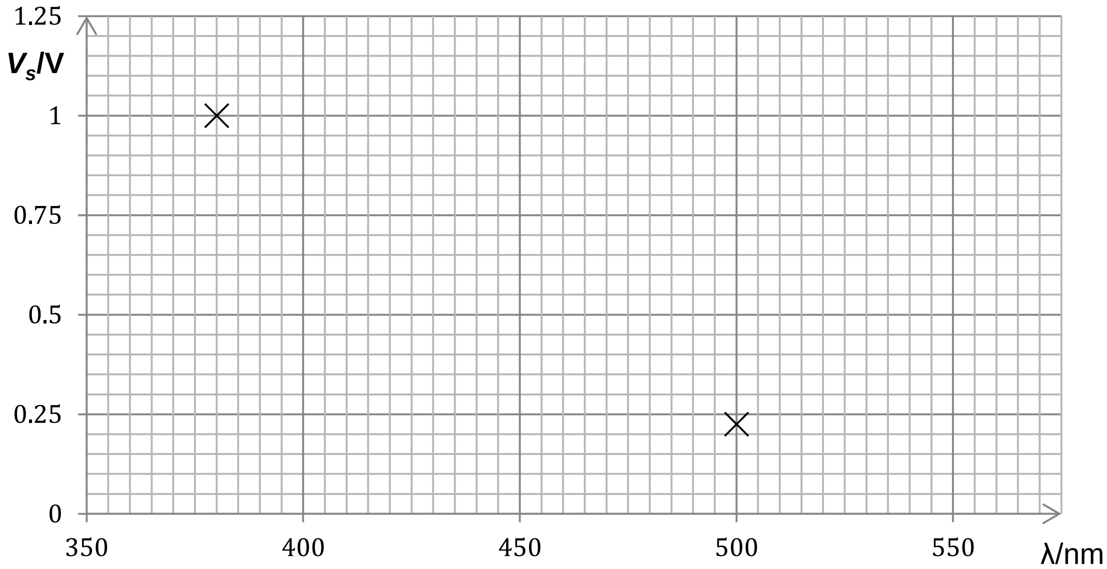


Fig. 17.2

(i) Calculate the energy of a photon of wavelength 380 nm.

$$E = \frac{hc}{\lambda}$$
$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{380\times10^{-9}}$$
$$= 5.23\times10^{-19}\text{ J}$$

energy of photon = ... J [1]

(ii) What is the maximum speed of a photo-electron emitted from the metal surface by radiation of wavelength 380 nm?

At λ = 380 nm, V_s = 1.00 V

$$eV_s = KE_{max}$$
$$= \frac{1}{2}mv_{max}{}^2$$
$$v_{max} = \sqrt{\frac{2eV_s}{m}}$$
$$= \sqrt{\frac{2(1.60\times10^{-19})(1.00)}{9.11\times10^{-31}}}$$
$$= 5.93\times10^{5}\text{ m s}^{-1}$$

maximum speed = ... ms^{-1} [2]

(iii) Using your answers in part **(a)(i)** and **(ii)**, calculate the threshold wavelength.

$$E = \phi + KE_{max}$$
$$= hf_0 + eV_s$$
$$f_0 = \frac{E - eV_s}{h}$$
$$= \frac{5.23\times10^{-19} - \left(1.60\times10^{-19}\right)(1.00)}{6.63\times10^{-34}}$$
$$= 5.48\times10^{14}\ \text{Hz}$$
$$c = f_0\lambda_0$$
$$\lambda_0 = \frac{c}{f_0}$$
$$= \frac{3.00\times10^{8}}{5.48\times10^{14}}$$
$$= 5.47\times10^{-7}\ \text{m}$$

threshold wavelength = ... m [2]

(iv) Explain why it is not possible to obtain the exact threshold wavelength of this metal surface directly from Fig. 17.2. [2]

Since $V_s = \dfrac{hc}{e\lambda} - \dfrac{hc}{e\lambda_0}$, in order to linearise this function, V_s has to be plotted against $\dfrac{1}{\lambda}$ in order to obtain the y-intercept to determine the threshold wavelength.

The graph in Fig. 17.2 shows the relationship between V_s and λ, which is non-linear. Hence with only 2 points, it is insufficient to know what the threshold wavelength is when $V_s = 0$.

(v) State and explain one piece of evidence provided by this experiment supporting the theory that light has a particulate nature. [2]

Any one of the three:

1. Existence of threshold frequency: For a given metal, no photoelectrons were emitted when the EM radiation falling onto the metal surface is below a certain minimum frequency even though the intensity is increased.

2. No time delay in emission of photoelectrons: When the frequency of the EM radiation falling onto the metal surface is above the threshold frequency, photoelectrons are emitted as soon as the radiation is shone onto the metal surface even if the intensity of radiation is very low.

3. The maximum kinetic energy of the photoelectrons is independent of the intensity of the electromagnetic radiation falling onto the metal surface: Stopping potential remains constant even with an increase in the intensity of the EM radiation.

[NJC 2013]

18 **(a)** A junction is formed between slices of p-type and n-type semiconductor material, as shown in Fig. 18.1.

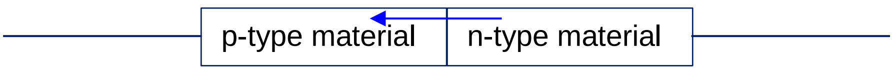
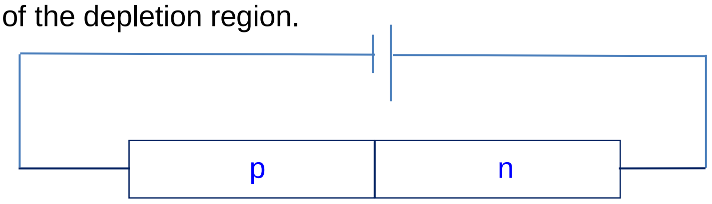


Fig. 18.1

(i) On Fig. 18.1, draw an arrow to show the direction of movement of electrons as the two slices are brought into contact. [1]

(ii) Describe the origin of the depletion region at the junction. [3]
When p-type and n-type materials are placed together, free electrons, from n-type material, diffuse across junction to fill up holes in the p-type material producing negative ions in p-type material leaving positively charges ions in n-type material.
This process continues until an electric field is set up to prevent any further diffusion of electron through the p-n junction.
This leads to the formation of a layer depleted of any mobile charges at the junction and this layer is called the depletion region.

(iii) On Fig. 18.1, draw the symbol for a battery, connected so as to increase the width of the depletion region. [1]



(b) By reference to the band theory of conduction, explain why the electrical resistance of an intrinsic semiconductor material decrease as its temperature rises. [4]
The energy between valence band and conduction band is narrow at 1 eV. At 0K, there are no electrons in the conduction band and the valence band is fully filled. At temperatures > 0K, a significant number of electrons become thermally excited and move into the conduction band, leaving holes behind in the valence band. As temperature rises, more electrons-holes pairs are produced resulting in more charge carriers and thus reducing the resistance.

