PROJECT *DASH* PART VI

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

MCQ

1 The number of radioactive nuclides in two different samples *P* and *Q* are initially 4*N* and *N* respectively. If the half-life of *P* is *t* and that of *Q* is 2*t*, the number of radioactive nuclides in *P* will be the same as the number of radioactive nuclides in *Q* after a time of

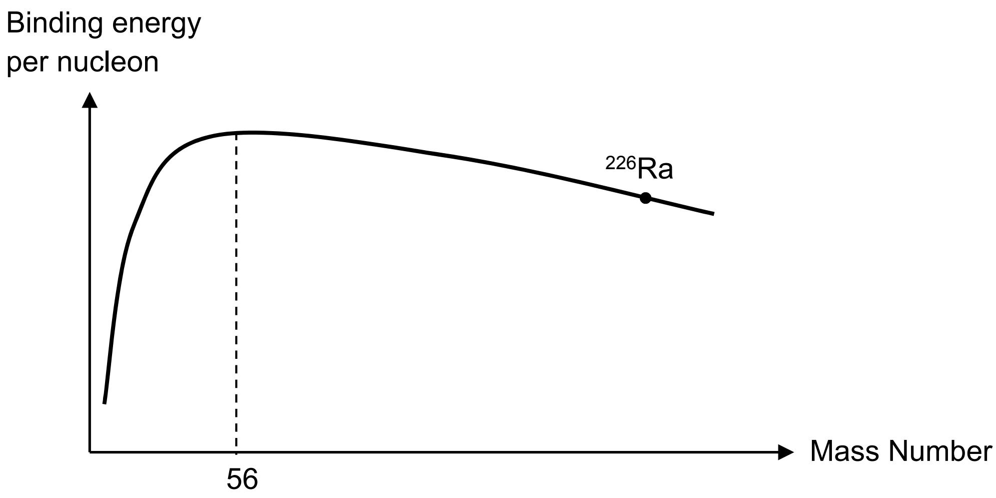
A *t*/2 **B** 2*t* **C** 4*t* **D** 8*t*

[NJC 2011]

N_P & N_Q are numbers of P and Q after time T respectively.
N_P / 4N = $(1/2)^{T/t}$
N_Q / N = $(1/2)^{T/2t}$

(C)

2 The graph below is drawn for a group of naturally-occurring nuclides.



Which of the following statements is correct?

A Nuclei with high mass numbers undergo fusion with release of energy.

B When a nucleus of mass number 56 is formed, it releases the greatest amount of binding energy compared to the formation of nuclei of other mass numbers.

C When the nuclide ^{226}Ra undergoes fission, the binding energy per nucleon is reduced.

D When small nuclei undergo fusion, the products have higher binding energy per nucleon.

[JJC 2011]

(D)

3 Which of the following statements is **not** true about the p-n junction?

A The holes from the p-type material and the electrons from the n-type material diffuse and recombine, forming a region free of mobile charge carriers.

B At the depletion layer, the electric potential at the n-type material is higher than the electric potential at the p-type material.

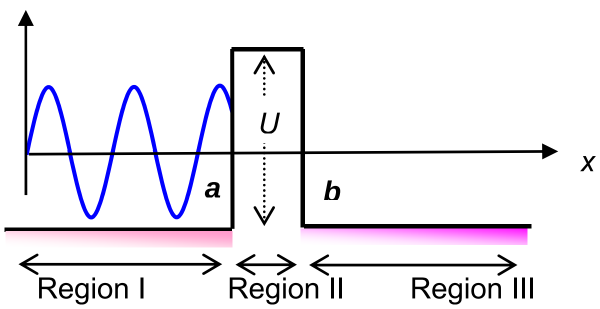
C When forward-biased, the electrons from the n-type material move to the p-type material, resulting in a current flow.

D When reverse-biased, the electric potential at the p-type material is higher than the electric potential at the n-type material.

[RVHS 2010]

(D)

4 A particle is incident on a finite potential barrier at displacement $x = a$. The particle has energy E such that $0 < E < U$. The probability of the particle detected at $x = b$ is 0.04.



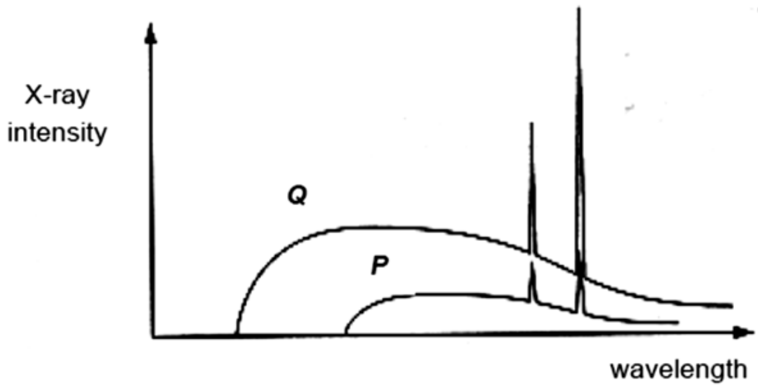
The amplitude of the wave function of the particle in Region I is A. Which of the following best describe the amplitude of the wave function of the particle in Region II and in Region III respectively?

	Region II	Region III
A	Exponentially decaying	0.2 A
B	0.48 A	0.04 A
C	Exponentially decaying	0.016 A
D	0.2 A	0.016 A

[ACJC 2011 *modified*]

Probability $\propto$ amplitude^2 **(A)**

5 X-ray spectra are taken from two X-ray tubes P and Q. The intensity of the X-rays is plotted against the wavelength in both cases and is shown below.



What deduction can be made from these plots?

A X-ray tube P has the higher voltage applied to it and the target material in both tubes is the same.

B X-ray tube P has the higher voltage applied to it and the target material in both tubes are different.

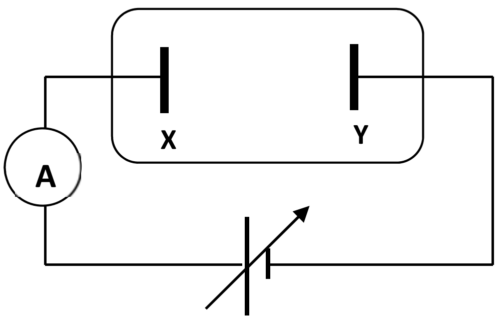
C X-ray tube Q has the higher voltage applied to it and the target material in both tubes is the same.

D X-ray tube Q has the higher voltage applied to it and the target material in both tubes are different.

[IJC 2011]

(C)

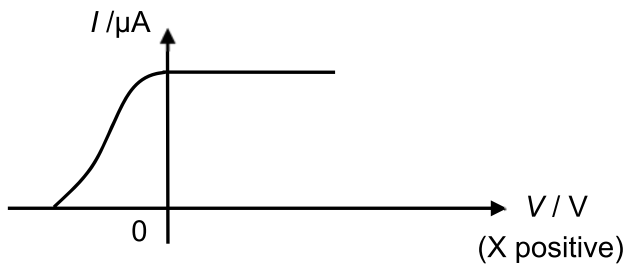
6** The diagram shows a circuit used for photoelectric emission experiments.



The 2 electrodes X and Y are made of different metals. The work function of electrode X is greater than the work function of electrode Y.

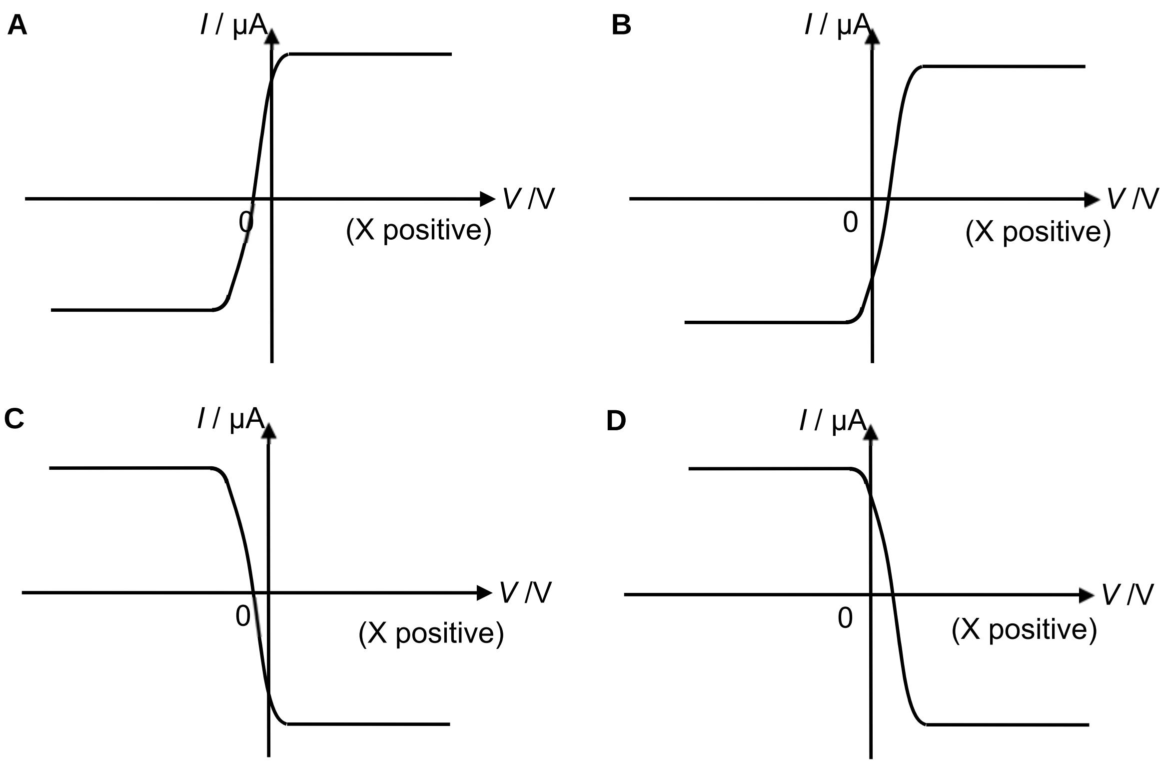
Current-voltage (I-V) characteristics are obtained when both electrodes are illuminated with monochromatic light.

When the wavelength of the light is λ_1, the I-V characteristic is as shown.



Light of wavelength of λ_2, less than λ_1, is then illuminated onto the setup.

Which of the following graphs shows the corresponding *I*-*V* characteristic?



[SRJC 2011]

I-V graph given is for Y emitting photoelectrons only. (Because $\phi_Y < \phi_X$ and stopping potential for Y is when V is negative)
I-V graph for X only would have a negative current (photoelectrons emitted in opposite direction) and a stopping potential when V is positive which smaller than that for Y (because $\phi_Y < \phi_X$).

(A)

7 A student shone a beam of monochromatic light of wavelength 580 nm that is totally reflected at normal incidence by a plane mirror. The light exerts a force of 2.50×10^{-20} N on the mirror, what is the number of photons hitting the mirror per second?

