25*

RADIOACTIVITY

Learning Outcomes

Candidates should be able to:

(a) name the common detectors for alpha particles, beta particles and gamma rays (structure and mode of operation of the detectors are not required)

(b) *show understanding that radioactive emissions occur randomly over space and time

(c) distinguish between the three kinds of emissions in terms of
(i) their nature
(ii) their relative ionising effects
(iii) their relative penetrating powers

(d) describe the deflection of radioactive emissions in electric fields and magnetic fields

(e) explain what is meant by radioactive decay, using equations (involving symbols) to represent changes in the composition of the nucleus when particles are emitted

(f) discuss the existence, origin and significance of background radiation

(g) explain what is meant by the term half-life

(h) apply their understanding of half-life to solve simple problems which might involve information in tables or decay curves

(i) describe how radioactive materials are handled, used and stored in a safe way

25.1 Detection of radioactivity

MCQs

[2013.p1.39] [Nuclear Physics]
A school keeps radioactive sources for use in radioactivity experiments in a laboratory.

The background radiation is measured at the start of an experiment.

Which statement is correct?

A The background radiation is caused by the school's radioactive sources in the laboratory.
B The background radiation is present when there are no radioactive sources in the laboratory.
C The background radiation is radiation that is not detected in radioactivity experiments.
D The background radiation is the same in laboratories in different countries.

Ans: B

☺ **Teachers' Comments**

The correct option here was the most popular. There were candidates, however, who chose **A** and who need to be aware that background radiation is always present everywhere even in the absence of laboratory radioactive sources.

☺ **Publisher's Note**

Very unusual question. One needs to be versatile in answering this question-type, else one would be tricked to no end.

1. Which one of the following is true of both α-particles and X-rays?

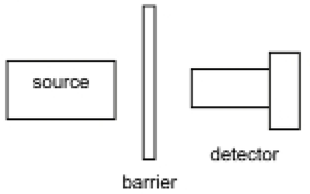
(A) They cause ionization of the air when they pass through it.

(B) They can be detected after passing through a few mm of aluminium.

(C) They can be deflected by electric fields.

(D) They can be deflected by magnetic fields.

2. The diagram shows a radioactive source and a detector placed a few centimeters apart and separated by a barrier. The table gives the count rates by the detector for four difference sources.



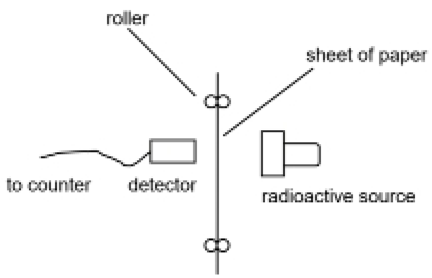
Source	Count rate / counts per minute			
	No Barrier	Paper	Thin aluminium	Thick lead
(A)	249	245	246	25
(B)	619	23	25	22
(C)	724	573	568	24
(D)	851	677	314	22

Which source emits alpha particles and gamma rays only?

Questions – 25.1

1. (a) $^{37}_{15}Y$ and $^{240}_{56}Z$ are two radioactive isotopes with half-lives of 6 hours and 4 years respectively. Both isotopes decay by emitting β-particles to form more stable isotopes. Describe the differences in the rate of disintegration of $^{37}_{15}Y$ and $^{240}_{56}Z$.

(b) Aluminum is being manufactured by a factory and the thickness of 1 mm is being monitored by using a gauge, as shown below.

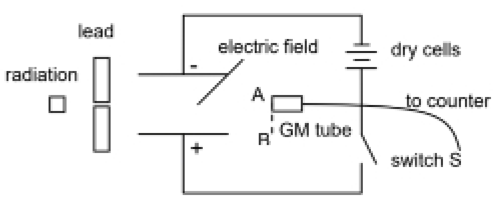


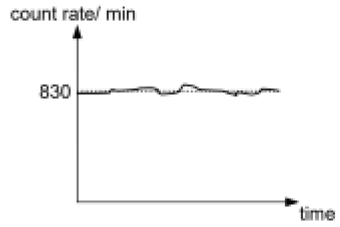
(i) Which radioactive particle should be used to check the thickness of the sheet of aluminium? Explain your choice.

(ii) Which isotope, $^{37}_{15}Y$ or $^{240}_{56}Z$ should be used for the radioactive source? Explain your choice.

(iii) Explain what it means when the detector detects a lower count rate than usual.

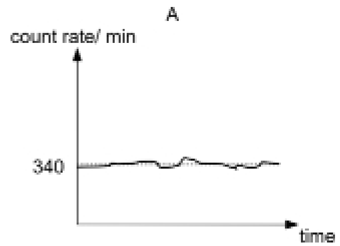
2. The diagram above shows an experimental set-up to study radiation from radiation from radiation sources. Initially, the switch S is open and the variation of count rate with time is shown in the table below. The GM tube is positioned at A.

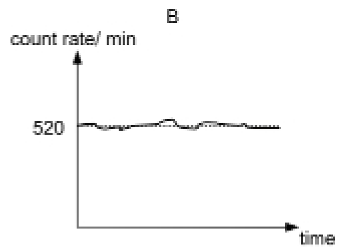




(a) Explain why the count rate will be the same, regardless of the nature of the radioactive emission from the source.

(b) Switch S is now closed. The count rates at position A and B are as shown below.





(i) What can be deduced about the nature of the radiation from the source from these two tables? Explain your answers.

(ii) What radioactive particle, if any, will be detected when the GM tube is moved above A.

(iii) Explain why the sum of the count rates in A and B is greater than that when the switch S is not switched on.

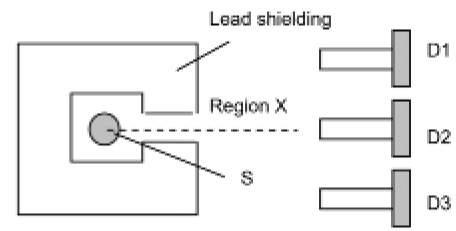
3. A teacher is investigating into the nature of the emissions from a sample of a radioactive isotope. The sample is placed about 5 cm from a detector. The table shows various absorbers are placed between the sample and the detector and values of (in counts/min) are obtained in each case.

absorber	none	paper	aluminium	lead
Thickness/mm	0	0.1	1.0	5.0
Count-rate (counts/min)	504	312	312	20

The background radiation count-rate is approximately 20 counts/min.