[PJC 2013]

19 **(a)** State what is meant by the *binding energy* of a nucleus. [1]
The binding energy of a nucleus is the work which must be done on the nucleus to separate it completely into its constituent nucleons

(b) On Fig. 19.1 below, sketch the variation with nucleon number of the binding energy (B.E.) per nucleon. [1]

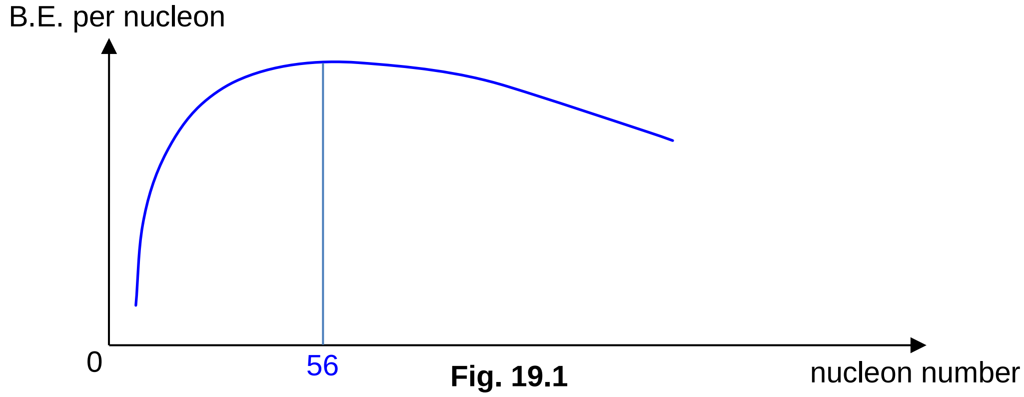


Fig. 19.1

(c) Using your sketch in Fig. 19.1, explain why fusion of nuclei having high nucleon numbers is not associated with a release of energy. [2]
For nuclei having high nucleon numbers, the binding energy per nucleon decreases with larger nucleon numbers. When two such nuclei fuse together, they will produce a daughter nucleus which has an even larger nucleon number and smaller binding energy per nucleon. This means that the daughter nucleus is less stable than the

parent nuclei. The total binding energy of the products is less than that of the initial nuclei, hence there is an increase in the total mass of the system, and energy has to be supplied for such a reaction to take place.

(d) **(i)** Calculate the binding energy per nucleon, in MeV, of $^{35}_{17}\text{Cl}$, using the following data:

Rest mass of $^{35}_{17}\text{Cl}$ nuclide = 34.96885 u
Rest mass of proton = 1.00728 u
Rest mass of neutron = 1.00866 u

$$\text{B.E. per nucleon} = \frac{\left[17(1.00728)+(35-17)(1.00866)-34.96885\right](1.66\times10^{-27})(3.00\times10^{8})^2}{35}$$

$$=1.33\times10^{-12}\text{ J}$$

$$=8.29\text{ MeV}$$

B.E. per nucleon of $^{35}_{17}\text{Cl}$ = ... MeV [2]

(ii) The binding energy per nucleon of another isotope of chlorine, $^{37}_{17}\text{Cl}$, is 8.35 MeV. State and explain which of these two isotopes of chlorine is more stable. [1]

$^{37}_{17}\text{Cl}$ is more stable, as it has a larger binding energy per nucleon.

[RIJC 2013]

20 The radioactive nuclide $^{60}_{27}\text{Co}$ is used in radiotherapy. It has a half-life of 5.27 years and, at each disintegration, two γ-rays are emitted, one of energy 1.17 MeV and the other of energy 1.33 MeV.

(a) This nuclide is prepared by bombarding a suitable target (a stable nuclide) with an appropriate particle. Possible projectiles are neutrons $^{1}_{0}\text{n}$ and deuterons $^{2}_{1}\text{H}$. Write down the equations for three separate reactions, involving the target nuclei $^{63}_{29}\text{Cu}$, $^{62}_{28}\text{Ni}$ and $^{59}_{27}\text{Co}$ respectively, and one or the other of the projectiles $^{1}_{0}\text{n}$ and $^{2}_{1}\text{H}$, by which $^{60}_{27}\text{Co}$ might be produced. [3]

The possible reactions include:

$$^{63}_{29}\text{Cu}+{}^{1}_{0}\text{n}\rightarrow{}^{60}_{27}\text{Co}+{}^{4}_{2}\text{He}$$

$$^{62}_{28}\text{Ni}+{}^{2}_{1}\text{H}\rightarrow{}^{60}_{27}\text{Co}+{}^{4}_{2}\text{He}$$

$$^{59}_{27}\text{Co}+{}^{1}_{0}\text{n}\rightarrow{}^{60}_{27}\text{Co}$$

(b) In a radiotherapy treatment, it is necessary to determine the amount of energy absorbed from the radiation. A fresh 1.0 g sample of $^{60}_{27}\text{Co}$, which may be treated as a point source, is placed at a position 1.50 m from a patient. Calculate the intensity of the radiation received by the patient.

The activity of the 1.00 g sample, A,

$$A=\lambda N$$

$$=\left(\frac{0.693}{t_{1/2}}\right)\left(\frac{m}{M}N_A\right)$$

$$=\left(\frac{0.693}{5.27\times365\times24\times60\times60}\right)\left(\frac{1.0\times10^{-3}}{60\times10^{-3}}\right)(6.02\times10^{23})$$

$$=4.18\times10^{13}\text{ s}^{-1}$$

Power of radiation from source, P

$$P = AE$$
$$= \left(4.18\times10^{13}\right)\left[\left(1.17+1.33\right)\times10^{6}\right]\left(1.60\times10^{-19}\right)$$
$$= 16.7 \text{ W}$$

Hence the intensity of radiation at 1.50 m, I,

$$I = \frac{P}{4\pi r^2}$$
$$= \frac{16.7}{4\pi\left(1.50\right)^2}$$
$$= 0.592 \text{ W m}^{-2}$$

intensity = ... W m^{-2} [3]

[VJC 2013]

21 **(a)** Explain what is meant by the *half-life* of a nuclide.

The average time taken for half the original number of nuclei in a sample of radioactive nuclide to decay or the average time taken for the activity of a sample of radioactive nuclide to halve.

[1]

(b) Targeted Alpha Therapy (TAT) is a cancer treatment that offers high potency and specificity. Actinium ($^{225}_{89}\text{Ac}$) is a radioactive nuclide that is used in TAT.

In the first decay in a reaction chain, a stationary $^{225}_{89}\text{Ac}$ nucleus decays into a Francium ($^{221}_{87}\text{Fr}$) nucleus and an alpha particle: $^{225}_{89}\text{Ac} \rightarrow {}^{221}_{87}\text{Fr} + {}^{4}_{2}\text{He}$

(i) If the total amount of energy produced is E, calculate the percentage of E carried by the alpha particle. Assume that no gamma radiation is produced. Explain your working clearly.

$$^{225}_{89}\text{Ac} \rightarrow {}^{221}_{87}\text{Fr} + {}^{4}_{2}\text{He}$$

By principle of conservation of momentum, the total momentum remains zero before and after emission, therefore $p_{Fr} = p_{He}$

KE = $p^2/2m$. Hence $KE_{He}/KE_{Fr} = m_{Fr}/m_{He}$ = 221/4

% of E carried by He = 221/225 × 100% = 98.2 %

[2]

percentage of E = ... %

(ii) To provide the correct dose, a tube containing $^{225}_{89}\text{Ac}$ is implanted in a patient for one day. The tube contains 0.10 μg of $^{225}_{89}\text{Ac}$.

$^{225}_{89}\text{Ac}$ has a half-life of 10 days.

1. Show that the initial number of $^{225}_{89}Ac$ nuclei is about 2.7×10^{14}.

No. of Ac = $0.10 \times 10^{-6} \times 10^{-3}/225u = 2.7 \times 10^{14}$

OR $0.10 \times 10^{-6}/225 \times (6.02 \times 10^{23}) = 2.7 \times 10^{14}$

[1]

2. Determine the initial activity of the implant.

$A = \lambda N = \frac{\ln 2}{10\times24\times3600}\times2.7\times10^{14}$
$= 2.2 \times 10^{8}$ Bq

initial activity = …………………….. Bq [2]

3. Calculate the number of $^{225}_{89}Ac$ nuclei that have decayed at the end of the treatment period.

No. decayed $= N_0 - N_0e^{-\lambda t}$
$= (2.7 \times 10^{14})(1 - e^{-\frac{\ln 2}{10}(1)})$
$= 1.8 \times 10^{13}$

number of $^{225}_{89}Ac$ nuclei decayed = ……..…………….. [2]

[HCI 2015]