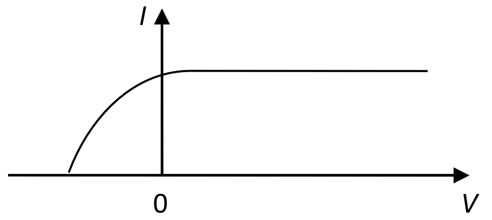
A 5.5×10^6 **B** 1.1×10^7 **C** 2.2×10^7 **D** 2.8×10^7

[IJC 2011]

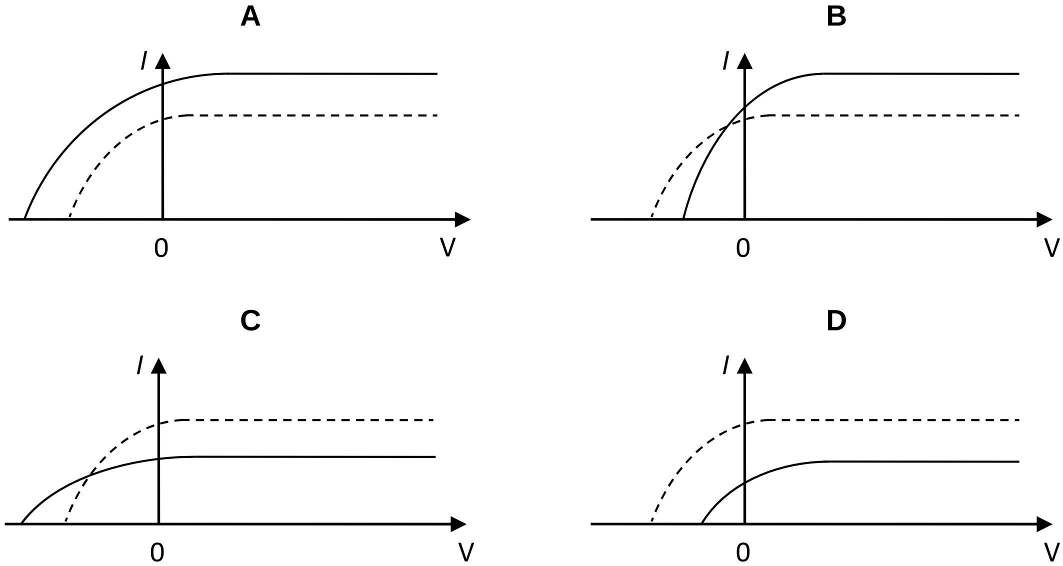
Momentum of photon = h / λ
Change in momentum of 1 photon upon reflection = 2 h / λ
Force = rate of change in momentum = dN/dt $\times$ (2h/λ)
where dN/dt is the rate of incidence of photons on the mirror

(B)

8 A metal surface in an evacuated tube is illuminated with monochromatic 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 *I* depends on the potential difference *V* between the electrodes is as shown in the diagram below.



If the wavelength and the intensity of the incident light are both reduced, which of the graphs below would represent the new relationship between *I* and *V*? (In these graphs, the result of the original experiment is indicated by a broken line.)

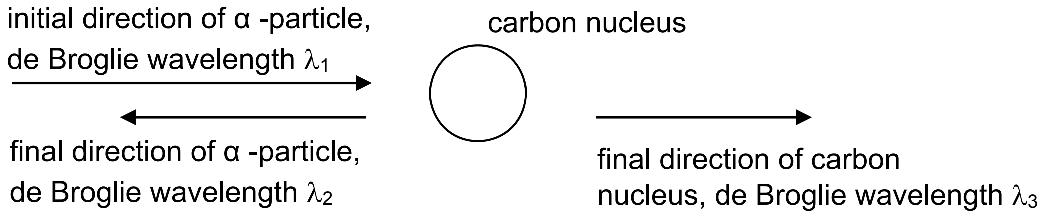


[RVHS 2011]

Lower intensity → Lower (saturation) current
Shorter wavelength → Greater (max) KE → Higher stopping potential required

(C)

9 An α-particle having a de Broglie wavelength λ_1 collides elastically with a stationary carbon nucleus and the particles subsequently move off in opposite directions as shown below.



After the collision, the de Broglie wavelengths of the α-particle and the carbon nucleus are λ_2 and λ_3 respectively. Which of the following statements relating the wavelengths of the particles is true?

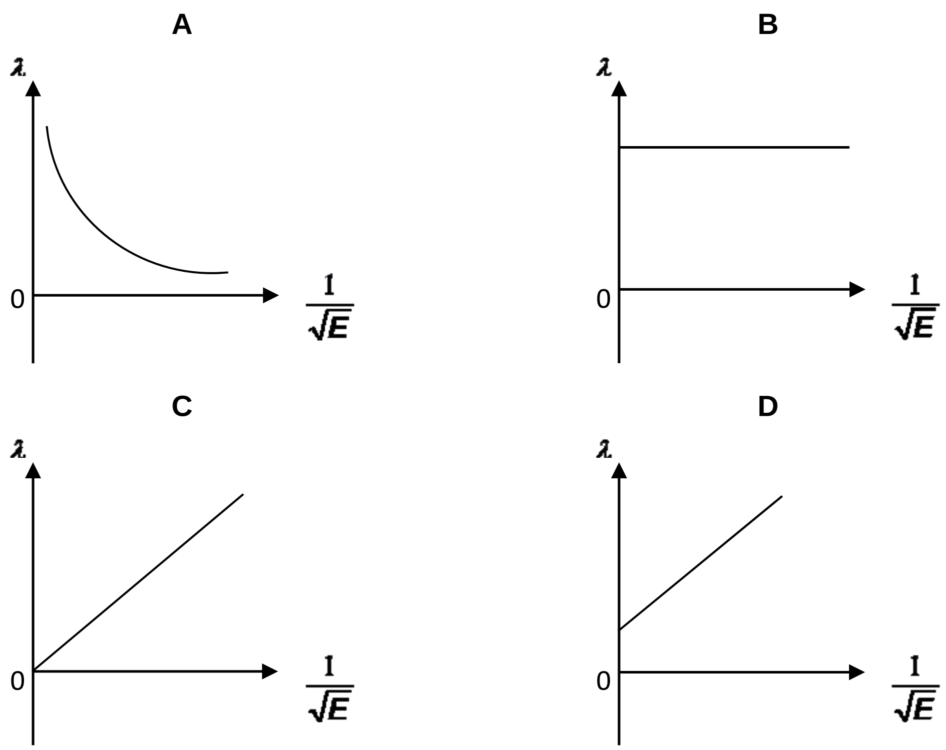
A $\lambda_1 > \lambda_2$ **B** $\lambda_1 > \lambda_3$ **C** $\lambda_2 = \lambda_3$ **D** $\lambda_1 = \lambda_2$

[TJC 2010 modified]

By conserving momentum and K.E., it can be concluded that $|p_2| < |p_1| < |p_3|$.
Thus $|\lambda_2| > |\lambda_1| > |\lambda_3|$.

(B)

10 An electron with kinetic energy E has a de Broglie wavelength of λ. Which of the following graphs correctly represents the relationship between λ and E?

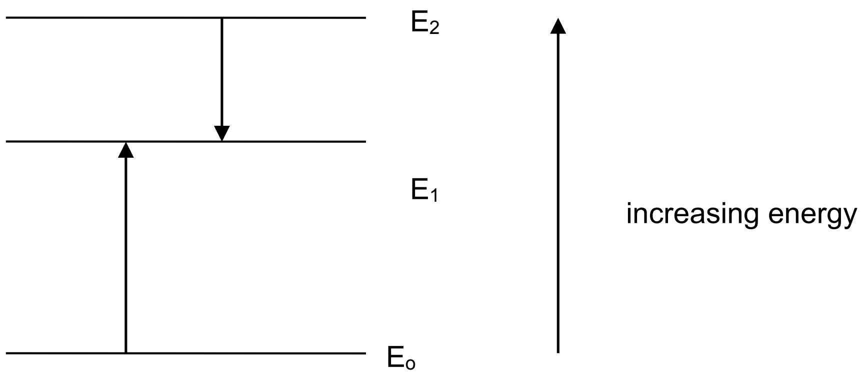


[MJC 2011]

$E = ½\, m v^2 = p^2 / 2m \rightarrow p = \sqrt{(2mE)}$
$\lambda = h / p = h / \sqrt{(2mE)} \propto 1/\sqrt{E}$

(C)

11 The diagram shows part of the energy level picture of a particular element. The energy change for E_o to E_1 is the greater than that for E_2 to E_1.



If the transition E_2 to E_1 corresponds to a red coloured line in the element's spectrum, then the transition E_o to E_1 is possibly associated with

A the absorption of infrared radiation.

B the emission of infrared radiation.

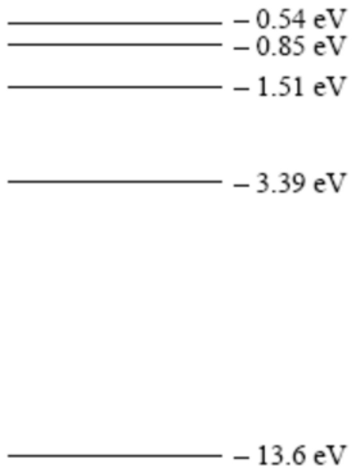
C the absorption of ultraviolet radiation.

D the emission of ultraviolet radiation.

[NYJC 2010]

(C)

12 Some of the energy levels of the hydrogen atom are shown below.



The atoms are excited using electrons of energy 12.4 eV level. How many different photon frequencies can be released?

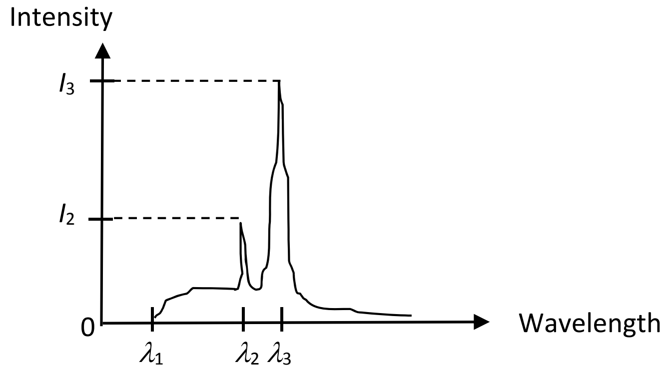
A zero **B** 3 **C** 4 **D** 6

[CJC 2011]

Electrons have enough energy to excite the atoms to the –3.39 eV and –1.51 eV levels.

(B)

13 A beam of electrons are accelerated to hit a metal target and the corresponding X-ray spectrum is as shown below.



Which of the following statements is **true** of the features of the spectrum?

A Increasing the accelerating voltage increases λ_1

B Changing the type of metal changes λ_1

C Both I_2 and λ_2 decrease when the electron beam is made less intense

D I_3 includes the number of X-ray photons of wavelength λ_3 emitted by the 'braking radiation' process.

[YJC 2010]

λ_1 is dependent on the energy of the electrons provided by the accelerating voltage and λ_2 and λ_3 are dependent on the atoms of the target.

(D)

14 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 the reflection coefficient is 0.87. How wide is the barrier?

A 9.7×10^{-22} m **B** 4.0×10^{-20} m **C** 6.8×10^{-12} m **D** 1.0×10^{-10} m

[RI 2011]

(D)

15 The momentum of a moving electron is measured to be 1.77×10^{-24} kg m s^{-1}, to a precision of 0.5%. What is the minimum uncertainty with which its position can be simultaneously measured?