What can be concluded about the nature of the emission from radioactive source?

4. (a) The experimental set-up below is used to investigate the radiation emitted by a source S which is enclosed in a lead shielding. D1, D2 and D3 are three GM tubes measuring the radiation from different angles simultaneously.



The readings for 1 minute are tabulated as follows:

Detector	D1	D2	D3
Counts/ minute	132	507	125

However, when a magnetic field out of the paper is applied at region X, the count rate becomes:

Detector	D1	D2	D3
Counts/ minute	465	35	32

When a 5 cm thick lead is placed at the opening of the lead shielding, the count rates of the 3 detectors drop to nearly the same level as follows. When the thickness of lead sheet is increased to 10 cm, the count rates do not change.

Detector	D1	D2	D3
Counts/ minute	33	31	34

(i) It is found that the GM tube register a count rate even though there is no radioactive source. Where does the count rate come from?

(ii) Explain why the source is kept in the lead shielding with a narrow opening.

(iii) Which type of radiation does the source emit? Give two reasons to support your answer.

(b) The magnetic field and the lead sheet are then removed and the activity of the source S is then monitored by D2 every 5 hours for 40 hours. The count rates are shown below.

Time /h	0	5	10	15	20	25	30	35	40
Count rate	504	374	280	210	157	118	88	66	50

(i) Plot a graph of count rate (counts per minute) against time (hour) for the source S.

(ii) Determine the half-life from the curve drawn in (b)(ii).

(iii) In order to protect the person who performs this experiment, can you suggest one precaution that should be taken?

(c) A student suggests that this source is suitable for use in gauging the thickness of iron plates in a factory which manufacture these products. Do you agree? Explain briefly.

5. (a) Describe an experiment which could be used to show that the emission from a radioactive source is random in both direction and time. Indicate the procedure you would adopt using a source which emits only alpha particles. Make clear how the random nature f the emission would be deducted from the readings or observations.

(b) In an experiment, various numbers of sheets of plastic, each of the same thickness, were placed between the Geiger-Muller tube and a radioactive source. The average background count rate was found to be 85 per minute.

No. of sheets of absorber used	4	5	6	7	8	9
Count rate per minute	256	204	162	137	120	106

(i) Plot a graph of count rate against the number absorbers.

(ii) Draw a line on the graph to represent the background count rate.

(iii) Find the smallest number of absorbers to reduce the count rate to the background level.

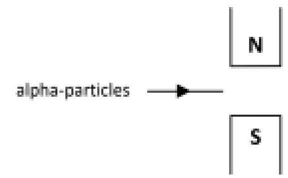
(c) (i) A source and detector are used in a factory to monitor the thickness of aluminium sheet. Why is it advantageous to use a source with a longer half-life?

(ii) A radioactive liquid and a detector are used in a factory to detect a leak in the pipe. Why is it an advantage to use a source with a shorter half-life?

25.2 Characteristics of the three types of emission

MCQs

[2014.p1.34] [Nuclear Physics]
A beam of alpha-particles enters the magnetic field between the poles of a magnet.



In which direction is the magnetic force on the beam?

A down the page **B** into the page
C out of the page **D** up the page

Ans: B

> ☺ **Teachers' Comments**
>
> The charge on an α-particle is positive and so the current direction is from left to right. The application of the right-hand rule for the motor effect then gives the direction of the magnetic force on the beam of α-particles. The correct answer was only the second most frequently chosen, possibly suggesting an unfamiliarity with this part of the syllabus.

> ☺ **Publisher's Note**
>
> **Nuclear Physics** is normally the last section of the syllabus to be taught and revised. Some slower schools might even delay the delivery of this section to even after their own internal preliminary exams. Students are advised to revise this section on their own in good time. Self-teaching is very possible as the subject matter is only introductory and rudimentary in nature.

[2014.p1.39] [Nuclear Physics]
Which row states the nature and range of beta-particles in air?

	nature	range in air
A	electromagnetic radiation	1 – 10 cm
B	electromagnetic radiation	10 – 100 cm
C	electron	1 – 10 cm
D	electron	10 – 100 cm

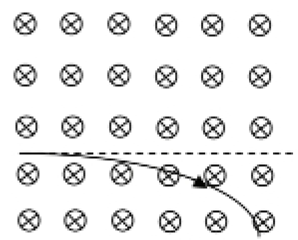
Ans: D

> ☺ **Teachers' Comments**
>
> Most candidates realized that a beta-particle is an electron and the majority of these selected the correct range. There were candidates, however, who chose answer **C**; this answer does not include the correct range.

1. The radiation from a radioactive substance passes through a piece of cardboard and then through a strong magnetic field. A Geiger-Muller tube detects radiation passing straight through the field as well as to one side of the field. Which type/s of radiation is/are being detected?

(A) alpha (B) beta
(C) gamma (D) beta and gamma

2. The radiation from a radioactive source is sent through a magnetic field pointing into the paper. The path of the radiation is shown in the figure below.



Path of radiation

The radiation consists of

(A) β particles (B) α and β particles
(C) α and γ rays (D) β and γ rays

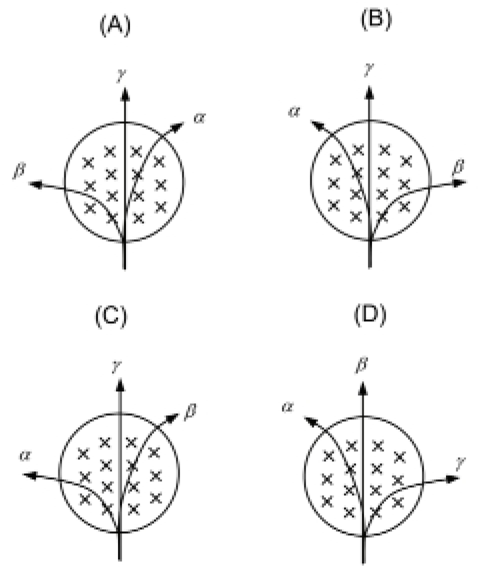
3. The table below shows the count rate recorded when different materials are inserted between a radioactive source and a GM tube. Given that the average background count is 25 counts min^{-1}.