22 (a) (i)

$$\frac{hc}{\lambda} = 1.60\times10^{-19}\times2.3+\phi----(1)$$

$$\frac{hc}{620\times10^{-9}} = 1.60\times10^{-19}\times1.1+\phi----(2)$$

$$(1)-(2): hc\left(\frac{1}{\lambda}-\frac{1}{620\times10^{-9}}\right) = 1.60\times10^{-19}\times1.2$$

$$\lambda = 3.87\times10^{-7}\,m$$ [3]

(ii) For the same incident power, the rate of photon incident on the surface is proportional to the wavelength of the radiation. Since the unknown radiation has a shorter wavelength, the rate of photons incident on the silver surface is less and hence less photoelectrons are ejected, giving rise to a lower saturation current. [2]

(b) (i)

$$\frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{436\times10^{-9}} = 4.56\times10^{-19} = 2.85\ eV$$

Since $E_4 - E_2 = 2.85$ eV, the transition is from E_4 to E_2 [2]

(ii) The bombarding electron must have a minimum kinetic energy of (13.6 eV – 0.54 eV) 13.06 eV in order for the hydrogen atom to be excited from ground state E_1 to E_4. Hence a transition from E_4 to E_2 can take place. So the minimum value is 13.06 V. [2]

[TJC 2015]

Long structured questions

23 The decay of radioactive nuclei is said to be *random* and *spontaneous*. In a radioactive decay, the activity at time t is given by

$$A = A_o\, e^{-\lambda t}$$

where A_o is the activity at the start of the decay and λ is the decay constant.

At the beginning of each year, officials from the Nuclear Regulatory Commission visit a nuclear waste disposal site to check the activity of a particular radioactive isotope. This isotope decays into a stable nuclide.

A Geiger counter is used to record the count rate of the isotope. The count rate C at time t follows the same relationship as the activity:

$$C = C_o\, e^{-\lambda t}$$

where C_o is the count rate at the start of the decay and λ is the decay constant.

Fig. 21.1 shows the count rates recorded from the year 2000 to the year 2007.

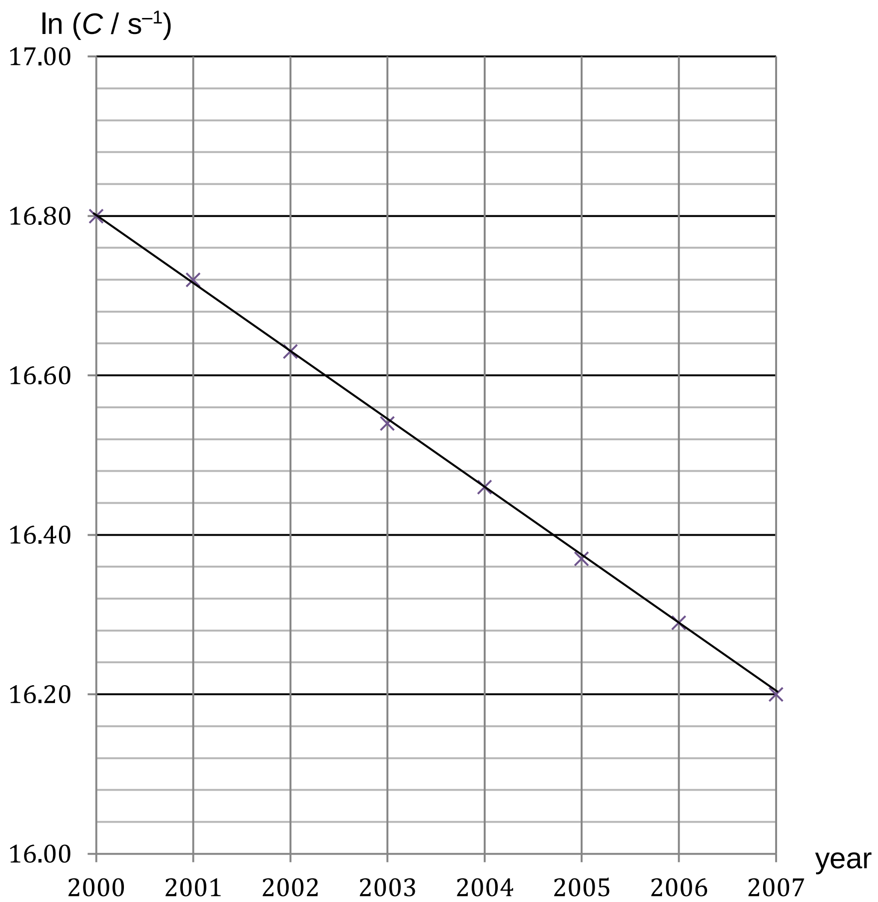


Fig. 21.1

(a) Explain what is meant by the terms *random* and *spontaneous* in radioactive decay. [2]

Spontaneous means that the decay occurs on its own **without external trigger** and unaffected by environmental factors like temperature and pressure. Random means it cannot be predicted **which** nucleus will decay next or **when** a particular nucleus will decay.

(b) **(i)** Using Fig. 21.1, show that the decay constant λ is approximately 2.7×10^{-9} s^{-1}.

$$C = C_0 e^{-\lambda t}$$

$$\ln C = \ln C_0 - \lambda t$$

Gradient of ln C against t graph will give $-\lambda$

$$-\lambda = \frac{16.20 - 16.80}{(2007 - 2000) \times 365 \times 24 \times 60 \times 60}$$

$$= -2.72 \times 10^{-9}$$

$$\lambda = 2.7 \times 10^{-9} \text{ s}^{-1} \ (\text{shown})$$

[2]

(ii) Hence determine the half-life of the radioactive isotope.

$$\lambda = \frac{0.693}{t_{1/2}}$$

$$t_{1/2} = \frac{0.693}{\lambda}$$

$$= \frac{0.693}{2.7 \times 10^{-9}}$$

$$= 2.6 \times 10^{8} \text{ s}$$

half-life = ... s [1]

(c) The radiation of the isotope can be taken as coming from a point source. The officials record the count rate at the gate which is 10 m from the source.

(i) Using Fig. 21.1, calculate the activity of the isotope at the beginning of 2007, given that each radiation particle intercepted by the counter is registered as a single count and that the Geiger counter has a receiving window of diameter 44 mm.

$$C = e^{16.20}$$

$$= 1.09 \times 10^{7} \text{ s}^{-1}$$

$$C = \frac{\text{area of counter}}{4\pi r^2} A$$

$$= \frac{\pi \left(\frac{d}{2}\right)^2}{4\pi r^2} A$$

$$= \frac{d^2}{16r^2} A$$

$$A = \frac{16Cr^2}{d^2}$$

$$= \frac{16\left(1.09 \times 10^7\right)\left(10\right)^2}{\left(44 \times 10^{-3}\right)^2}$$

$$= 9.0 \times 10^{12} \text{ s}^{-1}$$

activity = …………………… s^{-1} [3]

(ii) Suggest with a reason what type of radiation particle was intercepted by the counter. [1]

Gamma radiation, because it has penetrated a large expanse of air. Beta and alpha would have been stopped.

(d) On their visit in 2008, the officials noticed a significant increase in the count rate. They suspected that illegal dumping has taken place. They continued to monitor the count rate for the next few years. The results are shown in Fig. 21.2.