A 3×10^{-11} m **B** 3×10^{-39} m **C** 6×10^{-11} m **D** 6×10^{-9} m

[JJC 2011]

(D)

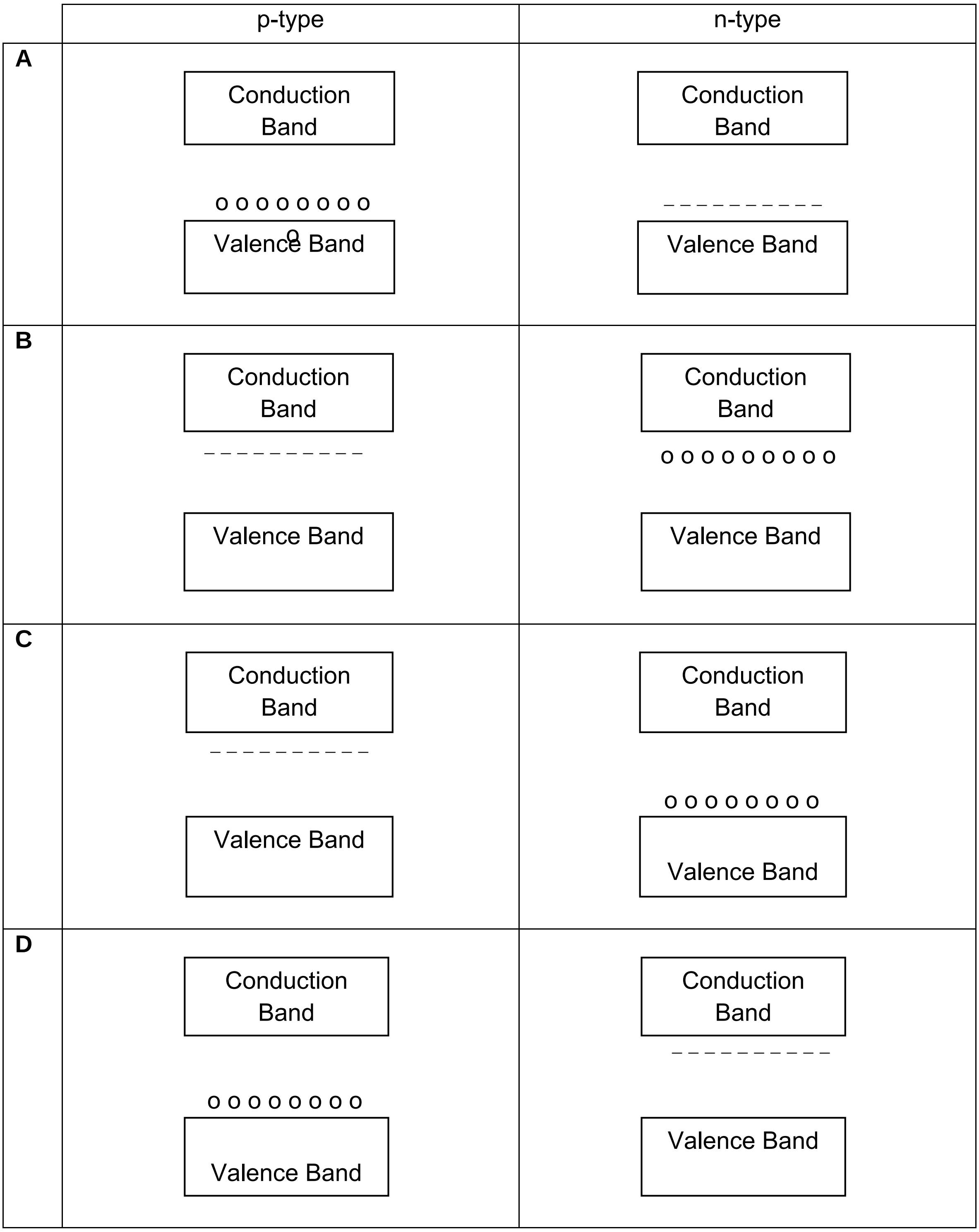
16 A radar dish emits a pulse of 200 MHz electromagnetic waves of duration 9.3 ms. Determine the percentage uncertainty in the frequency of the waves.

A 4×10^{-10} % **B** 4×10^{-6} % **C** 0.09 % **D** 9 %

[VJC 2011]

(B)

17 Which of the following is the correct band diagram for p-type and n-type semiconductors?

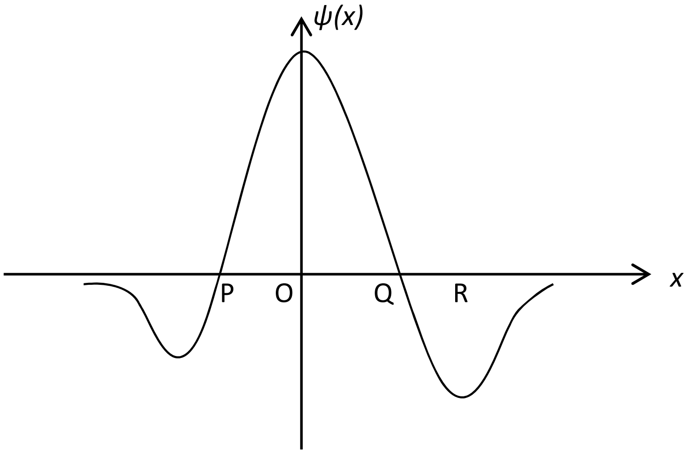


[DHS 2010]

- - - - represent donors, o o o o represent acceptors

(C)

18 The figure below shows the wave function $\psi(x)$ of an electron.



Which of the following statements is correct?

A The probability of locating the electron at O is the highest.

B $|\psi(x)|$ gives the probability of locating the electron within a given region.

C There is greater probability of locating the electron where x is negative.

D The probability of locating the electron at R is the lowest.

[RI 2010 modified]

(A)

19 For a p-n junction at equilibrium after the depletion region has formed, which of the following describes the net charge of the respective regions?

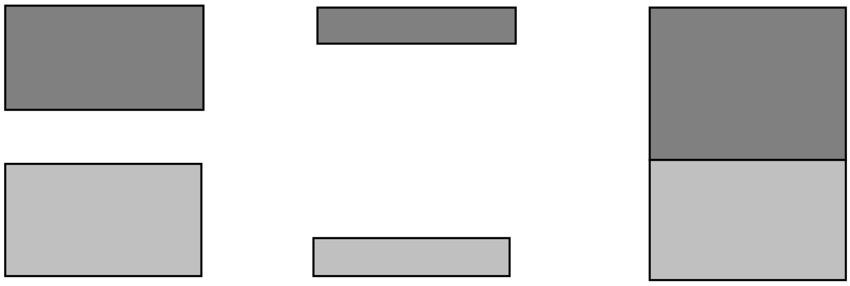
	p-type region	n-type region	entire p-n junction
A	Positive	Negative	Neutral
B	Negative	Positive	Neutral
C	Positive	Positive	Positive
D	Neutral	Neutral	Neutral

[MJC 2011]

p-type and n-type semiconductors are electrically neutral on their own. When put together, the n-type semiconductors loses electrons to the p-type (i.e. gain electrons) at their junction, forming the depletion layer.

(B)

20 The following diagrams show the conduction and valence bands of three different materials:



Which of the following options correctly identify the three materials?

	Material X	**Material Y**	**Material Z**
A	Semiconductor	Insulator	Metallic conductor
B	Metallic conductor	Semiconductor	Insulator
C	Insulator	Semiconductor	Metallic conductor
D	Metallic conductor	Insulator	Semiconductor

[VJC 2010]

(A)

21 Which of the following best describes the meaning of population inversion?

A The frequency of the incident photons is the same as the frequency of the stimulated photons.

B An atom in an excited state undergoes a transition to the ground state and emits a photon.

C The number of electrons at a lower energy level exceeds the number of electrons at a higher energy level.

D The number of electrons at a higher energy level exceeds the number of electrons at a lower energy level.

[TJC 2011]

(D)

22 Which of the following is **not** a characteristic of a laser?

A Monochromatic

B Coherent

C Concentrated

D Visible light

[CJC 2011]

(D)

23 Population inversion is important for the generation of a laser beam because it ensures that

A stimulated emission does not occur more than spontaneous absorption.
B stimulated emission does not occur more than spontaneous emission.
C more photons are emitted than are absorbed.
D more photons are absorbed than are emitted.

[RVHS 2011]

(C)

24 Which of the following statements most accurately describes stimulated emission?

A An electron transiting from a higher energy level to a lower energy level emitting a photon.
B An electron is emitted from an atom after being hit by a high energy photon.
C A photon incident on an electron causing the emission of an electron.
D A photon causing a transition of an electron resulting in the emission of another photon of exactly the same frequency.

[RVHS 2010]

(D)

25 Which conclusion can be drawn from the results of the experiment showing the scattering of α-particles by gold foil?

A Electrons orbit the atomic nucleus in well-defined paths.
B Nuclei of different isotopes contain different numbers of neutrons.
C The atomic nucleus contains protons and neutrons.
D The nucleus is very small compared to the size of the atom.

[DHS 2011]

(D)

26 Uranium-235 undergoes fission as shown in the equation below.

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{143}_{55}\text{Cs} + {}^{90}_{37}\text{Rb} + 3\,{}^{1}_{0}\text{n}$$

195 MeV of energy was released in the reaction. Given that the binding energy per nucleon for uranium-235 is 7.6 MeV, and those for caesium and rubidium are approximately **X** MeV, determine the value of **X**.

A 8.5 **B** 9.7 **C** 11.2 **D** 13.3

[SAJC 2010]

195 MeV of energy released → BE of Cs + BE of Rb > BE of U-235 by 195 MeV

(A)

27 A nickel nucleus $^{59}_{28}\text{Ni}$ can be transformed by a process termed K-capture. In this process the nucleus absorbs an orbital electron.

If no other process is involved, what is the resulting nucleus?

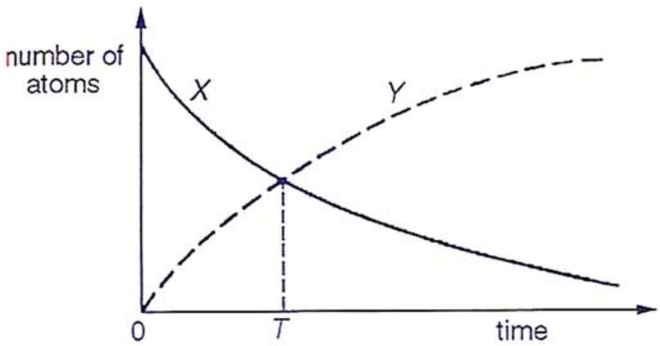
A $^{58}_{28}\text{Ni}$ **B** $^{58}_{27}\text{Co}$ **C** $^{59}_{27}\text{Co}$ **D** $^{59}_{29}\text{Cu}$

[RVHS 2011]

$^{59}_{28}Ni + ^{0}_{-1}e$

(C)

28 The graph represents the decay of a newly prepared sample of radioactive nuclide *X* to a stable nuclide *Y*. The half-life of *X* is τ. The growth curve for *Y* intersects the decay curve for *X* after time *T*.