Material inserted	Count rate/ counts min^{-1}
Nil	988
A piece of paper	456
5 mm of aluminium sheet	28
A thick lead sheet	27

Which type(s) of radiation does the source emit?

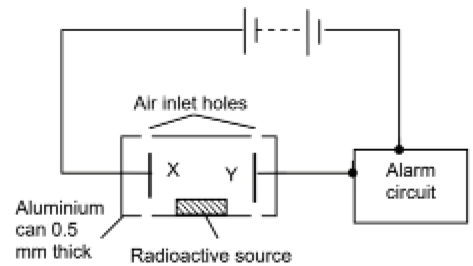
(A) α particles (B) β particles
(C) γ rays (D) α and β particles

4. Which of the following diagrams correctly shows the deflections of α, β and γ in a uniform magnetic field pointing into the plane of the paper?



Questions – 25.2

1. The figure below shows a smoke detector cell and circuit which could be used in the home. Due to the presence of the radioactive source a small current can pass between the plates marked X and Y. Smoke or fumes entering the cell cause a change in the current which sets off the alarm.



(a) Explain why a radioactive source is necessary for this small current to pass between X and Y.

(b) The source used usually emits alpha radiation. Why is the radiation safe to use in this cell and why is it effective?

(c) If the source is replaced by a gamma source, would the smoke detector cell remains effective? Explain.

(d) What is meant by half-life?

(e) The source most commonly used has a half-life of 460 years. Give one advantage and one disadvantage of using such a source.

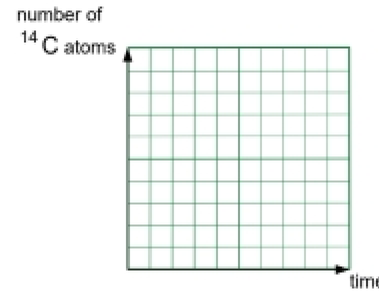
(f) Give an application of radioactive sources which has a short half-life.

2. (a) Carbon-14 (^{14}C) is a radioactive isotope of carbon. It decays by emitting β-particles. It has a half-life of 5000 years.

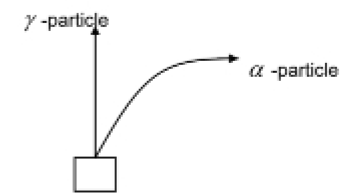
(i) What is the nature of a β-particle?

(ii) One particle sample of Carbon-14 contains 4000 atoms.

On the graph below, plot the graph of number of Carbon-14 atoms against time for the next 15000 years.

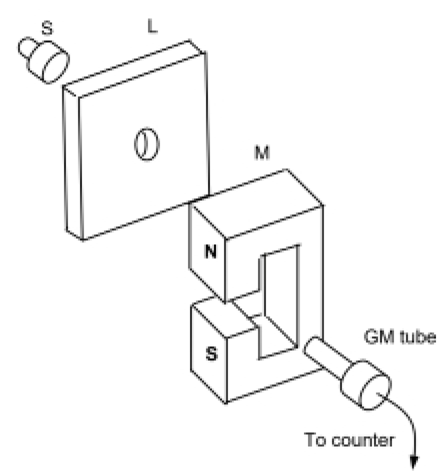


(b) A radioactive source that emits α and γ particles is placed in a vacuum. The diagram below shows how the radiation is deflected when a uniform magnetic field is applied at right angles from the plane of the paper.



Explain why the γ - particles do not deflect and why the α -particles deflect.

3. The figure shows an arrangement for demonstrating that beta particles can be deflected by a magnetic field. S is the source of beta particles. L is a lead sheet with a small hole in it, M is the magnet with poles as shown and GM is a Geiger-Muller tube connected to a counter The GM tube can be placed anywhere in the space near the magnet.



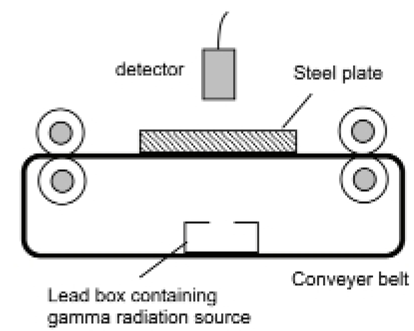
(a) What is the purpose of L?

(b) Where would you advise the experimenter to place the GM tube in order to detect the deflected beam of beta particles? Explain your answer.

(c) S is now replaced by an alpha source, in order to see how they can be detected. No particles can be detected in any direction. What is the most possible reason for this?

(d) State two modifications that would be necessary to produce the deflection of alpha particles and to detect them.

4. The figure below shows a setup found in a factory which produces steel plates of 2 cm thickness.

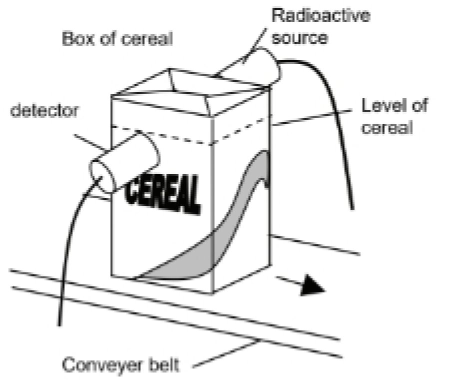


(a) Explain how this arrangement may be used to check that all plates have equal thickness.

(b) Suggest a reason for using gamma rays rather than alpha or beta particles.

(c) A technician working near this setup would need protection against the danger of radioactivity. Suggest one way pf reducing the danger due to radioactivity.

5. A company which manufactures cereal breakfast wishes to check the level of cereal in the boxes in which it is packed. The company proposes to put a radioactive source on one side and a suitable detector on the other side of the conveyer belt which carries the cereal boxes, as shown below.