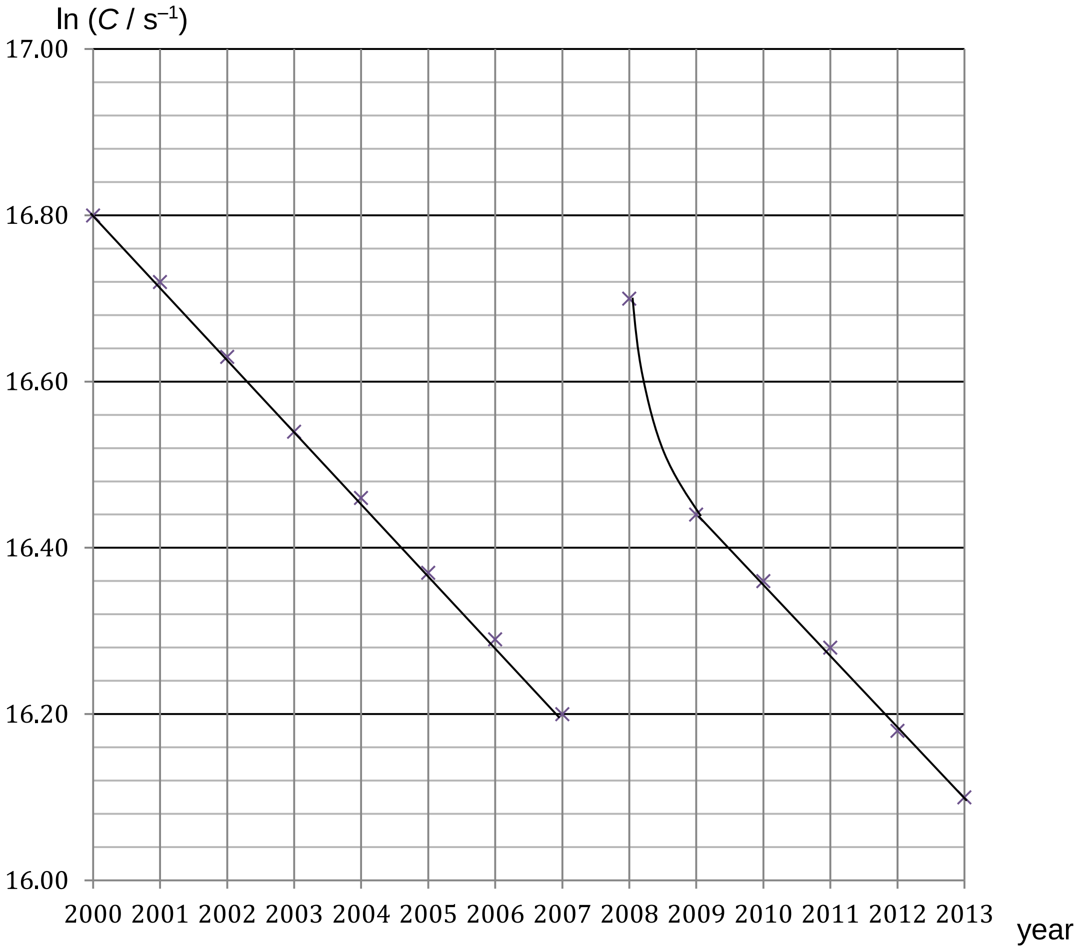


Fig. 21.2

(i) Calculate the percentage increase in the count rate due to this suspected illegal dumping over the expected count rate in 2008.

$C_{\text{expected}} = e^{16.10}$

$C_{\text{recorded}} = e^{16.70}$

$$\text{Percentage increase} = \frac{e^{16.70} - e^{16.10}}{e^{16.10}} \times 100\%$$

$$= 82.2\%$$

percentage increase = ... % [2]

(ii) Explain what the shape of the graph from 2008 to 2013 suggests about the radioisotopes that were illegally dumped. [4]

The initial part of the graph is a **curve**, but it quickly becomes a **straight line** with the **original gradient.**

At least another species with a **shorter half-life** has been dumped.

Even though the gradient eventually becomes the same as the original gradient, extrapolating the straight line portion backward to 2008 the ln(count rate) is **higher** than the expected ln(count rate) if no dumping had occurred, implying higher count rate still detected.

One of the radioisotopes dumped is the **same type** as the original isotope (or **same/similar half-lives**),

OR The radioisotope with the shorter half-life **decayed** to give a radioisotope that is the **same type** as the original isotope (or a radioisotope of **same/similar half-lives** as the original isotope).

[HCI 2013]

24 In a nuclear fusion process, two deuterons ($^{2}_{1}H$) combine to form a Helium-3 nuclide ($^{3}_{2}He$) and a neutron. The rest masses of the particles are given in the table below.

particle	rest mass / *u*
$^{2}_{1}H$	2.014102
$^{3}_{2}He$	3.016029
neutron	1.008665

(a) Write down the nuclear equation for this reaction, including the mass number and atomic number for each nuclide. [1]

$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$

(b) For two nuclei to undergo fusion, they must come together to within the range of the nuclear force, typically of the order of 2.0×10^{-15} m.

(i) Calculate the coulomb force of repulsion between the deuterons when they are 2.0×10^{-15} m apart from each other.

$$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$$

$$= \frac{\left(1.60 \times 10^{-19}\right)^2}{4\pi\left(8.85 \times 10^{-12}\right)\left(2.0 \times 10^{-15}\right)^2}$$

$$= 58 \text{ N}$$

force = ... N [2]

(ii) In one reaction, both deuterons are traveling towards each other at the same speed. At this speed, the deuterons have just the minimum kinetic energies required for the reaction to occur.

Show that the value for this speed is 5.9×10^6 m s^{-1}. [3]

By conservation of energy,

Loss in KE = gain in EPE

$$2\left(\frac{1}{2}mu^2\right) = \frac{Qq}{4\pi\varepsilon_0 r}$$

$$mu^2 = \frac{Qq}{4\pi\varepsilon_0 r}$$

$$u = \sqrt{\frac{Qq}{\left(4\pi\varepsilon_0 r\right)m}}$$

$$= \sqrt{\frac{\left(1.60 \times 10^{-19}\right)^2}{4\pi\left(8.85 \times 10^{-12}\right)\left(2.0 \times 10^{-15}\right)\left(2.04102\right)\left(1.66 \times 10^{-27}\right)}}$$

$$= 5.9 \times 10^6 \text{ m s}^{-1}$$

(iii) The average translational kinetic energy E_k of a particle at temperature T can be approximated by the expression

$$E_k = \frac{3}{2}kT$$

Calculate the temperature associated with the motions of the deuterons in **(b)(ii)**.

$$E_k = \frac{3}{2}kT$$

$$\frac{1}{2}mu^2 = \frac{3}{2}kT$$

$$T = \frac{mu^2}{3k}$$

$$= \frac{2.014102\left(1.66\times10^{-27}\right)\left(5.9\times10^{6}\right)^2}{3\left(1.38\times10^{-23}\right)}$$

$$= 2.8\times10^{9}\ \text{K}$$

temperature = ...K [2]

(iv) Explain why, for a system of large number of particles, nuclear fusion is still possible below the temperature calculated in **(b)(iii)**. [2]

For a particular temperature, there is a distribution of speeds / KE. Hence, even at a lower temperature, there will be some particles with sufficient KE for the reaction to occur.

(v) Calculate the energy released in this nuclear reaction.

$$\text{Energy released} = \Delta mc^2$$

$$= \left[2\left(2.014102\right) - 3.016029 - 1.008665\right]\left(1.66\times10^{-27}\right)\left(3.00\times10^{8}\right)^2$$

$$= 5.2\times10^{-13}\ \text{J}$$

energy released = ... J [3]

(c) After the reaction in **(b)(ii)**, the Helium-3 nuclide and neutron travels with speeds v_H and v_n respectively.

(i) Express v_H in terms of m_H, the mass of Helium-3 nuclide, m_n, the mass of neutron, and v_n. [2]

By conservation of linear momentum,

$$0 = m_H v_H - m_n v_n$$

$$v_H = \frac{m_n v_n}{m_H}\ \left(\text{where } v_H \text{ and } v_n \text{ move off in opposite directions}\right)$$

(ii) State one assumption you have made in your working in **(c)(i)**. [2]

Gamma radiation is not produced.

OR

No net external force acting on the system of two deuterons.

(iii) Use your answers from **(b)(ii)**, **(b)(v)** and **(c)(i)** to determine the kinetic energy of the neutron.