What is the time *T*?

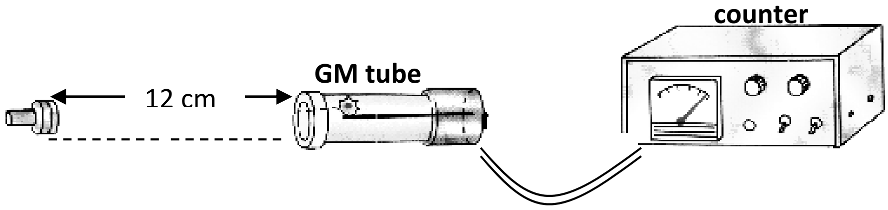
A $\dfrac{\tau}{2}$ **B** $\ln\left(\dfrac{\tau}{2}\right)$ **C** τ **D** 2τ

[ACJC 2010]

$N_X = N_Y$ when half of X has decayed to form Y and the other half of X remains.

(C)

29 An experiment is set up to estimate the activity of a radioactive source. The source is placed a distance of 12 cm from a GM tube which is connected to a counter. The GM tube is capable of detecting all types of radioactive emissions.



The following data is obtained:

	count-rate / min^{-1}		
t / hour	without aluminium sheets (1 cm thick) between source and GM tube		with aluminium sheets (1 cm thick) between source and GM tube
	without source	with source	with source
0	605	4481	4479
18	620	1117	1120

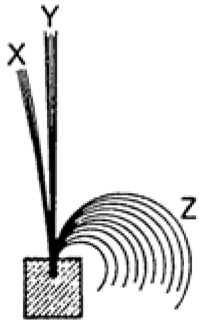
Identify the type of emission and deduce the half-life of the source.

	type of emission	**half-life of source / hour**
A	γ	6
B	β	6
C	β	9
D	γ	9

[ACJC 2011]

A_0 = (4480 – 610) = 3870
A_{18} = (1120 – 620) = 500
A_{18} / A_0 = $(1/2)^{18/T}$ where T is the half life
Absorption by 1cm aluminium sheet is negligible. **(A)**

30 In the early years of the last century, Marie Curie drew an illustration of the investigation of radioactive decay similar to the diagram below (not drawn to scale), which indicated how the three types of radiation from radioactive decay travelled in air in a uniform magnetic field directed into the page.



Which of the following statements about the three types of radiation is false?

A Radiation Y does not carry any charge

B Radiation X consists of particles of roughly the same energy

C Z shows a range of energy and is positively charged

D Radiation Y travels at the speed of light, *c*

[VJC 2011]

Since Z is deflected rightward by the magnetic field (inward), charge on Z is negative.
(C)

Short structured questions

1 **(a)** By reference to band theory, describe how conduction of electrons takes place in an intrinsic semiconductor.

- **Small energy band gap**
- **Above 0 K temperature, some electrons have enough energy to overcome gap.**
- **Electron in conduction band and hole in valence band allows conduction of electricity.**

[3]

(b) Explain how the resistivity of silicon can be decreased when it is doped to be n-type silicon.

- **Doping using group V atom**
- **5th electron not used in covalent bonds, so it is at energy level above valence band (donor level).**
- **Energy gap between donor level and conduction band is smaller.**
- **Conductivity increased, resistivity decreased.**

[3]

(c) Discuss how a p-n junction is able to carry a current under forward bias.

- **p-type at higher potential than n-type**
- **battery pulls electrons away from the p-type and pushes electrons towards the n-type**
- **depletion layer diminishes, conductivity increases**
  (draw diagram)

[3]

(d)* In a light-emitting diode, which is actually a p-n junction, suggest why visible light is sometimes emitted.

- **(creation of an electron-hole pair requires external energy)**
  recombination of an electron with a hole releases energy could be in the form of a photon

[1]

[ACJC 2011]

2 The Scanning Tunnelling Microscope (STM) is an instrument in which a sharp probe is scanned across a sample to detect changes in the surface structure on the atomic scale.

(a) Explain, using the concept of quantum tunnelling, how the STM detects changes in the topography of the surface.

- **Gap between the STM probe and surface acts like a potential barrier**
- **Probability of electrons tunnelling through the barrier is inversely related to the size of the gap**
- **As the probe moves above the surface, the variation in the transmission current will reflect the topography of the surface.**

[3]

(b) When the tip of a STM probe is set at a distance d of 1.0×10^{-10} m from the sample, its transmission coefficient T is 0.0001. The sample has a work function of 4.0 eV.

Compute k given

$$T \propto \exp(-2kd) \quad \text{where } k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$$

(From photoelectric effect, work function is additional energy required for electron to be free from the surface.)

Use m = 9.1×10^{31} kg and (U–E) = 4.0 eV *(convert to J)*, **k = 1.07×10^{25} m^{-1}**

k = ... [2]

[JJC 2011]

3 **(a)** A particular material is designed to emit photoelectrons when visible light is incident on it. When light of wavelength 535 nm is incident on it, electrons are emitted has a stopping potential of about 1.30 V.

(i) Calculate the energy of the photon incident onto the material.

$E = h f = h c / \lambda = 3.71\times10^{-19}$ J

energy = ... J [2]

(ii) Calculate the work function of the material.

Energy of photon absorbed = Work function + KE_{max}
$E = \phi + e V_S \rightarrow \phi = 1.63 \times 10^{-19}$ J

work function = ... J [2]

(b) The material used in **(a)** is most likely metallic in nature. By considering the band theory of materials, state and explain what will happen if the experiment is repeated for a semiconductor instead of a metal.

- **Energy band gap much greater for semiconductors**
- **Work function also greater**
- **Energy of photon not likely enough to produce photoelectrons**

[3]

[DHS 2010]

4 **(a)** **(i)** State one observation from Einstein's photoelectric experiment that led to the conclusion that light has particle-like properties.

- **Existence of a threshold frequency**
- **KE of emitted electrons is dependent on frequency but not intensity of radiation**
- **Very short time lag between radiation and emission of electrons**

[1]

(ii) Explain the reasoning behind your conclusion in **(a)(i)**.

- **Energy of light particle is proportional to its frequency. Energy of light particle must be greater than work function for emission.**
- **KE of emitted electrons is dependent only on the energy of the light particle absorbed, which is proportional to its frequency.**
- **Absorption of energy is almost instantaneous. Time required is duration of (perfectly inelastic) collision between light particle and electron.**

[1]

(iii) Write down Einstein's photoelectric equation, identifying each of the three terms in it.

$E = \phi + K_{max}$
E – energy of photon absorbed, ϕ – work function of metal surface,
K_{max} – maximum kinetic energy of emitted electron

[2]

(b) In a photoelectric experiment, light of various frequencies was shone onto a metal surface, and the stopping potential V_s was measured in each case. The resulting graph of stopping potential against frequency is shown in **Fig. 4.1**.

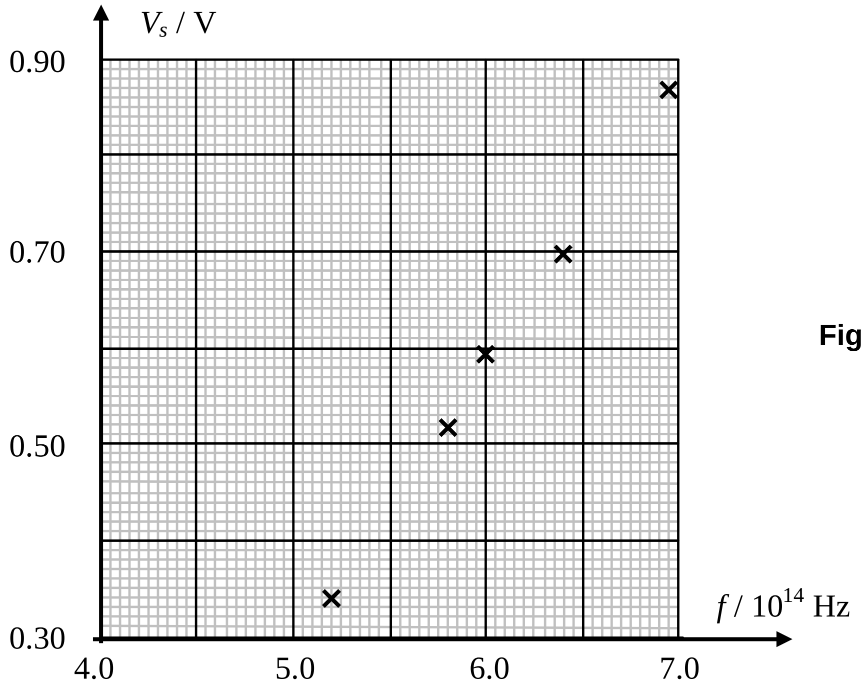


Fig. 4.1

(i) Determine the threshold frequency for the metal. (Note that the graph in Fig. 27.1 does not start from the true origin.)

- **Draw a best fit straight line**
- **Determine gradient of line**
- **Use gradient to calculate horizontal intercept i.e. $y = m(x - x_0)$**

f_0 = horizontal intercept = 4.10×10^{14} Hz

threshold frequency = ... Hz [3]

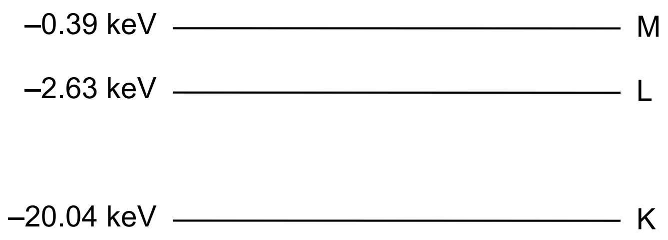
(ii) Determine the work function of the metal.

$\phi = h f_0 = 2.72 \times 10^{-19}$ J

work function = ... J [1]

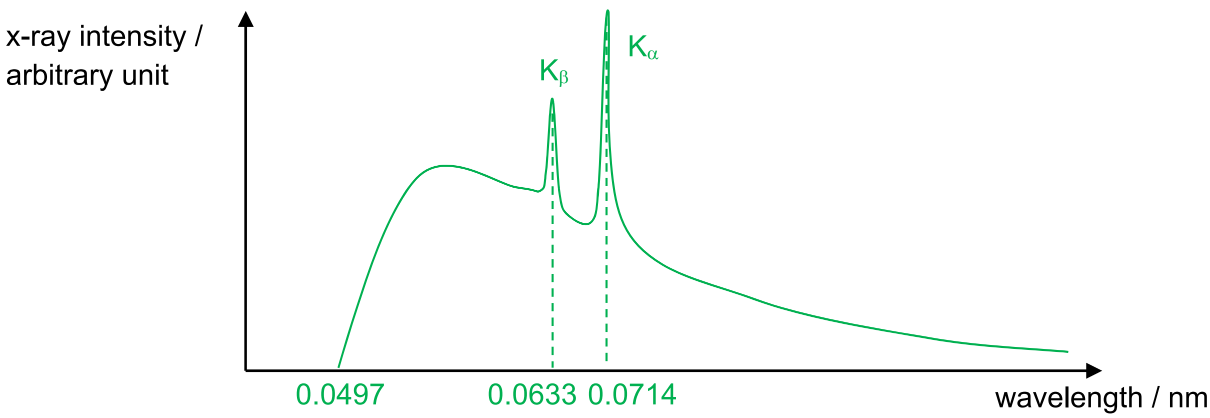
[VJC 2011]

5 **(a)** The diagram shows the energy levels of the innermost electrons of an element:



Electrons accelerated through a potential difference of 25.0 kV are beamed at the element.