The company obtains the following information about radioactive sources which are available:

Source	Radiation emitted	Half-life
A	Alpha	600 years
B	Alpha and gamma	4000 million years
C	Beta	10 days
D	Beta	30 years
E	Gamma	50 minutes

Imagine you are the engineer responsible for installing a suitable system for the company.

(a) Explain which of the types of radiations you would use.

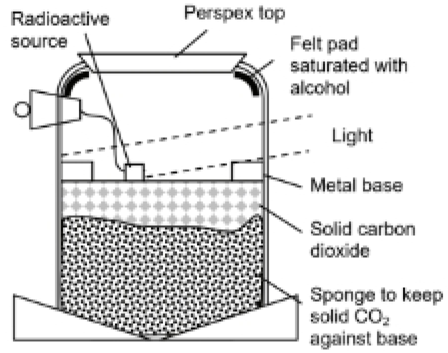
(b) In what way does the half-life of a source affect your choice?

(c) Which source in the list above would you use?

(d) Explain how the system will allow the correct level of cereal to be checked.

(e) In order to check that the box is actually present on the conveyer belt, another detector is used. This uses a light beam and sensor placed on either side of the belt so that a passing box will interrupt the beam. Name a suitable sensor.

6. The figure below shows a diffusion cloud chamber.



(a) Explain briefly how it marks the tracks of radiation emitted fro a radioactive source.

(b) Draw three separate diagrams to show the tracks of each of the three types of radiation, namely alpha, beta and gamma, as seen in the diffusion cloud chamber.

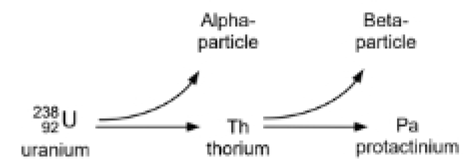
25.3 Nuclear reactions

MCQs

1. $^{234}_{92}X$ decays by emitting an alpha particle and two beta particles. Which of the following represents the resulting nuclide Y?

(A) $^{228}_{90}Y$ (B) $^{228}_{92}Y$
(C) $^{230}_{90}Y$ (D) $^{230}_{92}Y$

2. The uranium atom $^{238}_{92}U$ emits an alpha-particle to become thorium, which then emits a beta-particle to become protactinium.



What is the proton number of protactinium?

(A) 89 (B) 90
(C) 91 (D) 95

3. The radium nucleus $^{226}_{88}Ra$ decays to radon (Rn) by alpha particle emission. The nuclear equation is

(A) $^{226}_{88}Ra + ^{4}_{2}He \rightarrow ^{222}_{86}Rn$
(B) $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn - ^{4}_{2}He$
(C) $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$
(D) $^{226}_{88}Ra + ^{222}_{86}Rn \rightarrow ^{4}_{2}He$

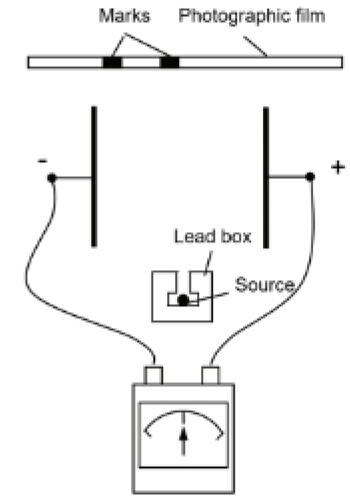
4. An unstable nucleus initially comprises X protons and Y neutrons. It emits two beta particles followed by two alpha particles.

What is its nuclear composition then?

	No. of protons	No. of neutrons
(A)	X	Y – 4
(B)	X – 2	Y – 2
(C)	X – 2	Y – 6
(D)	X – 2	Y – 8

Questions – 25.3

1. The figure below shows the set-up of an experiment carried out in a vacuum chamber to study the radiations from the source $^{218}_{84}Po$.



Po emits α, β and γ radiation. An electric field is applied. During the experiment, two marks have developed on the photographic film and the sensitive ammeter shows a deflection.

(a) Explain why there is a current shown on the ammeter.

(b) After a series of decays, a nucleus of $^{218}_{84}Po$ is transformed into a nucleus of $^{210}_{82}Pb$. How many α-particle(s) and β-particle(s) have been emitted?

2. The radioactive isotope of the element $^{43}_{21}Z$ decays by emitting an α particle to the a stable daughter nucleus X.

(a) State the mass number and proton number of radioactive isotope

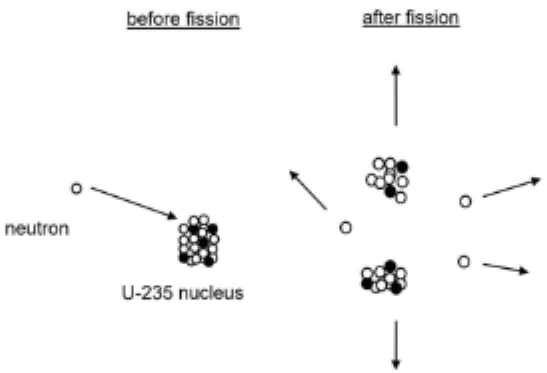
(b) Write the equation for this decay.

3. Radium-228 is a radioactive isotope which decays by α-emissions to an isotope of radon (Rn). Two further α-emissions give, in turn, isotopes of polonium (Po) and lead (Pb). The lead isotope normally decays by β-emission to an isotope of bismuth (Bi). There is significant γ-emission with the decays of the radium and the lead.

The proton (atomic) number Z of Radium (Ra) is 88.

Draw up a table showing the nucleon (mass) numbers, proton (atomic) numbers and neutron numbers of the radium, radon, polonium, lead and bismuth isotopes described above.

4. The figure below illustrates nuclear fission of Uranium- 235 in a nuclear reactor.



(a)(i) Describe the process illustrated in the figure above.

(a)(ii) Describe how the process of nuclear fusion differs from the process of nuclear fission as illustrated above.

(b) The waste products from a nuclear reactor contain isotopes such as Iodine-131 and Caesium-137. These waste products are highly radioactive and dangerous. They are stored in sealed metal cans which are placed under water for a few months.