By conservation of energy,

Total KE before reaction + energy released ΔE = total KE after reaction

Let v_d be speed of deuterons before the reaction.

$$KE_i + E = KE_f$$

$$2\left(\frac{1}{2}m_d v_d^{\ 2}\right) + E = \frac{1}{2}m_H v_H^{\ 2} + \frac{1}{2}m_n v_n^{\ 2}$$

$$m_d v_d^{\ 2} + E = \frac{1}{2}\left(m_H v_H^{\ 2} + m_n v_n^{\ 2}\right)$$

$$= \frac{1}{2}\left[m_H\left(\frac{m_n v_n}{m_H}\right)^2 + m_n v_n^{\ 2}\right]$$

$$= \frac{1}{2}m_n v_n^{\ 2}\left(\frac{m_n}{m_H} + 1\right)$$

$$= \frac{1}{2}m_n v_n^{\ 2}\left(\frac{m_n + m_H}{m_H}\right)$$

$$KE_n = \frac{m_H\left(m_d v_d^{\ 2} + E\right)}{m_n + m_H}$$

$$= \frac{(3.016029u)\left[(2.014102u)\left(5.9\times10^6\right)^2 + 5.2\times10^{-13}\right]}{(1.008665 + 3.016029)u}$$

$$= 4.8\times10^{-13}\ \text{J}$$

kinetic energy = ... J [4]

[AJC 2013]

25 A collision takes place between an α-particle travelling at 3.0 × 10^7 m s^{-1} and a stationary nitrogen nucleus. It results in the following nuclear reaction.

$${}^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \rightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$$

The masses of the nuclei involved are listed below.

${}^{14}_{7}\text{N}$	13.9993 u
${}^{4}_{2}\text{He}$ (α-particle)	4.0015 u
${}^{17}_{8}\text{O}$	16.9947 u
${}^{1}_{1}\text{H}$ (proton)	1.0073 u

The particles move in a straight line, as shown in Fig. 23.1. The speed of the proton after the collision is 6.0 × 10^7 m s^{-1}.

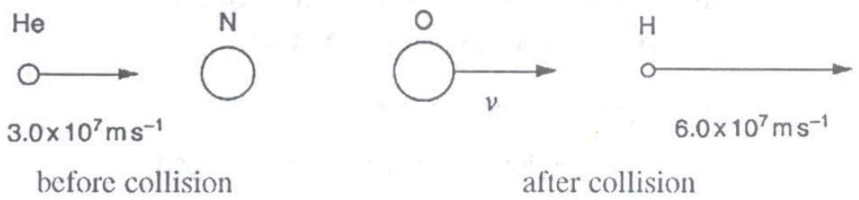


Fig. 23.1

(a) State the number and type of particles which form an α-particle. [1]

Type of particle	Number of particle
proton	2
neutron	2

(b) State and explain whether the reaction is a fusion or fission process. [2]

This is a fusion process, because smaller nuclei fused to form a heavier nucleus.

(c) Calculate the small change in mass, in kilograms, which takes place in this nuclear reaction.

$$\Delta m = m_{\text{products}} - m_{\text{reactants}}$$
$$= \left[(16.9947 + 1.0073) - (13.9993 + 4.0015)\right](1.66 \times 10^{-27})$$
$$= 1.99 \times 10^{-30} \text{ kg}$$

change in mass = ... kg [3]

(d) Calculate the minimum kinetic energy needed by the α-particle to cause the nuclear reaction.

$$KE_{\min} = \Delta mc^2$$
$$= (1.99 \times 10^{-30})(3.00 \times 10^{8})^2$$
$$= 1.79 \times 10^{-13} \text{ J}$$

kinetic energy = ... J [2]

(e) Use the principle of conservation of momentum to determine the magnitude and direction of v, the velocity of the oxygen nucleus after the collision.

By conservation of linear momentum,

$$\Sigma p_i = \Sigma p_f$$
$$(4.0015u)(3.0 \times 10^{7}) = (16.9947u)v + (1.0073u)(6.0 \times 10^{7})$$
$$v = 3.51 \times 10^{6} \text{ m s}^{-1}$$

Right

magnitude of v = ... m s^{-1}

direction = ... [4]

(f) **(i)** What is meant by the *momentum* of a body? [1]

Momentum of a body is the product of its mass and velocity.

(ii) A body, initially at rest, explodes into two unequal fragments of mass m_1 and m_2. Mass m_1 has a velocity v_1 and mass m_2 has a velocity v_2. Using the principle of conservation of momentum, derive an expression for $\frac{v_1}{v_2}$.

By conservation of momentum,

$$0 = m_1 v_1 + m_2 v_2$$
$$\frac{v_1}{v_2} = -\frac{m_2}{m_1}$$

$\frac{v_1}{v_2}$ = ... [2]

(iii) An isolated nucleus of mass 4.0×10^{-25} kg is initially at rest. It decays, emitting an alpha particle of mass 6.7×10^{-27} kg with kinetic energy of 1.2×10^{-14} J.

1. Find the speed of the alpha particle.

$$KE = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2\left(1.2\times10^{-14}\right)}{6.7\times10^{-27}}}$$
$$= 1.9\times10^{6}\ \text{m s}^{-1}$$

speed = ... m s^{-1} [1]

2. Hence, by considering the mass of the recoiling nucleus, use the expression found in **(f)(ii)** or otherwise to find the speed of the recoiling nucleus.

$$\frac{v_1}{v_2} = -\frac{m_2}{m_1}$$
$$\frac{v}{1.9\times10^{6}} = -\frac{6.7\times10^{-27}}{4.0\times10^{-25} - 6.7\times10^{-27}}$$
$$= -3.2\times10^{4}\ \text{m s}^{-1}$$

Speed = 3.2×10^4 m s^{-1}

speed = ... m s^{-1} [2]

3. Explain how alpha-particle decay is possible using quantum tunnelling. [2]
The alpha-particle has energy less than the energy of the potential barrier of the nucleus. However, since its wave function is non-zero beyond the barrier (outside the nucleus), it has a finite probability of decaying / emitting / escaping from the nucleus.

[IJC 2013]

26 **(a)** **(i)** State what is meant by the *photoelectric effect*. [1]
Photoelectric effect is the emission of electrons from the surface of a metal when it is exposed to electromagnetic radiation of sufficiently high frequency

(ii) Describe two experimental observations associated with this effect and explain how each deviates from predictions of the classical wave theory. [4]
Any two of the following observations:

1. For every surface irradiated, there exists a threshold frequency below which no photoemission occurs regardless of the intensity of the electromagnetic radiation. This contradicts the classical wave theory, which predicts that photoelectrons should be emitted for all frequencies.

2. The maximum kinetic energy of the photoelectron is independent of the light intensity, but dependent on the frequency of the light. This is contrary to the classical wave theory which predicted that increasing the light intensity should lead to ejection of photoelectrons with greater speed and hence kinetic energy.

3. There is no time lag between illuminating the metal plate and the emission of photoelectrons, even at very low intensities. This deviates from the classical wave theory which predicts that there should be a measurable time lag since energy is arriving in a continuous manner and a certain amount of time is needed for the electron to gather enough energy before it gets ejected.

(b) In a photoelectric emission experiment, light of wavelength 420 nm was shone on a metal surface of work function energy of 2.0 eV so that an area of 25 mm^2 was illuminated. A saturated photocurrent of 4.8×10^{-10} A was observed.
Determine

(i) the threshold frequency,

$$hf_0 = \phi$$

$$f_o = \frac{\phi}{h}$$

$$= \frac{2.0\left(1.60\times10^{-19}\right)}{6.63\times10^{-34}}$$

$$= 4.8\times10^{14}\ \text{Hz}$$

threshold frequency = ... Hz [1]

(ii) the stopping potential,

$$hf = \phi + eV_s$$

$$V_s = \frac{hf-\phi}{e}$$

$$= \frac{\left(6.63\times10^{-34}\right)\left(\dfrac{3.00\times10^{8}}{420\times10^{-9}}\right) - \left[2.0\left(1.60\times10^{-19}\right)\right]}{1.60\times10^{-19}}$$

$$= 0.96\ \text{V}$$

stopping potential = ... V [2]

(iii) the rate of emission of photoelectrons,

$$Q = It$$

$$N_e e = It \quad \left(N_e \text{ is the number of electrons}\right)$$

$$\frac{N_e}{t} = \frac{I}{e}$$

$$= \frac{4.8\times10^{-10}}{1.60\times10^{-19}}$$

$$= 3.0\times10^{9}\ \text{s}^{-1}$$

rate of emission of photoelectrons = ... s^{-1} [1]

(iv) the intensity of the light source, assuming that 1 in 2500 photons succeeds in ejecting an electron from the surface.

$$N_e = \frac{1}{2500}N_p \quad \left(N_p \text{ is the number of photons}\right)$$

$$N_p = 2500N_e$$

$$I = \frac{P}{A}$$

$$= \frac{N_p hf}{At}$$

$$= \frac{N_p hc}{At\lambda}$$

$$= \frac{2500\left(3.0\times10^{9}\right)\left(6.63\times10^{-34}\right)\left(3.00\times10^{8}\right)}{\left(25\times10^{-6}\right)\left(420\times10^{-9}\right)}$$

$$= 0.14\ \text{W m}^{-2}$$

intensity = ... W m^{-2} [3]

(c) The scanning tunnelling microscope (STM) is an instrument which makes use of quantum tunnelling to detect changes in the surface structure on the atomic scale.