On the following axes, sketch the x-ray spectra produced from the collisions of the electrons. Calculate meaningful values of wavelength and include them in your graph. [3]



(b) A neutron is confined within an atomic nucleus of size 1.0×10^{-14} m. Taking the uncertainty in the position of the neutron to be equal to the size of the nucleus, calculate the minimum uncertainty with which the velocity of the neutron can be simultaneously measured.

$\Delta p\, \Delta x = h / 4\pi \rightarrow \Delta p = 5.3\times10^{-21}$
$\Delta p = m\, \Delta v \rightarrow \Delta v = 3.2\times10^{6}$ m s^{-1}

uncertainty of velocity = ... m s^{-1} [2]

(c) A stationary radon nucleus may decay spontaneously into a polonium nucleus and an α-particle:

$$^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$$

The rest masses of these nuclei are ^{222}Rn, 222.0176 u; ^{218}Po, 218.0090 u; ^{4}He, 4.0026 u, and it may be assumed that no γ-ray is emitted. Find the speed of the alpha particle.

Energy released = $\Delta m\, c^2$ where Δm is the decrease in rest mass of the particles
$\Delta m = 0.0060$ u = 10×10^{-30} kg → $\Delta E = 9.0\times10^{-13}$ J

By conservation of momentum, $p_{Po} + p_{\alpha} = p_{Rn} = 0$ → $|p_{Po}/p_{\alpha}| = 1$
Since $E = \frac{1}{2}mv^2 = p^2/m$ → $E_{Po}/E_{\alpha} = m_{\alpha}/m_{Po} = 4/218$
Thus $E_{\alpha} = 218/222 \times \Delta E = 8.8\times10^{-13}$ J

→ $v_{\alpha} = 1.6\times10^{7}$ m s^{-1}

speed = ... m s^{-1} [3]

[TPJC 2011]

6 **(a)** The uncertainty in the measurement of the momentum, Δp of a bullet and an electron are 2.0×10^{-3} kg m s^{-1} and 2.7×10^{-32} kg m s^{-1} when they have the same speed of 300 m s^{-1} respectively.

(i) The Heisenberg position-momentum uncertainty principle can be stated as follows:

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

where Δx and Δp represents the uncertainty in the position and momentum respectively.

Hence determine the uncertainty of locating the position of the bullet and electron using the Heiserberg Uncertainty Principle.

Using equation provided: $\Delta x_{bullet} = 2.7\times10^{-32}$ m and $\Delta x_{electron} = 2.0\times10^{-3}$ m

uncertainty of bullet position = ... m

uncertainty of electron position = ... m

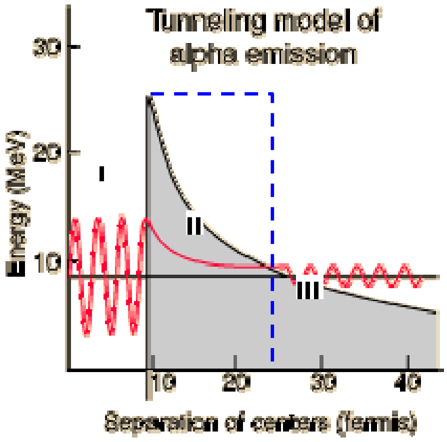
[1]

(ii) Discuss the implication of your answers found in **(a)(i).**

Position of a bullet can be determined to high precision relative to its size (uncertainty 10^{-32}m vs size 10^{-2}m) i.e. deterministic.
Position of an electron more probabilistic (uncertainty 10^{-3}m vs size 10^{-16}m).

[1]

(b) The shaded region in **Fig. 6.1** shows the coulomb potential barrier as seen by the alpha particle during its decay in polonium-212 and also the wave functions of the alpha particle in regions I, II and III respectively.



Region I: Potential energy of alpha particle due to presence of Nuclear and Coulomb force
Region II: Potential energy of alpha particles when it is still within the atom but experiences mainly the Coulomb repulsive force.

Fig. 6.1

Note that 1 fermi metre = 10^{-15} m

(i) Explain the phenomenon that tells us that alpha particle have the probability of appearing in Region III.

- **Quantum tunnelling**
- **Probability of the alpha particle passing through the barrier is non-zero even though it has less energy than what is required to do so.**

[1]

(ii) Assuming a rectangular potential barrier of height 26.4 MeV taken at the peak of the coulomb barrier and width 17.9 fm as shown by the dotted lines, the half-life is determined to be 1.5×10^7 s. However, the actual half-life is only about 0.30 μs.

Comment on the large difference on the order of magnitude of 13 using the concept of the transmission probability and decay constant of the alpha particles.

- **Rectangular barrier causes transmission to be greatly underestimated.**
- **Thus the alpha decay rate is actually much higher → shorter half life.**

[2]

(iii) State a possible improvement to the method of determining the transmission probability to get a better estimate of the half-life.

(Inaccuracy is the result of transmission probabilities being very different from one end of barrier to the other.)

- **Breaking barrier into smaller segments and determine the transmission probability for each segment.**

[1]

[ACJC 2010]

7 **(a)** An electron has kinetic energy 5.0000 eV and its momentum is accurate to within 0.01%. Find the minimum uncertainty in determining the position of this electron.

$E = p^2 / 2m \rightarrow p = 1.2\times10^{-24}$ kg m s^{-1} *(Note KE must be converted to J)*
$E = p^2 / 2m \rightarrow \Delta E/E = 2\Delta p/p \rightarrow \Delta p = 6\times10^{-29}$ kg m s^{-1}

$\Delta p\,\Delta x = h / 4\pi \rightarrow \Delta x = 9\times10^{-7}$ m

uncertainty of position = ... m [4]

(b) The electron described in **(a)** is now incident on a potential barrier with thickness 0.200 nm and height 10.0 eV (see **Fig. 7.1** below).

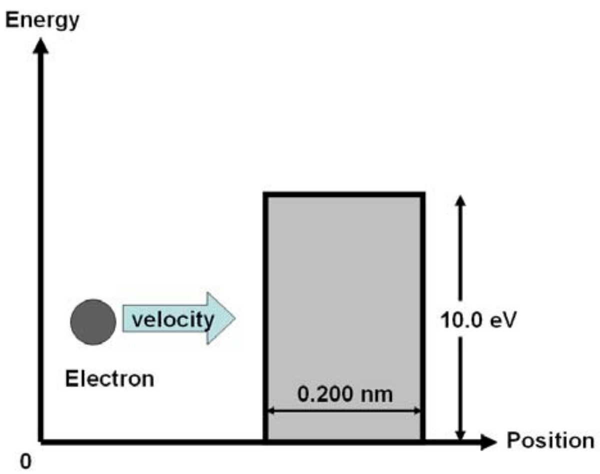


Fig. 7.1

(i) Calculate the probability that the electron will tunnel through the barrier.

E = 5.0000 eV, U = 10.0 eV, d = 0.200 nm, m = 9.1×10^{-31} kg
Convert the above to SI units and sub into

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

T = 0.010

probability = ... [3]

(ii) Calculate the probability that the electron will be reflected.

$T + R = 1 \rightarrow R = 0.990$

probability = ... [2]

(c) Suppose that the barrier height is now reduced. Discuss how the amplitude of the reflected wave function of the electron changes.

- **U decreased → k decreased → T increased → R decreased**
- **Amplitude of reflected wave function decreased**

[2]

[VJC 2010]

8 **(a)** State and explain briefly the *conditions* necessary for the production of a laser beam.

- **Metastable state to promote stimulation**
- **Population inversion to promote emissions and reduce absorptions**
- **Retention of emitted photons to stimulate further emissions**

[3]

(b) Complete the table below to show the *three* differences between *light from a filament lamp* and *laser light*. [3]

Light from a filament lamp	Laser light
continuous range of wavelengths	monochromatic
not coherent	coherent
not polarised	polarised

[MI 2010]

9 A stationary radon nucleus may decay spontaneously into a polonium nucleus and an α-particle as shown below.

$$^{222}_{86}Rn \rightarrow \, ^{218}_{84}Po + \, ^{4}_{2}He$$

(a) Explain what is meant by the term spontaneous with regard to the decay of radon.

No external stimulation or excitation energy required

[1]

(b) In addition to obeying the laws of conservation of charge, mass and energy, state another conservation law which applies to the decay process of the radon nucleus described above. Hence explain clearly the motion of the product particles after decay.

Conservation of momentum
Po-218 and He-4 must separate with equal momentum in opposite directions.

[1]

(c) Explain the origin of the energy carried by the decay products.

Potential energy of the nucleons (nuclear energy).
When nucleus decays, part of this energy is converted into kinetic energy.

[2]

(d) Deduce an expression for the ratio of the energy carried by the α-particle to the total energy E of the product particles in terms of their mass numbers.

*See **5 (c)**.*
K_α / E = 218 / 222 = 0.982

ratio = ... [3]

[VJC 2011]

10 **Fig. 10.1** shows the variation with nucleon number of the binding energy per nucleon of a nucleus.

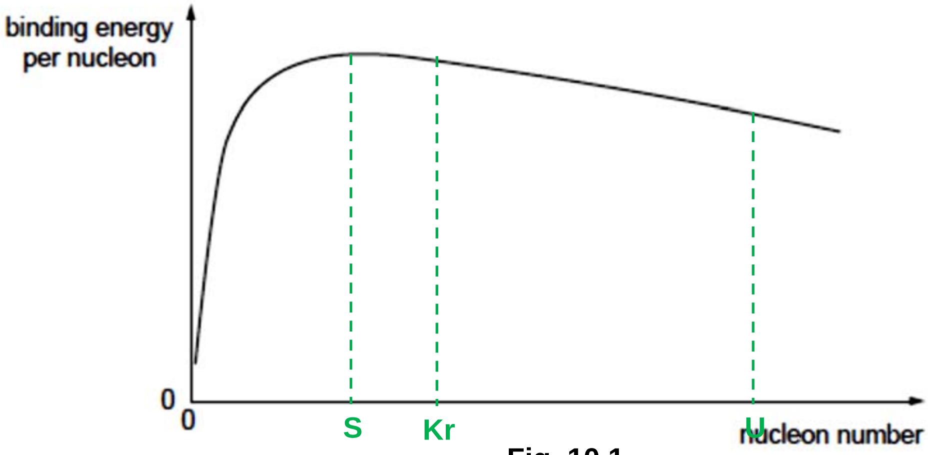


Fig. 10.1

(a) Define binding energy of a nucleus.

Energy required to completely separate the nucleus into its constituents (protons and neutrons).

[1]

(b) On **Fig. 10.1**, mark with the letter S the position of the nucleus with the greatest stability. [1]

(c) One possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2\,^{1}_{0}n$$

(i) On **Fig. 10.1**, mark possible positions for

1 the Uranium-235 nucleus (label this position U), [1]

2 the Kyroton-90 nucleus (label this position Kr). [1]

(ii) Using **Fig. 10.1**, explain how greater stability is achieved in this reaction.