(i) Explain how these isotopes were produced.

(ii) Explain what is meant by the term radioactive.

(iii) Give a reason why metal cans are used and a reason why they are placed under water.

5. Four radioactive sources A, B, C and D are placed one at a time in front of a Geiger-Muller counter. The number of counts in 10 seconds for each source is measured at 1-minutes intervals. The results are recorded in the table as shown.

Source	Counts in 10 seconds				
	Time				
	0 min	After 1 min	After 2 min	After 3 min	After 4 min
A	1200	412	133	46	13
B	200	15	16	13	14
C	800	561	396	283	207
D	1000	791	627	503	392

(a) Which source has the longest half-life? Explain your answer.

(b) It is known that source B is uranium, U (with nucleon number 238 and proton number of 92), which decays to thorium, Th, by the emission of an unknown radiation. The count rate of the unknown radiation drops drastically to the background count when a piece of paper is placed between the source and a Geiger-Muller counter.

(i) From the information given, identify the unknown radiation.

(ii) Write out an equation of decay for the radioactive process.

25.4 Half–life

MCQs

[2015.p1.39] [Nuclear Physics]
A source contains a radioactive material.

Without the radioactive source present, a detector records a background count rate of 20 counts per minute.

This source is placed in a fixed position near the detector. Initially a count rate of 520 per minute is recorded.

What count rate is recorded after a time of two half-lifes of the radioactive source?

A 125 counts per minute
B 130 counts per minute
C 135 counts per minute
D 145 counts per minute

Ans: D

☺ **Teachers' Comments**

In the question, the count-rate on the detector includes the background count-rate. Two common errors were to ignore the background count-rate altogether or to subtract it initially and then not to add it at the end.

1. The initial activity of a radioactive source is 600 counts per second. After a time T, its activity becomes 75 counts per second. If the half-life of the source is 16 hours, what is T?

(A) 16 hours(B) 32 hours

(C) 40 hours(D) 48 hours

2. A radioactive source has a half-life of 5 minutes. A detector connected to a ratemeter records a rate of 80 counts per second. Which rate does it record after 10 minutes?

(A) 0 counts per second

(B) 20 counts per second

(C) 40 counts per second

(D) 160 counts per second

3. 10 g of a certain fossil shows a count rate of 100 min^{-1}. Another living sample of twice the mass gives 800 counts min^{-1}. It is given tat the half-life of carbon-14 is 5700 years, then the remains has probably been dead for how many years?

(A) 713 (B) 5700

(C) 11400 (D) 17100

4. The activity of a radioactive isotope is 16 000 disintegrations s^{-1}. The activity drops to 1000 disintegrations s^{-1} in 8 hours. What is the half-life of the isotope?

(A) 1 hour (B) 2 hours

(C) 4 hours (D) 8 hours

5. A radioactive isotope has a half-life of 5 minutes. What fraction of the material is left after 25 minutes?

(A) $\frac{1}{4}$ (B) $\frac{1}{10}$

(C) $\frac{1}{5}$ (D) $\frac{1}{32}$

6. The table shows the count-rate recorded at a point in a laboratory at various times, with and without a source in position.

Time/ days	Count-rate / s^{-1}	
	With source	Without source
10	60	20
30	30	20
90	20	20

From these readings, what is the half-life of the source?

(A) 10 days (B) 15 days

(C) 20 days (D) 30 days

7. A radioactive source consists of 6.4×10^{11} atoms of a nuclide of half-life 2 days. A second source consists of 8.0×10^{10} atoms of another nuclide of half-life 3 days.

After how many days will the number of radioactive atoms in the two sources be equal?

(A) 6 (B) 9

(C) 12 (D) 18

8. The carbon in the body of all animals contains some radioactive carbon. At the time when any animal dies, each gram of carbon in its body emits about 16 beta particles per minute.

Some animal remains are discovered. It is found that 4 beta particles are emitted per minute for each gram of carbon in the remains. The half-life of radioactive carbon is 6000 years. How old are the remains of the animal?

(A) 1 500 years (B) 3 000 years

(C) 6 000 years (D) 12 000 years

9. The half-life of a certain radioactive element is such that $\frac{7}{8}$ of a given quantity decays in 12 days. What fraction remains undecayed after 24 days?

(A) 0 (B) $\frac{1}{32}$

(C) $\frac{1}{64}$ (D) $\frac{1}{128}$

Questions – 25.4

1. (a) There are 3 types of emissions from radioactive sources.

(i) State the nature of these 3 types of emissions

(ii) State the characteristics of this 3 types of emissions in terms of mass, charge, penetrative power and ionization strength.

(c) $^{124}_{58}Z$ is a radioactive isotope. Its proton number is 58 and its nucleon number is 124. It decays by emitting α -particles to form a daughter nucleus Y. It has a half-life of 5 days.

(i) Explain what is meant by 'half-life' of a radioactive isotope.

(ii) A sample of Z is left on for 20 days. What fraction of the mass of the initial sample is left?

2. Sodium-24 is a radioactive isotope which can be used to detect leaks in underground water pipes. It is a β -emitter and a γ -emitter and it decays to a stable isotope of magnesium. The table gives the count-rate of a freshly prepared sample of sodium-24 over a period of 60 hours.

$\frac{time}{h}$	0	12	24	36	48	60
$\frac{count - rate}{counts / second}$	100	58	33	19	11	6

(a) Plot a graph of count-rate (y-axis) against time (x-axis).

(b) Use your graph to determine the half-life of sodium-24.

3. (a) (i) State the nature of alpha, beta and gamma emission.

(ii) State the size of the charge, if any, on each of these emissions in terms of the charge on an electron (i.e. charge on an electron is -1).

(b) A Geiger counter is used to measure the activity of a sample of a radioactive substance. The results were recorded in the table below.

Count-rate /min	248	208	174	148	126	108
Time /min	0	10	20	30	40	50

The background radiation was found to be 28 counts per minute. Taking the background radiation into consideration, plot a graph of the count rate against time.

(i) From the graph, determine the half-life of the sample.