(i) Explain what is meant by

1. potential barrier, [1]

Potential barrier refers to a potential energy distribution of which the energy height is higher than the incident particle's energy.

2. quantum tunnelling. [1]

Quantum tunnelling refers to the phenomenon where a particle has a non-zero probability of existing outside the potential barrier.

(ii) Briefly describe how the STM operating in the constant height mode is used to obtain atomic-scale images of surfaces. [2]

Electrons can tunnel through the empty space barrier between the tip of the STM and the sample surface. The tunnelling current *I* decreases exponentially with the tip-to-surface distance *d*, so a small change in *d* will cause a large change in *I*. In constant-height mode, the tip travels in a fixed vertical position above the sample and *I* varies depending on the local surface electron density of the sample. The tunnelling current measured at each location on the sample surface constitute the data set which can be mapped into an atomic-scale image of the surface.

(iii) When the tip of a STM probe is set at a small distance from the sample, its tunnelling current is proportional to the transmission coefficient. The work function energy ($U - E$) of the sample is 4.0 eV. Determine the ratio of the current when the STM tip is 0.50 nm above a surface to the current when it is 0.75 nm above the surface.

$I \propto T$ and $T \propto e^{-2kd}$ $\therefore I \propto e^{-2kd}$

$$k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$$

$$= \sqrt{\frac{8\pi^2(9.11\times10^{-31})(4.0)(1.60\times10^{-19})}{(6.63\times10^{-34})^2}}$$

$$= 1.02\times10^{10}$$

$$\frac{I_{0.50}}{I_{0.75}} = \frac{e^{-2kd_{0.50}}}{e^{-2kd_{0.75}}}$$

$$= e^{2k(d_{0.75}-d_{0.50})}$$

$$= e^{2(1.02\times10^{10})\left[(0.75-0.50)\times10^{-9}\right]}$$

$$= 170$$

ratio = ... [4]

[RIJC 2013]

27 The decay of radioactive materials is a random and spontaneous process. On average, nuclides which decay rapidly exist for a shorter time than nuclides which decay slowly. It is common practice when making calculations on decay to make use of the half life of a nuclide. One difficulty arises with these calculations when the radioactive material is a mixture of two or more nuclides. This question considers the case when a mixture of two radioactive nuclides is present. In decommissioning a nuclear power station, this difficulty is compounded by the presence of about a hundred different radioactive nuclides in significant quantities.

The table below gives the variation with time of the total activity A_{mix} of a mixture of cobalt and nickel together with the separate activities A_C and A_N due to cobalt and nickel.

time/year	A_C/Bq	A_N/Bq	A_{mix}/Bq	ln(A_{mix}/Bq)
0	6900	250	7150	8.87
5	3540	241	3781	8.24
10	1820	232	2052	7.63
20	479	215	694	6.54
30	126	199	325	5.78
40	33.3	185	218	5.38
50	8.79	172	181	5.20
60	2.32	159	161	5.08
70	0.611	147	148	5.00
80	0.161	137	137	4.92
90	0.0425	127	127	4.84
100	0.0112	118	118	4.77

(a) Explain what it means to say that the radioactive decay is a *random* and *spontaneous* process. [2]

Spontaneous since that it is not triggered by external factors such as temperature change. Random since it in impossible to determine which nucleus or exactly when a particular nucleus will disintegrate.

Alternatively, spontaneous means that it is not affected by chemical reactions, external factors such as temperature and pressure or the presence of other nuclei. Random implies it is impossible to say which particular nucleus in a sample is going to decay next and each nucleus in the sample has the same probability (chance) of decay per unit time.

(b) A graph showing how ln(Ac/Bq) varies with time is plotted for the cobalt nuclides in Fig. 25.1.

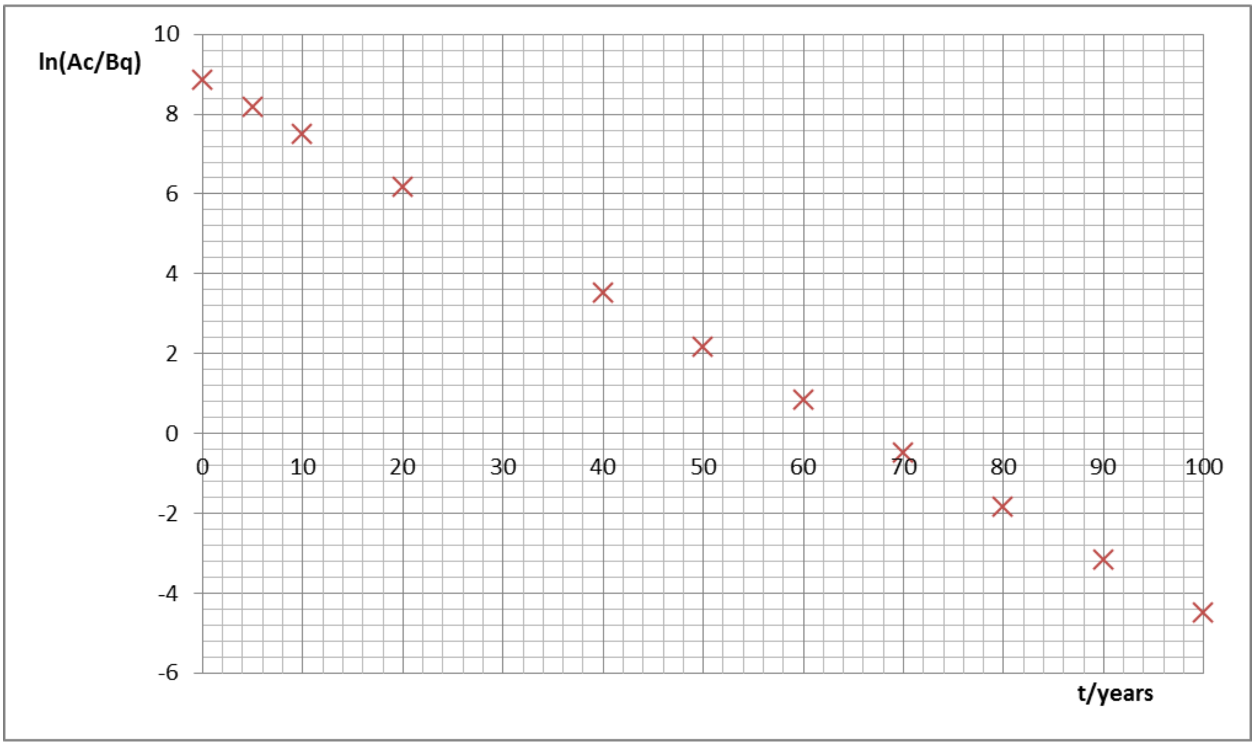


Fig. 25.1

(i) Balance the nuclear reaction below:

$$^{60}_{27}\text{Co} \rightarrow ^{M}_{N}X + ^{0}_{-1}\beta$$

What are the values for M and N?