- **Total binding energy of products Ba and Kr is greater than binding energy of U.**
- **More energy is now required to completely separate the system into individual particles → more stable.**

[2]

(iii) The binding energy per nucleon of each nucleus is as follows.

$^{235}_{92}U$: 1.2191×10^{-12} J
$^{144}_{56}Ba$: 1.3341×10^{-12} J
$^{90}_{36}Kr$: 1.3864×10^{-12} J

Use these data to calculate the energy released in this fission reaction.

Energy released = Increase in binding energy of system
= (BE of Ba + BE of Kr) – BE of U
= 3.040×10^{-11} J

energy released = ... J [2]

(iv) Explain why the neutrons were not included in your calculation in **(iii)**.

Neutron is already a single particle → No binding energy

[1]

[IJC 2011]

11 The isotope Iron-59 is a β–emitter with a half-life of 45 days. In order to estimate engine wear, an engine component is manufactured from non-radioactive iron throughout which the isotope Iron-59 has been uniformly distributed. The mass of the component is 2.4 kg and its initial activity is 8.5×10^7 Bq.

The component is installed in the engine 60 days after manufacture of the component, and then the engine is tested for 30 days. During the testing period, any metal worn off the component is retained in the surrounding oil. Immediately after the test, the oil is found to have a total activity of 880 Bq.

Calculate

(a) the decay constant for the isotope Iron-59

$\lambda = \ln 2 / T = 0.0154\ \text{day}^{-1} = 1.78\times10^{-7}\ \text{s}^{-1}$

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

(b) the total activity of the component when it was installed

$A_{60} / A_0 = (1/2)^{t/T}$ → $A_{60} = 3.4\times10^7$ Bq

total activity = ... Bq [2]

(c) the mass of iron worn off the component during the test.

Activity α mass of component
$A_{90} / A_0 = (1/2)^{t/T}$ → $A_{90} = 2.1\times10^7$ Bq
$A_{worn} / A_{90} = m_{worn} / m_{Total}$ → $m_{worn} = 1.0\times10^{-4}$ kg

mass = ... kg [3]

[RVHS 2010]

12 **(a)** For a spacecraft launched into the outer regions of the solar system, it is not practical to have its battery recharged by solar panels. Such spacecrafts use Plutonium-238 (Pu-238), which is an alpha emitter with a half-life of 88 years, as fuel.

(i) If each alpha particle is emitted with a kinetic energy of 5.0 MeV, calculate that the minimum activity of the source required to produce an alpha particle beam of power 20 W.

Rate of emission required = Power / KE of 1 emission = 2.5×10^{13} s^{-1}

minimum activity = ... Bq [2]

(ii) Show that the decay constant, λ, of Pu-238 is 2.5×10^{-10} s^{-1}.

λ = ln 2 / T = 7.9×10^{-3} $year^{-1}$

[1]

(iii) Calculate the mass of Pu-238 required to generate the activity shown in **(i)**.

$A = \lambda N \rightarrow N = 1.0\times10^{23}$
mass = $N \times 238u = 4.0\times10^{-2}$ kg

mass = ... kg [3]

(iv) Plutonium is one of the most dangerous radioactive substances known. It has been estimated that even a small amount of this substance, suitably distributed, would be enough to kill more than a billion people. Comment on the risks on the population on Earth involved in using plutonium as a fuel for spacecraft.

- **Wide distribution due to height of source (spacecraft).**
- **Long half life → stays in ecosystem for a long time.**

[2]

(b) The radioactive isotope, Iodine-131, with a half-life of 30 years, and Caesium-137, with a half-life of 8 days, are the nuclear wastes generated from nuclear power plants. Consider that each of these wastes is of similar mass and sufficient to pose a hazard initially, explain which of these nuclear wastes should be stored for a longer period of time.

- **Total binding energy of products Ba and Kr is greater than binding energy of U.**
- **More energy is now required to completely separate the system into individual particles → more stable.**

[2]

[SAJC 2010]

13 **(b)** **Fig. 13.2** below shows the path of an α-particle as it passes near the nucleus of a gold atom.

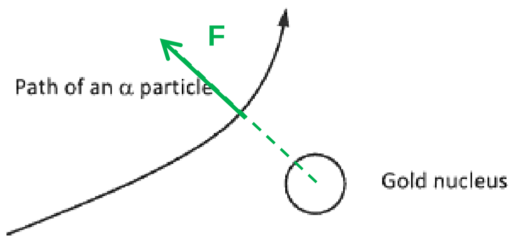


Fig. 13.2

(i) Explain why the α-particle was deflected as shown in **Fig. 13.2**.

- **Repulsion by nucleus**
- **Nucleus and alpha particle are both positively charged**

[2]

(ii) Indicate on **Fig. 13.2** the direction of the electric force acting on the α-particle. [1]

(c) Xenon-139 has a half-life of 41 s and is generated at a constant rate during the fission of a specific sample of Uranium-235. The number of Xenon-139 nuclei in the sample increases initially and finally becomes constant.

(i) Explain the meaning of the following terms:

1 half-life

Time for half of radioactive nuclei in fixed sample to decay

[1]

2 fission

Splitting of nucleus into smaller nuclei

[1]

(ii) Suggest a reason why the number of Xenon-139 nuclei in the sample becomes constant.

Activity of Uranium-235 (rate of production of Xenon-139) =
Activity of Xenon-139 (rate of decay of Xenon-139)

[1]

[MI 2010]

Long structured questions

1 In an experiment to investigate photoelectric effect, a line emission spectrum from hydrogen discharge tube is used.

(a) Explain how a line emission spectrum leads to an understanding of the existence of discrete electron energy levels in atoms.

- **Only specific frequencies of light emitted by isolated atoms.**
- **Only specific quanta of energy given out.**
- **Energy transitions by atoms are of specific quanta.**
  (Thus there must be existence of discrete energy levels in atoms.)

[3]

(b) Some of the lines of emission spectrum of atomic hydrogen are shown in **Fig. 1.1**.

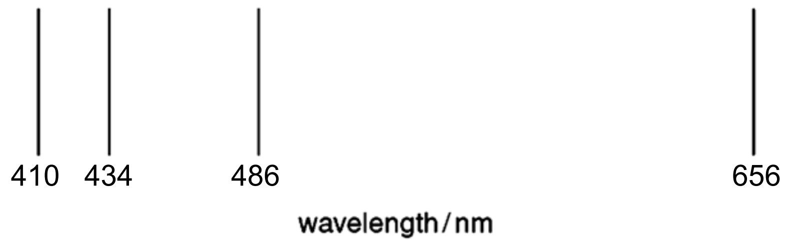


Fig. 1.1

The photon energies associated with some of these lines are shown in **Fig. 1.2**.

wavelength / nm	Photon energy / 10^{-19} J
410	4.85
434	4.58
486	**4.09**
656	3.03

Fig. 1.2

(i) Complete **Fig. 1.2** by calculating the photon energy for a wavelength of 486 nm. [2]

$E = h f = h c / \lambda$

(ii) Energy levels of a single electron in a hydrogen atom are shown in **Fig. 1.3**.

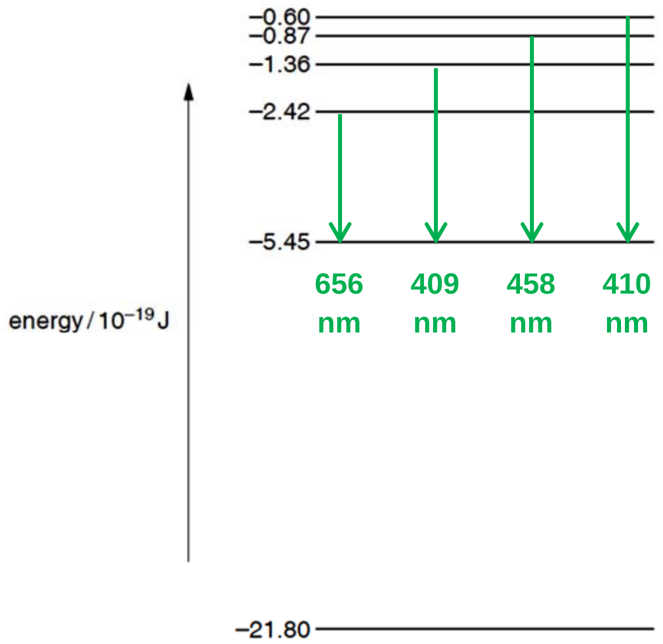


Fig. 1.3 (not to scale)

Use data from **(i)** to show, on **Fig. 1.3**, the transitions associated with each of the four spectral lines shown in **Fig. 1.1**. Show each transition with an arrow. [2]

(c) **Fig. 1.4** shows a photocell.

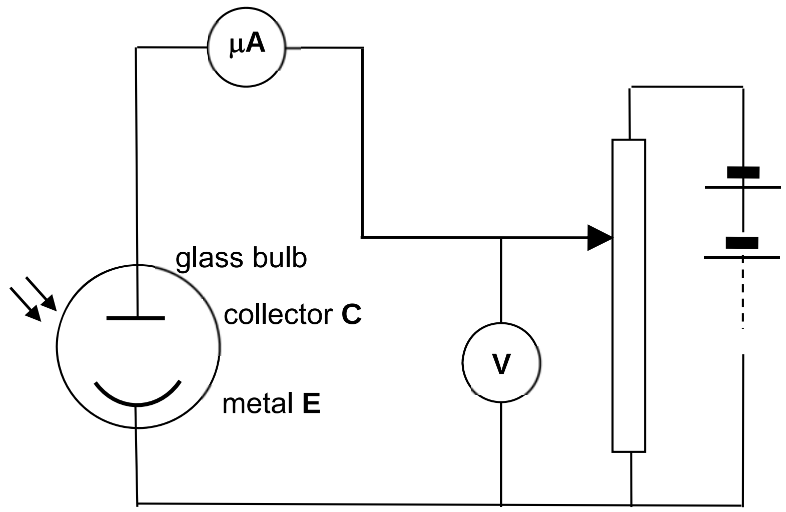


Fig. 1.4

When the metal surface is exposed to electromagnetic radiation, photoelectrons are ejected. The collector collects the photoelectrons and the sensitive ammeter indicates the presence of a tiny current.

(i) The light of a wavelength of 434 nm from the hydrogen discharge tube was selected to shine on the photocell. The ammeter shows a current of 1.2×10^{-7} A. Calculate

1. the charge reaching the detector in 5.0 s

$Q = I\,t = 6.0\times10^{-7}$ C

charge = ... C [1]

2 the number of photoelectrons reaching the collector in 5.0 s

$Q = N\,e \rightarrow N = 3.8\times10^{12}$

number of photoelectrons = ... [1]

(ii) The work function energy of the metal is 2.2 eV. Calculate

1 the maximum kinetic energy of an ejected photoelectron

Energy of photon $E = 4.58\times10^{-19}$ J
$E = \phi + K_{max} \rightarrow K_{max} = 1.06\times10^{-19}$ J

maximum kinetic energy = ... J [2]

2 the potential to stop the most energetic electrons from reaching the collector.