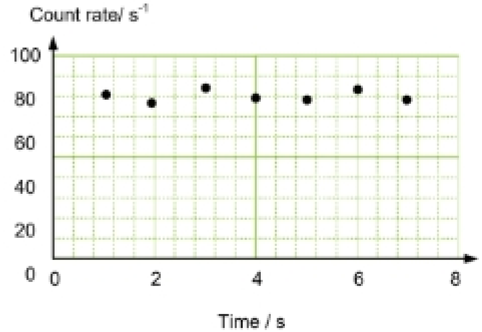
(ii) Suggest two possible causes of he occurrence of background radiation.

(c) (i) Carbon-14 (atomic number 6) disintegrates to nitrogen by the emission of beta particle. What will be the number of nucleons in the resulting nucleus? Write an equation to show the process.

(ii) It is known that one gram of carbon from a living plant which contains a definite proportion of carbon-14 decays at a rate of 15 disintegrations per minute. A specimen which was formed from a living plant a long time ago shows 15 disintegrations every 4 minutes from one gram of carbon present in it.

Given that the count rate from carbon-14 begins to fall only when the tree dies, estimate the age of the specimen. (The half-life of carbon-14 is 5000 years). Show your working clearly.

(d) The figure below shows the count rate for a radioactive substance with a long half-life of several years. Explain the presence of the fluctuations, giving two reasons.



25.5 Uses of radioactive isotopes including safety precautions

MCQs

[2015.p1.38] [Nuclear Physics]

A factory continuously produces plastic sheets. A radioactive isotope and a detector are used to check the thickness of the sheets.

What is the most suitable source to use?

A an alpha source with a half-life of a few minutes
B an alpha source with a half-life of several years
C a beta source with a half-life of a few minutes
D a beta source with a half-life of several years

Ans: D

☺ **Teachers' Comments**

In the question, the alpha-radiation would not penetrate even very thin plastic sheets and so could not be used here. Secondly, a factory would not wish to keep changing the source and so a longer half-life is desirable.

1. Why are lead boxes used to store radioactive substances?

(A) It is a good thermal conductor.

(B) It prevents contamination of the box's contents from external radiation

(C) It prevents much of the radiation from escaping into the surroundings.

(D) It stops the box from being knocked over easily.

2. A radioactive tracer is to be used to study the flow of blood in the human body. Which of the following properties should the tracer have?

(A) short half-life and emit alpha particles

(B) short half-life and emit beta particles

(C) long half-life and emit beta particles

(D) long half-life and emit gamma rays

Questions – 25.5

1. A patient is examined to find out if his kidneys are working properly. A liquid containing some gamma emitting radioactive material is injected into the patient's blood stream. This radioactive material and other impurities should be absorbed by the kidneys and then pass to the patient's bladder. A gamma camera is used to detect the radiation coming from the patient's kidneys. The gamma camera produces images of the patient's left and right kidneys on a monitor as shown in Fig 1.1 and Fig 1.2 below.

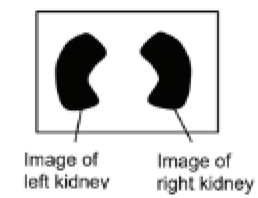


Fig 1.1

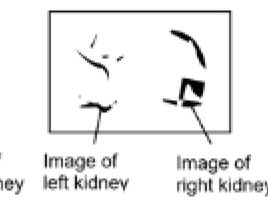


Fig 1.2

Fig 1.1 shows the image 2 minutes after the injection and Fig 1.2 shows the image 10 minutes after the injection.

(a) Which kidney is not working properly? Explain briefly.

(b) The half-life of four gamma sources W, X, Y and Z are listed in the table below.

Gamma source	Half-life
W	1 min
X	5 min
Y	4 hours
Z	5 days

(i) If the initial activity of Y is 8 000 counts per minute, what is the activity of Y after one day?

(ii) The examination of the patient lasts for 15 minutes. Which one of the above gamma sources would be most suitable for use in the examination?

(b) Alpha source materials are never injected into the body in order t obtain images of parts of the body. State two reasons why alpha emitting materials are unsuitable.

(c) While working with radioactive substances, the technician wears a film badge similar to that shown in Fig 1.3.

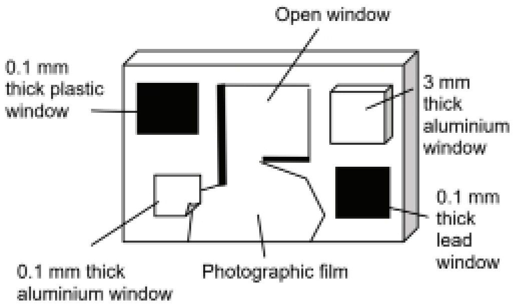


Fig 1.3

If the technician was exposed accidentally to too much beta radiation, which part of the film would be affected? Explain briefly.

2. (a) $^{24}_{11}Na$ and $^{23}_{11}Na$ are isotopes of sodium. $^{24}_{11}Na$ is radioactive with a half-life of 15 hours.

(i) Explain the terms 'radioactive' and 'half-life'.

(ii) If $^{24}_{11}Na$ emits beta radiation, describe briefly how would you confirm that this is true.

(iii) Owing to a leakage of the radioactive isotope in a laboratory, the radiation count-rate rises to eight times the safety level. After how long will it be safe enough to enter the laboratory again?

(b) A radioactive tracer can be injected into the blood stream to allow the flow of the blood through the blood vessels to be monitored. Figure 1.1 shows the basic arrangement used. Figure 1.2 shows the results of monitoring the blood in the leg of a patient.