Comparing nucleon number,

$M = 60$

Comparing proton number,

$N + (-1) = 27$

$N = 28$

M = ...

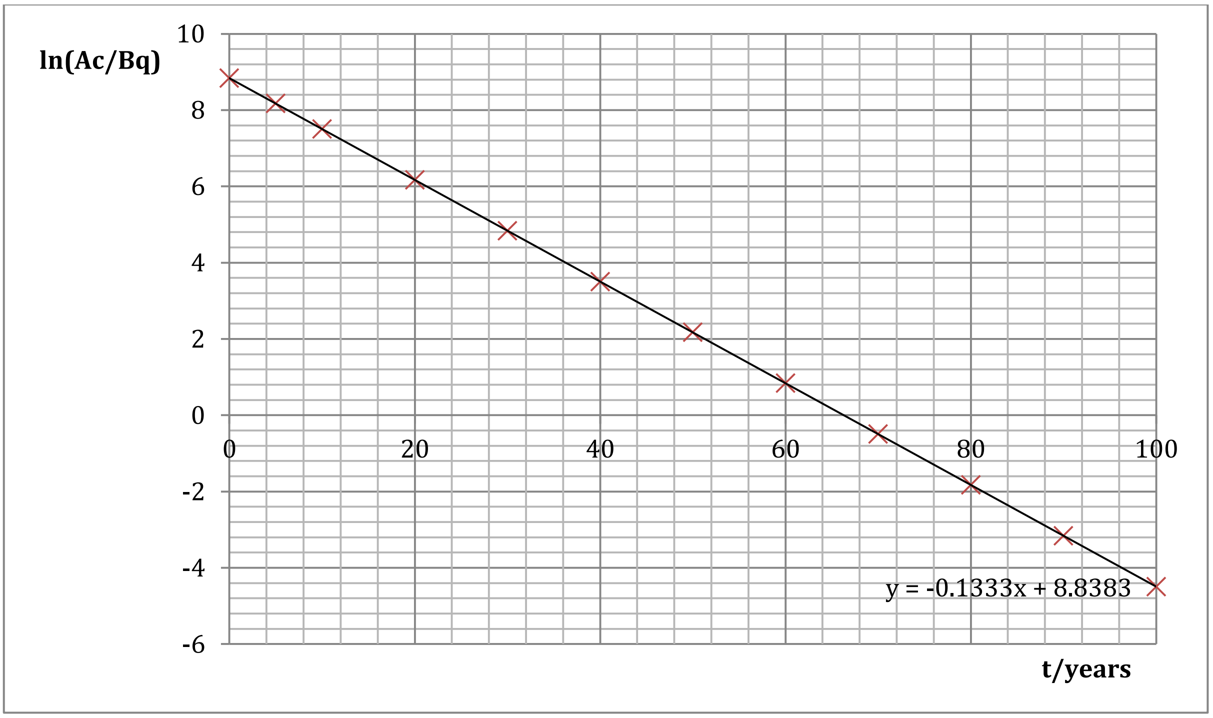
N = ... [1]

(ii) On Fig. 25.1,

1. plot a point corresponding to $t = 30$ years,

At $t = 30$ yrs, ln $A_c = 4.8$

2. draw the line of best fit for all the points. [2]



(iii) Use Fig. 25.1 to determine the gradient of the line drawn in **(ii)**.

$$m = \frac{-4.5 - 8.8}{100 - 0}$$

$$= -0.133$$

Acceptable range: – 0.130 to – 0.138

gradient = ... [1]

(iv) Applying the general decay law, determine the decay constant for cobalt nuclide.

Applying the general decay law,

$$A = A_0 e^{-\lambda t}$$

$$\ln A = \ln A_0 - \lambda t$$

From the linearised equation, gradient of ln A against t graph gives gradient of $-\lambda$.

From (iii)

$$-\lambda = -0.133$$
$$\lambda = 0.133 \text{ year}^{-1}$$
$$= \frac{0.133}{365 \times 24 \times 60 \times 60}$$
$$= 4.22 \times 10^{-9} \text{ s}^{-1}$$

decay constant = ... s^{-1} [2]

(v) The molar mass is the mass of 1 mole of the substance, calculate the rate $\frac{\lambda}{\text{molar mass}}$ for ^{60}Co where λ is the decay constant of the nuclide.

$$\frac{\lambda}{\text{molar mass}} = \frac{4.22 \times 10^{-9}}{60 \times 10^{-3}}$$
$$= 7.03 \times 10^{-8} \text{ mol kg}^{-1} \text{ s}^{-1}$$

rate = ... mol kg^{-1} s^{-1} [1]

(c) A graph showing how $\ln(A_{mix}/Bq)$ varies with time is plotted for the mixture of cobalt and nickel nuclides in Fig. 25.2.

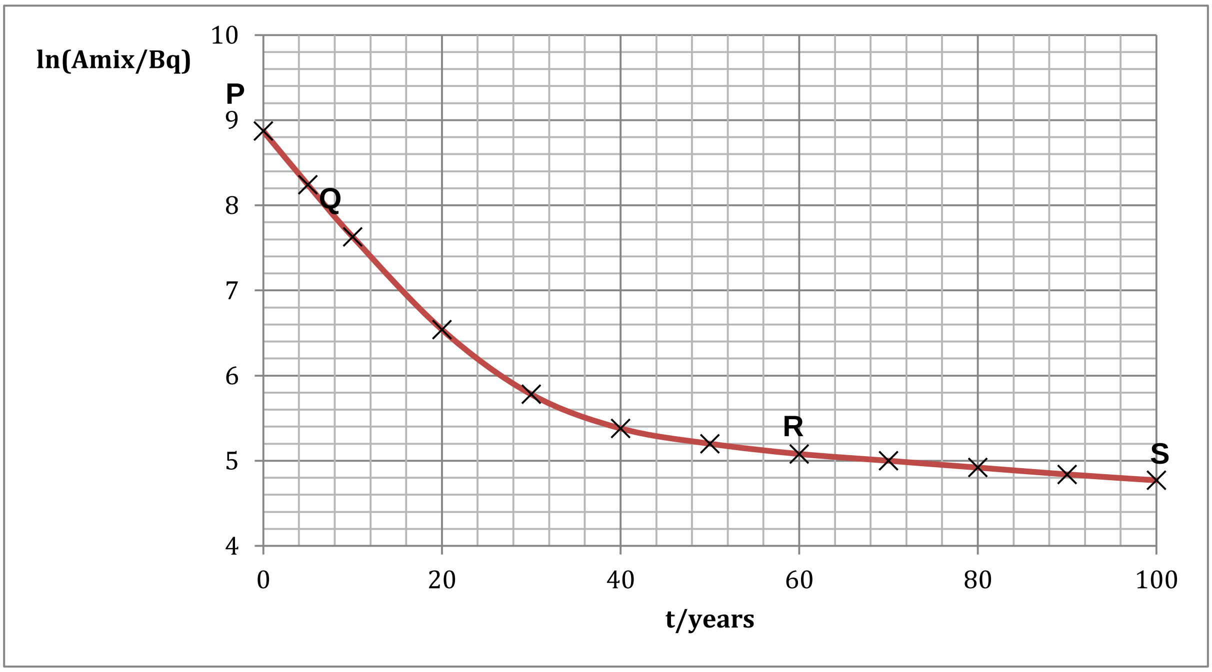


Fig. 25.2

(i) Suggest and explain if PQ or RS on the graph corresponds to the decay of nickel. [2]

Line RS corresponds to the decay of nickel. As observed from the activity table, from time = 60 years to time = 100 years, the change in activity of cobalt is very much smaller compared to that the change in activity of nickel. This is due to the shorter half life that cobalt has compared to nickel.