$e\,V_s = K_{max} \rightarrow V_s = 0.663$ V

potential = ... V [1]

(iii) The intensity of the incident radiation is doubled but the wavelength is kept constant. State and explain the effect this has on each of the following

1 the maximum kinetic energy of each photoelectron

- **wavelength unchanged → energy of photon absorbed unchanged**
- **→ Max KE of electron unchanged**

[2]

2 the current in the photocell

- **Intensity doubled → rate of incidence of photons doubled → probability of photon absorption doubled**
- **→ photoelectric current doubled**

[2]

(d) Moving electrons have a wave-like property.

(i) Calculate the speed v of an electron having a de Broglie wavelength equal to the wavelength of the light in **(c)**.

$\lambda = h / p = h / m v \rightarrow v = 1680 \text{ m s}^{-1}$

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

(ii) The electrons are directed into a thin film of graphite. Deduce and explain if the wave-nature of the electrons moving with the speed in **(d)(i)** is observable.

- **Atom separation in graphite is about 10^{-10} m which is very much smaller than wavelength of electrons.**
- **Diffraction pattern is not observable.**

[2]

[IJC 2011]

2 (a) Radiocarbon dating is possible because of the presence of radioactive carbon-14 caused by the collision of neutrons with nitrogen-14 in the upper atmosphere. The equation for the reaction is:

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + X$$

The radioactive carbon-14 decays with a half-life of about 5700 years by the emission of a particle Y of energy 0.016 MeV, changing back into nitrogen-14.

$$^{14}_{6}C \rightarrow ^{14}_{7}N + Y$$

(i) Identify the particle X.

proton $^{1}_{1}p$

[1]

(ii) Identify the particle Y.

beta particle $^{0}_{-1}e$

[1]

(iii) The amount of energy released in the first reaction is 0.7060 MeV. Using the data below, determine the mass of the particle X in atomic mass units.

The masses of the nuclei involved are listed below:

Carbon-14	14.003242 u
Nitrogen-14	14.003158 u
Neutron	1.008665 u

Mass-equivalent of released energy $\Delta m = 1.125\times10^{-30}$ kg = 0.000756 u
Conservation of mass-energy:
$m_{N14} + m_n = m_{C14} + m_X + \Delta m \rightarrow m_X = 1.007825$ u

mass = ... u [3]

(b) **(i)** Define half-life and decay constant.

Half life: Time for half of radioactive nuclei in fixed sample to decay.
Decay constant: Probability that a radioactive atom will decay in unit time.

[2]

(ii) Calculate the decay constant of carbon-14.

λ = ln 2 / T = 1.2×10^{-4} year^{-1}

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

(iii) Using your answers to **(i)** and **(ii)**, determine the average time each carbon-14 atom spends in a given sample until it decays.

Average life time = $1/\lambda$ = 8200 year

mean time = ... year [1]

(iv) The mass of carbon-14 produced by the reaction in the upper atmosphere in one year is 7.5 kg. Show that the number of carbon-14 atoms produced each year is approximately 3.2 x10^{26}.

Mass of 1 atom m = 14 u = 2.3×10^{-26} kg
Number of atoms in 7.5 kg = 7.5 / m = 3.2×10^{26}

[1]

(v) Assuming that the number of carbon-14 atoms in the Earth and its atmosphere stays constant, calculate the number of carbon-14 atoms in the Earth and its atmosphere.

Number of atoms is constant → rate of decay (activity) = rate of production
A = λ N = 3.2×10^{26} year^{-1}
N = 2.7×10^{30}

number of carbon-14 atoms = ... s [2]

(c) The carbon-14 dating technique for dating archaeological materials depends on the assumption that every living organism assimilates radioactive carbon-14 atoms from the atmosphere, thus becoming slightly radioactive and emitting Y particles at a rate of 0.80 Bq for each gram of total carbon content in each organism. When the organism dies, no more carbon is assimilated and the carbon-14 present decays. The radioactive decay is said to be a *random* and *spontaneous* process.

(i) Explain the meaning of the terms in italics.

random

- **Any atom can disintegrate at any time**

[1]

spontaneous

- **No external stimulation required**

[1]

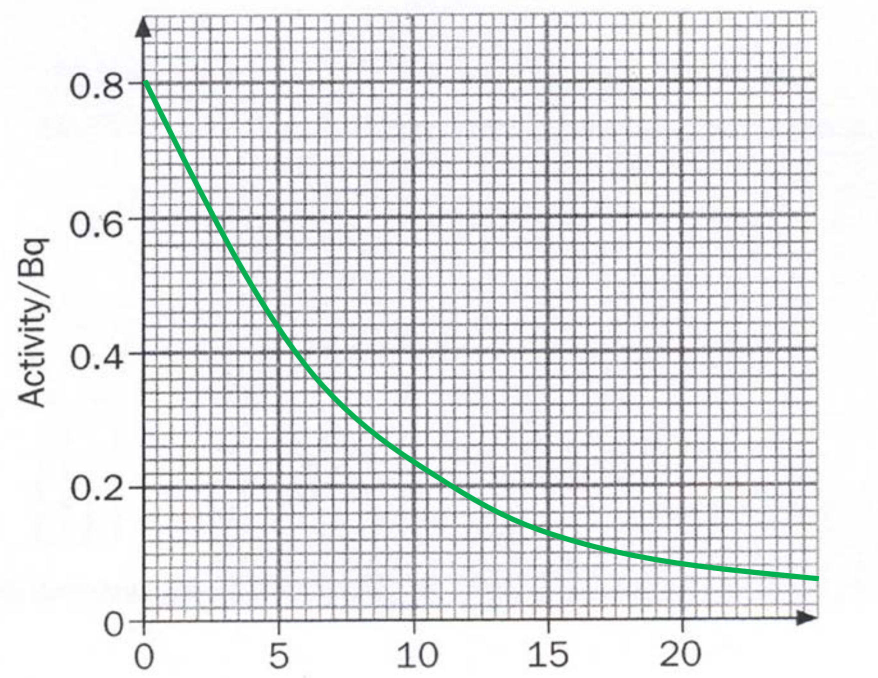
In a carbon dating experiment, 2.5 g of carbon from a sample of dead wood gave an activity of 0.75 Bq after allowing for background radiation.

(ii) Explain the term “background radiation”.

- **Radiation present without a known source**
- **Due to nature such as cosmic rays**

[1]

(iii) Sketch, on axes in the figure below, a graph to show how the activity of carbon-14 in one gram of sample having an initial activity of 0.80 Bq will vary with time over a period of three half-lives. [2]



(iv) Use the graph to estimate the age of the wood. [2]

Activity per gram of carbon = 0.30 Bq
From graph, age = 7750 years

(v) Suggest why an activity of 0.80 Bq would be hard to measure in a typical laboratory.

- **Too low compared to background radiation**

[1]

[RVHS 2011]

3 **(a)** The X-ray spectrum is first produced by an X-ray tube with tungsten (atomic number, Z = 74) anode. Another X-ray spectrum is then produced using barium (atomic number, Z =56).

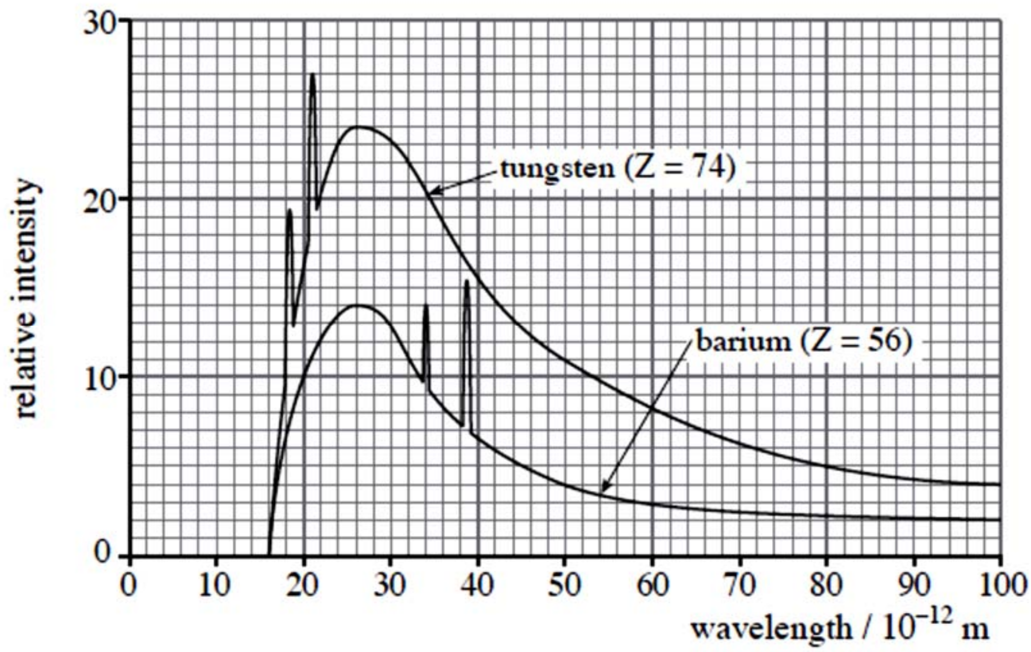


Fig. 3.1

(i) Describe how the characteristic X-ray spectrum is formed.

- **Electrons collide with target → lose kinetic energy → emit photons**
- **Loss in kinetic energy can be any amount less than the initial kinetic energy of the electrons → X-rays give continuous spectrum with minimum wavelength**

- **Some electrons knock out electrons in innermost (K) shell of target atom**
- **Electrons from higher shells fill hole in K shell → release specific amounts of energy in the form of photons → give rise to spikes / line spectrum**

[4]

(ii) The accelerating potential used to produce the X-ray spectra using tungsten and barium are the same. Explain how this can be deduced from **Fig. 3.1**.

- **Same minimum wavelength. Kinetic energy of electrons are the same.**

[1]

(iii) Hence calculate the accelerating voltage for the barium spectrum.

Max energy of photon = $h\,c\,/\,\lambda = 1.1\times10^{-14}$ J
= KE of electron
During acceleration: KE gain in electron = Loss in EPE
$1.1\times10^{-14} = q\,V \rightarrow V = 7.8\times10^{4}$ V

accelerating voltage = ... V [2]

(iv)* Suggest why there is a difference in intensities of the X-rays in the tungsten and barium spectra.

- **Difference is primarily in continuous spectrum (little difference in height of spikes).**
- **Tungsten nuclei are more massive → cause greater loss in K.E. of electrons during collisions**

[2]

(b) An X-ray machine is accelerating electrons through a p.d. of 200 kV. The current produced is 25.0 mA. The target is a heavy metal mass 1.00 kg, and specific heat capacity 300 J kg K^{-1} and has a melting point of 3000 K.

The machine is at 300 K when it is first started. While the machine is operating, the cooling fails and its temperature increases by 16.5 K within a second.

(i) Calculate efficiency of X-ray production.

Power supplied by current = I V = 5.00×10^3 W
Rate of heat generated = m c $d\theta/dt$ = 4.95×10^3 W
Power of X-ray = 0.05×10^3 W
Efficiency = P_{out} / P_{in} = 1%

efficiency = ... % [2]

(c) **Fig. 3.2** below shows portions of the energy-level diagrams of the helium (He) and neon (Ne) atoms. The He atom is excited from its ground state to state of 20.61 eV. The excited level of helium at 20.61 eV is very close to a level in neon at 20.66 eV. Upon collision with a neon atom, the energy can be transferred from the helium to the neon atom. This excites the Ne atoms to the E_3 state at 20.66 eV. Lasing action takes place for electron transitions from E_3 to E_2 in the Ne atoms.