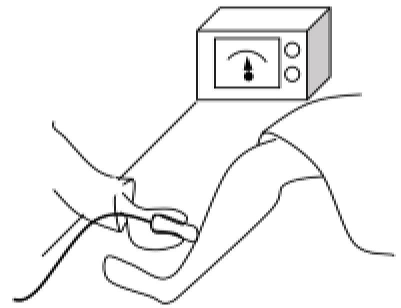


Fig 1.1

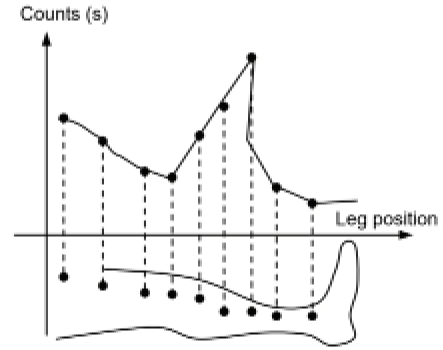


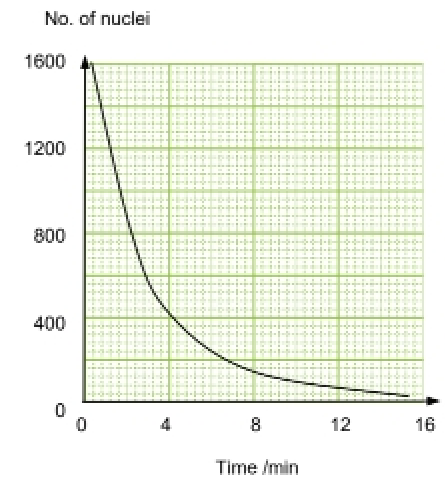
Fig 1.2

(i) Given that the particles from the tracer have to pass through the leg, explain why should the half life of the tracer be quite short?

(ii) Explain the results shown in Fig 1.2.

3. The number of nuclei of polonium (a radioactive substance) is counted and recorded in the table shown.

(a) Using the graph provided below,



(i) How many nuclei are left after 8 minutes?

(ii) Estimate the half-life of polonium.

(b) Iodine – 131 is sometimes used as a tracer for medical purposes. It has proton number 53, is a beta emitter with a half-life of about 8 days.

(i) Can polonium be used as a tracer as well? Justify your answer.

(ii) Give two reasons why alpha emitters are not used for tracing.

4. β and γ particles are emitted from iodine-131 ($^{131}_{53}I$), a radioisotope. Iodine-131 is used in hospitals to the check the functionality of the kidneys. The iodine is injected into the blood stream and it will be absorbed by the kidney and eventually leave the body through urine. If the kidney is not functioning properly, the absorption and excretion of iodine-131 will decrease. A γ-detector is placed near the kidney of the patient to detect the activity of the radiation from the kidney.

(a) The β-particles do not reach the γ-detector. Explain why.

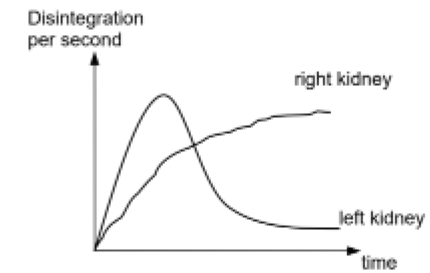
(b) Iodine-131 has a half-life of 8 days.

(i) Explain what is meant by half-life.

(ii) The disintegration rate of the iodine, when injected into the body, should not exceed 1.5×10^8, for safety reasons. One particular sample of iodine was prepared and the disintegration rate was 12×10^8.

How many days should have elapsed before the sample is safe for use?

(iii) The diagram below shows the variation of disintegration rate with time for both the kidneys.

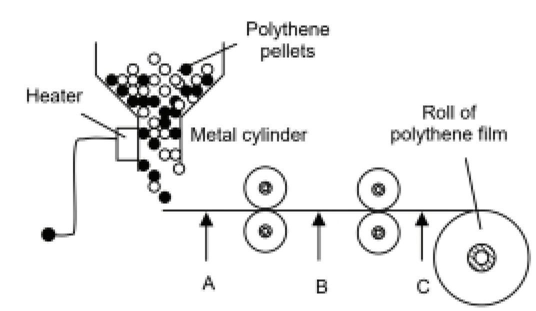


State which kidney is not functioning normally and explain why.

(iv) Another radioisotope, technetium-99 can be used in the kidney-test. It also emits γ particles and its half-life is 6 hours. Which of these isotopes are more suitable for use in the kidney? Explain your choice.

5. Radioactive isotopes are used in medicine and in industry. Describe and explain one use that is made of a radioactive isotope. In your account, indicate whether the isotope should have a long or a short half-life.

6. Polythene film is made by extruding polythene and drawing it into a long sheet which is wound onto a roll. The following diagram represents the manufacturing process.



(a) (i) Electrostatic charge builds up on the polythene as it passes through the rollers. If this charge is not removed, the rolls of polythene film retain the charge and this causes problems when the film is subsequently used in other process. State one problem arising from the electrostatic charge.

(ii) An 'active bar' containing a radio-isotope polonium-210 is used to remove the electrostatic charge from the polythene film. Explain why the 'active bar' is placed at point C rather than A or B.

(b) The 'active bar' contains the radio-isotope polonium-210 which decays by emitting alpha particles.

(i) What are alpha particles?

(ii) The following table contains information about radiation.

	Penetrating power	Ionising power
Greatest	Gamma	Alpha
↓	Beta	Beta
Least	Alpha	Gamma

Explain why alpha radiation has the highest ionizing power.

(iii) Explain why a gamma emitter, such as cobalt-60, would not be suitable for eliminating charge on the polythene film.

(iv) Explain how polonium-210 s able to remove electrostatic charge from the polythene film.

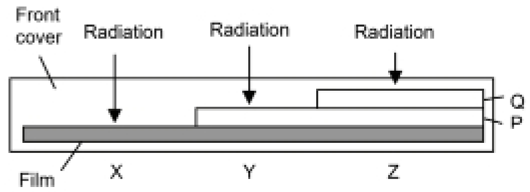
(c) Polonium-210 has a half-life of 138 days.

(i) An 'active bar' is supplied from the manufacturer with an activity of 800 counts per minute. How long would it take for the activity of the bar to reduce to 100 counts per minute?

(ii) Suggest why an 'active bar' is replaced after one year.

(d) The used 'active bars' are collected by the suppliers for safe disposal. Discuss why they are not simply thrown away with the other factory waste.

7. (a) (i) A film badge is designed to check their exposure to different types of radiations. The badge has three sections X, Y and Z as shown below. When the film is developed it turns black where it has been exposed to radiation.