(ii) Use the gradient of PQ or RS to estimate the decay constant for the nickel nuclides.

$$-\lambda_{\text{Ni}} = m_{RS}$$
$$= \frac{5.1 - 4.8}{(60-100)(365 \times 24 \times 60 \times 60)}$$
$$\lambda_{Ni} = 2.38 \times 10^{-10}\ \text{s}^{-1}$$

decay constant = ... s^{-1} [1]

(iii) Determine the ratio for the half life of cobalt to the half life nickel.

$$\lambda = \frac{0.693}{t_{1/2}}$$
$$\lambda t_{1/2} = 0.693$$
$$\lambda_{\text{Ni}} t_{1/2,\text{Ni}} = \lambda_{\text{Co}} t_{1/2,\text{Co}}$$
$$\frac{t_{1/2,\text{Co}}}{t_{1/2,\text{Ni}}} = \frac{\lambda_{\text{Ni}}}{\lambda_{\text{Co}}}$$
$$= \frac{2.38 \times 10^{-10}}{4.22 \times 10^{-9}}$$
$$= 0.0564$$

ratio = ... [2]

[NJC 2013]

28 a)

Wave Explanation	Quantum Explanation
The energy is carried to the screen by electromagnetic waves.	The energy is carried to the screen by photons.
The energy arrives continuously at the screen.	The energy arrives in discrete packets or discrete quanta.
The energy of the electromagnetic wave is proportional to (amplitude)^2 of the wave.	The energy of each packet is proportional to the frequency of the wave.
Where the patch of light on the screen is bright, the wave arriving there are in phase. OR The wave superpose/interfere constructively / constructive interference occurs	Where the patch of light on the screen is brighter, the probability of arrival of photons is greater.

Table 6.2

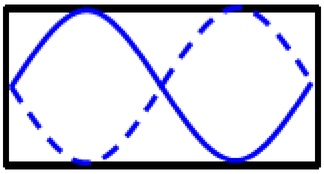
b)(i) $f = \frac{5.60 \times 10^{-19}}{6.63 \times 10^{-34}} = 8.45 \times 10^{14}\ Hz$

b)(ii) 1. It is the <u>minimum energy</u> required for <u>photoelectric emission</u> / to emit an electron from the surface of the metal.

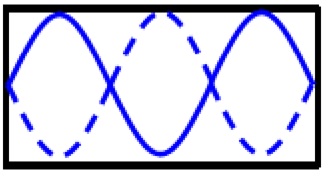
b)(ii) 2. Maximum kinetic energy $= hf - \Phi$

$= 5.60 \times 10^{-19} - 4.80 \times 10^{-19} = 8.0 \times 10^{-20}$ J

c)(i)



n = 2



n = 3

c)(ii) 1. $\lambda = \frac{h}{p}$ and since $p = \sqrt{2mE}$

$$\lambda = \frac{h}{\sqrt{2mE}}$$

c)(ii) 2. Since $L = n\left(\frac{\lambda}{2}\right)$, $\lambda = \left(\frac{2L}{n}\right)$

From $\lambda = \frac{h}{\sqrt{2mE}}$ $\frac{2L}{n} = \frac{h}{\sqrt{2mE}}$ $E = \frac{n^2h^2}{8mL^2}$

c)(iii) 3I. $32 \times 10^{-19} - 0 = (1.6 \times 10^{-19})V$

$$V = \frac{32\times10^{-19}}{1.6\times10^{-19}} = 20\text{v}$$

c)(iii) 3II. Accelerating electrons radiate electromagnetic waves, losing energy in the process.

c)(iii) 3III.

$$\lambda_1 = \frac{hc}{(21.2 - 2.36) \times 1.6 \times 10^{-19}} = 6.60 \times 10^{-8} = 66\ nm$$

$$\lambda_2 = \frac{hc}{(21.2 - 9.42) \times 1.6 \times 10^{-19}} = 1.06 \times 10^{-7} = 106\ nm$$

$$\lambda_3 = \frac{hc}{(9.42 - 2.36) \times 1.6 \times 10^{-19}} = 1.76 \times 10^{-7} = 176\ nm$$

d)(i)

	$k=\sqrt{\frac{8\pi^2\times 9.11\times 10^{-31}\times(7-5)\times 1.6\times 10^{-19}}{(6.63\times 10^{-34})^2}}$ = 7.236 283 × 10^9 $T=e^{-2kd}=e^{-2\times 7.236283\times 10^9\times 0.8\times 10^{-9}}$ = 9.37 × 10^{-6} R = 1 – T = 99.999 1 %
	d)(ii) The potential energy is constant in region 2 and since force = negative of the potential energy gradient, force is zero since potential energy gradient is zero.

[NJC 2015]

Answers

MCQ

1	A	**9**	B	**17**	C	**25**	B	**33**	B	**41**	C
2	-	**10**	B	**18**	B	**26**	C	**34**	B	**42**	D
3	C	**11**	C	**19**	C	**27**	C	**35**	A	**43**	D
4	D	**12**	C	**20**	C	**28**	C	**36**	D	**44**	A
5	A	**13**	D	**21**	D	**29**	C	**37**	D	**45**	D
6	A	**14**	B	**22**	A	**30**	C	**38**	C	**46**	A
7	D	**15**	A	**23**	D	**31**	D	**39**	B	**47**	C
8	B	**16**	D	**24**	D	**32**	C	**40**	C		

Structured Questions

1(a)(i)	P = 236, Q = 92, R = 143	**23(b)(ii)**	2.6×10^{8} s
1(b)	1.56×10^{3} s^{-1}	**23(c)(i)**	9.0×10^{12} s^{-1}
2(c)(i)1	4.66×10^{15}	**23(d)(i)**	82.2 %
2(c)(i)2	6.97×10^{-10} kg	**24(b)(i)**	58 N
2(c)(ii)	0.882	**24(b)(iii)**	2.8×10^{9} K
3(b)(ii)	10.4%	**24(b)(v)**	5.24×10^{-13} J
4(a)(i)	1740 MeV	**24(c)(iii)**	4.8×10^{-13} J
4(a)(ii)	93.9 u	**25(c)**	1.99×10^{-30} kg
7(a)	2.1×10^{-7} m	**25(d)**	1.79×10^{-13} J
8(c)(i)	6.2 V	**25(e)**	3.51×10^{6} m s^{-1}, right
8(c)(ii)	52.6 Ω	**25(f)(iii)1**	1.9×10^{6} m s^{-1}
9(b)(ii)	0.0249 nm	**25(f)(iii)2**	3.2×10^{4} m s^{-1}
10(b)(ii)	1.34×10^{13} s^{-1}	**26(b)(i)**	4.8×10^{14} Hz
10(b)(iii)	3.32	**26(b)(ii)**	0.96 V
12(b)(ii)	0.98	**26(b)(iii)**	3.0×10^{9} s^{-1}
13(b)(ii)	6.18×10^{-7} m, visible light	**26(b)(iv)**	0.14 W m^{-2}
14(a)(i)	1.02×10^{-22} N s	**26(c)(iii)**	170
16(a)(i)	25.8 MeV	**27(b)(i)**	M = 60, N = 28
16(a)(ii)	3.70×10^{38} s^{-1}	**27(b)(iii)**	–0.130 to –0.138
17(a)(i)	5.23×10^{-19} J	**27(b)(iv)**	4.22×10^{-9} W m^{-2}
17(a)(ii)	5.93×10^{5} m s^{-1}	**27(b)(v)**	7.03×10^{-8} W m^{-2}
17(a)(iii)	5.47×10^{-7} m	**27(c)(ii)**	2.38×10^{-10} s^{-1}
19(d)(i)	8.29 MeV	**27(c)(iii)**	0.0564
20(b)	0.592 W m^{-2}	**28(b)(i)**	8.45×10^{14} Hz
21(b)(i)	98.2%	**28(b)(ii)**	8.0×10^{-20} J
21(b)(ii)1	2.4×10^{14}	**28(c)(iii)3**	20 V
21(b)(ii)2	2.8×10^{8} Bq	**28(d)(i)**	99.9991%
22(a)(i)	3.87×10^{-7} m		