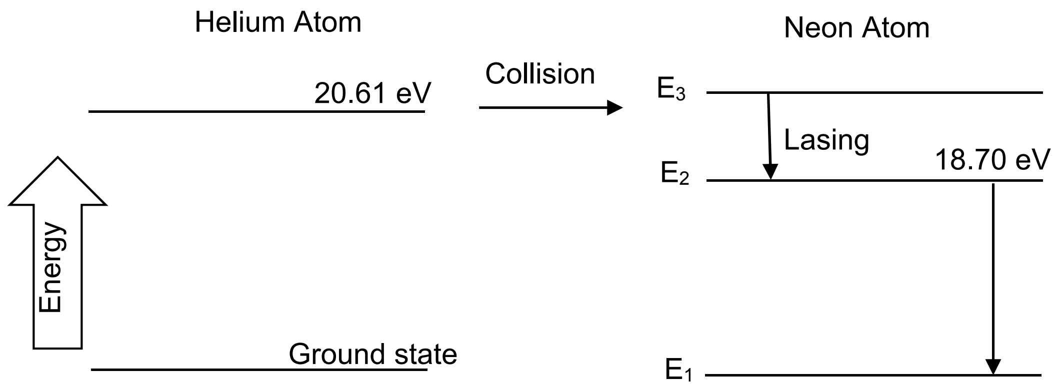


Fig. 3.2

(i) State any two unique characteristics of laser light.

- **Concentrated intensity**
- **Monochromatic**
- **Coherent**
- **Parallel beam**

[1]

(ii) Explain what is meant by population inversion and how energy state E_3 in Ne enables lasing to occur.

- **More atoms at higher energy state E_3 than at lower energy state E_2**
- **E_3 has a longer lifetime (metastable state) than E_2**
- **More stimulated emissions will be produced (E_3–>E_2) than absorptions (E_2–>E_3).**

[3]

(iii)* Explain why direct optical pumping (the supply of photons) excitation method using photons of energy $\Delta E = E_3 - E_1$ on Neon atom, in the absence of He atom, is generally not used.

- **E_1 being the ground state has a long lifetime.**
- **Difficult to achieve population inversion.**
- **Stimulated absorptions will at equal rate as emissions → no amplification effect**

[2]

[MJC 2010]

4 (a) Explain how the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation.

- **Existence of a threshold frequency**
  - **Energy of light particle is proportional to its frequency. Energy of light particle must be greater than work function for emission.**
- **KE of emitted electrons is dependent on frequency but not intensity of radiation**
  - **KE of emitted electrons is dependent only on the energy of the light particle absorbed, which is proportional to its frequency.**
- **Very short time lag between radiation and emission of electrons**
  - **Absorption of energy is almost instantaneous. Time required is duration of (perfectly inelastic) collision between light particle and electron.**

[5]

(b) Two metal plates X and Y are contained in an evacuated container and are connected as shown in **Fig. 4.1** Metal plate X is then illuminated with monochromatic light.

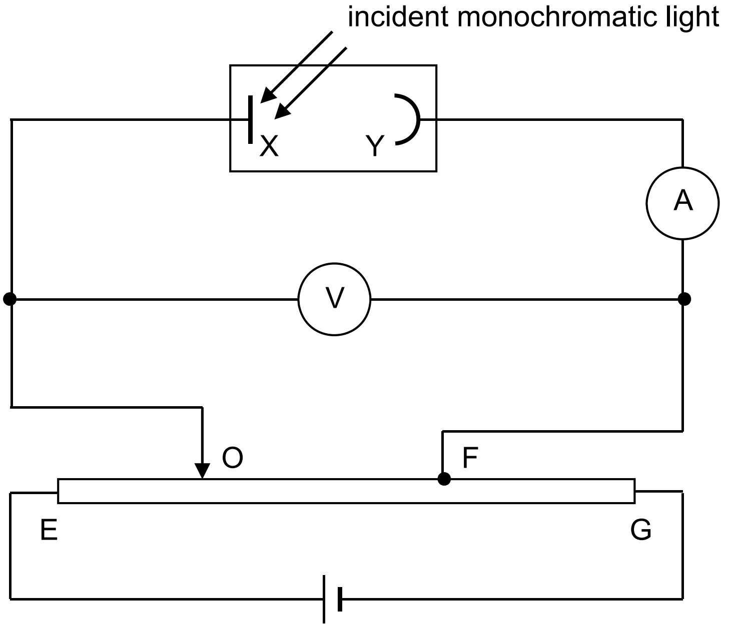


Fig. 4.1

Graph A shown in **Fig. 4.2** depicts the relationship between the voltmeter reading and the ammeter reading.

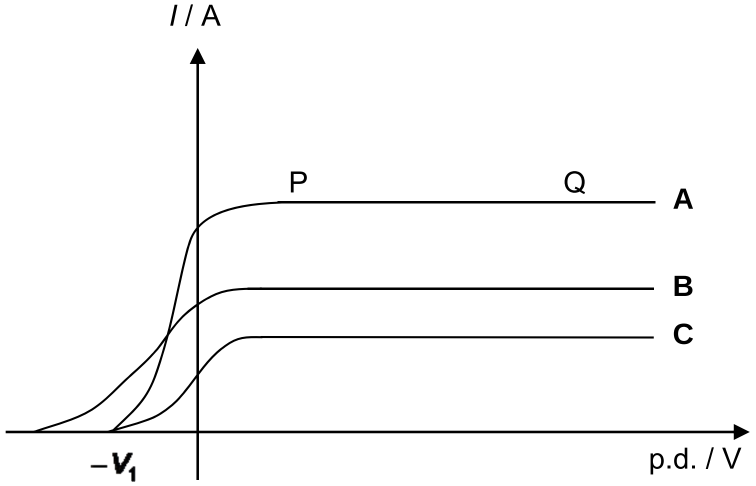


Fig. 4.2

(i) In order to obtain the part PQ on graph A, the sliding contact O would have to be shifted. Discuss and explain the position of O to obtain part PQ of graph A.

- **Shifted to other side of F such that O is at lower potential than F.**
- **Provide an accelerating voltage for the emitted electrons.**
- **So that all emitted electrons can be captured.**

[3]

(ii) Given that the work function of X is 1.3 eV and the wavelength of the light is 550 nm, calculate the value of the stopping potential V_1.

$E = h c / \lambda = 3.6\times10^{-19}$ J or 2.3 eV
$E = \phi + e V_1 \rightarrow V_1 = 1.0$ V

V_1 = ... V [2]

(iii) Discuss the changes that would have been made in the experiment to produce graphs B and C if the metal plate X used is the same.

- **B: Lower intensity and increase frequency of radiation**
- **C: Lower intensity and maintain frequency of radiation**

[3]

(c) **(i)** Explain the term *stimulated emission* in the production of laser.

- **An excited atom in the presence of a photon**
- **is stimulated to emit another photon that is identical to the photon**
- **in phase, frequency and direction.**

[2]

(ii) A 4.0 W laser emits a beam of wavelength 633 nm.

Calculate

1. the energy of each photon

$E = h c / \lambda = 3.14\times10^{-19}$ J

energy = ... J [1]

2. the number of photons emitted in 0.05 s

Total energy W emitted in 0.05 s = P t = 0.20 J
$W = N E \rightarrow N = W / E = 6.4\times10^{17}$

no of photons = ... [1]

(d) The simplest intrinsic semiconductor that can be used to fabricate a diode is Silicon (Si). Each silicon atom has four electrons in its outermost shell.

	Gp III	**Gp IV**	**Gp V**	**Gp VI**	**Gp VII**
	boron $^{11}_{5}B$	carbon $^{12}_{6}C$	nitrogen $^{14}_{7}N$	oxygen $^{16}_{8}O$	flourine $^{19}_{9}F$
	aluminium $^{27}_{13}Al$	silicon $^{28}_{14}Si$	phosphorus $^{31}_{15}P$	sulfur $^{32}_{16}S$	chlorine $^{35}_{17}Cl$
zinc $^{65}_{30}Zn$	gallium $^{70}_{31}Ga$	germanium $^{72}_{32}Ge$	arsenic $^{75}_{33}As$	selenium $^{79}_{34}Se$	bromine $^{80}_{35}Br$
cadium $^{112}_{48}Cd$	indium $^{115}_{49}In$	tin $^{119}_{50}Sn$	antimony $^{122}_{51}Sb$	tellurium $^{128}_{52}Te$	iodine $^{127}_{53}I$

Fig. 4.3

(i) From the extract of a periodic table provided in **Fig. 4.3**, suggest an element that can be used to dope silicon to obtain the n-type extrinsic semiconductor.

Group V: Arsenic As

[1]

(ii) Using the band theory, explain how doping changes the conductivity of silicon for n-type semiconductor.

- **One electron of dopant atom not used in covalent bond**
- **At an energy level above the valence band i.e. donor level (draw diagram)**
- **Less energy required to access holes in conduction band**
- **Increased condictivity**

[2]

[PJC 2010]

Solutions

MCQ

1	C	**2**	D	**3**	D	**4**	A	**5**	C	**6**	A
7	B	**8**	C	**9**	B	**10**	C	**11**	C	**12**	B
13	D	**14**	D	**15**	D	**16**	B	**17**	C	**18**	A
19	B	**20**	A	**21**	D	**22**	D	**23**	C	**24**	D
25	D	**26**	A	**27**	C	**28**	C	**29**	A	**30**	C

Short Structured Questions

2(b)	1.1×10^{10}	**9(d)**	0.982
3(a)(i)	3.71×10^{-19} J	**10(c)(iii)**	3.040×10^{-11} J
3(a)(ii)	1.63×10^{-19} J	**11(a)**	1.8×10^{-7} s^{-1}
4(b)(i)	4.10×10^{14} Hz	**11(b)**	3.4×10^{7} Bq
4(b)(ii)	2.72×10^{-19} J	**11(c)**	1.0×10^{-4} kg
5(b)	3.2×10^{6} m s^{-1}	**12(a)(i)**	2.5×10^{13} Bq
5(c)	1.6×10^{7} m s^{-1}	**12(a)(iii)**	0.040 kg
6(a)	2.7×10^{-32} m, 2.0×10^{-3}m		
7(a)	9×10^{-7} m		
7(b)(i)	0.010		
7(b)(ii)	0.990		

Long Structured Questions

1(c)(i)1	6.0×10^{-7} C	**3(a)(iii)**	7.8×10^{4} V
1(c)(i)2	3.8×10^{12}	**3(b)(i)**	1%
1(c)(ii)1	1.06×10^{-19} J	**4(b)(ii)**	1.0 V
1(c)(ii)2	0.663 V	**4(c)(ii)1**	3.14×10^{-19} J
1(d)(i)	1680 m s^{-1}	**4(c)(ii)2**	6.4×10^{17}
2(a)(iii)	1.007825 u		
2(b)(ii)	1.2×10^{-4} yr^{-1}		
2(b)(iii)	8200 years		
2(b)(v)	2.7×10^{30}		