Suggest the appropriate type of material and its thickness for each of the layers P and Q shown in the figure above.

(ii) A worker is exposed to beta radiation. Which of the sections X, Y or Z will be black when the film is developed?

(b) Technetium-99m is a radioactive isotope which is often used by hospitals in the examination of patients. It emits gamma rays and ahs a half-life of 6 hours. A doctor wishes to examine the action of a patient's heart. The patient's pulse rate is 70 per minute. The doctor injects a substance containing technetium-99m into the blood. It mixes with the blood. As the substance passes through the heart, the radiation from it is detected outside the patient's body. Measurements are made while 500 heartbeats take place.

(i) What is half-life of a radioactive substance?

(ii) Why does the doctor chose a gamma emitter with a half-life of 6 hours rather than one with a half-life of 6 minutes or days?

(iii) A sample of technetium-99m has a count rate of 6400 counts per minute. What is the count rate of the sample after 24 hours?

(iv) When a single measurement of the count rate was taken after 24 hours, it was 13 counts above the value calculated in (b)(iii). Suggest two reasons why the measured count rate is different from the calculated value.

Answer keys:

25.1

MCQs

1. A
2. C

25.2

MCQs

1. D
2. A
3. D
4. B

25.3

MCQs

1. D
2. C
3. C
4. D

25.4

MCQs

1. D
2. B
3. C
4. B
5. D
6. A
7. D
8. D
9. C

25.5

MCQs

1. C
2. B

25

RADIOACTIVITY

25•1 Detection of radioactivity

MCQs

1. A They cause ionization of the air when they pass through it.

2. C 724 573 568 24

There are two significant drops in count rate: when paper and thick lead are added respectively.

Alpha particles are stopped completely by a piece of paper and the thick lead plates can absorb the gamma rays passing through it. (ans)

Questions – 25.1

1. (a)

For a given sample of $^{37}_{15}Y$ and $^{240}_{56}Z$, for $^{37}_{15}Y$ to have a short half-life, it would have to disintegrate into a very small fraction of its initial mass in a day. $^{240}_{56}Z$, however, having a half-life of a 4 years, would have only disintegrated by an insignificant amount of its initial mass. (ans)

(b)(i)

β-particles should be used. β-particles are able to pass through aluminum. Having only sufficient penetrating power to pass through certain thickness of aluminum, β-particles can detect slight variations in the thickness of the aluminum. (ans)

(b)(ii)

$^{37}_{15}Y$ would be a more suitable isotope. Its half-life is shorter and the rate of β-particle emissions is much faster, which is required when checking the thickness of the aluminum as it moves quickly through the rollers. (ans)

(b)(iii)

When the detector displays a lower count rate than usual, it means that the aluminum passing through the rollers at the point in time is thicker than usual. (ans)

2. (a)

When the switch S is opened, there is no electric current in the electric field. Hence, all radioactive emissions are not affected by their charge and would all move in a straight line, towards the detector at A. (ans)

(b)(i)

From the graphs, we can deduce that the radioactive emission contains β and γ particles. When the emissions pass through the electric field, the β-particles are attracted to the positive plate. The β-particles are detected at B. The γ-particles do not have a charge and are undeflected by the electric field and are detected at A. (ans)

(b)(ii)

The α-particle will be detected. (ans)

(b)(iii)

The difference in the sum of the two readings as compared to the first reading is due to the background radiation. The sum of the two readings being greater is due to the background radiation is in both the readings and hence amounting to double-counting when added together compare to the first reading. (ans)

3. The isotope emits α-particles, as when it passes through paper, the count-rate drops from 504 to 312. The isotope does not contain β particles as the count-rate does not decrease as it passes through aluminum. The isotope contains γ-particles as the particles cannot pass through the lead causing the count rate to fall from 312 to 20, which is the background radiation. (ans)

4. (a)(i)

Background radiation. (ans)

(a)(ii)

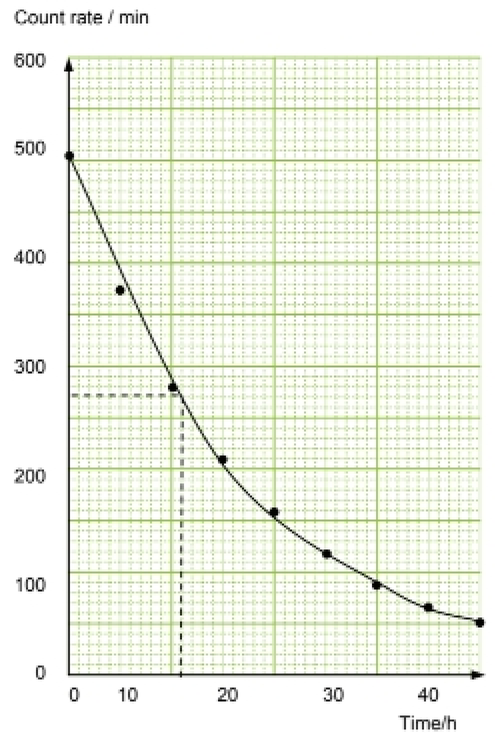
This is to guide the radiation towards the detectors. (ans)

(a)(iii)

The radiation is deflected by the magnetic field. By using Fleming's left hand rule, it is deduced to be β-particles. It is also unable to penetrate through both thin and thick lead. (ans)

(b)(i)

Graph of Count rate/min against Time/h



(ans)

(b)(ii)

Taking into account background radiation, when count rate = [(504 – 31) ÷ 2] + 31 ≈ 268

Time taken = 11 hours

∴ half-life is 11 hours. (ans)

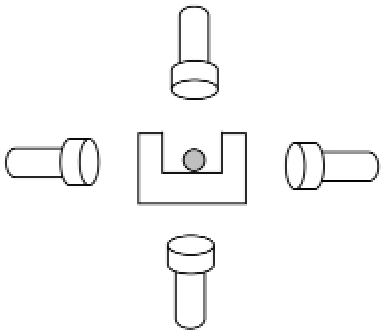
(b)(iii)

The person can be working behind a lead barrier. (ans)

(c)

Yes, this source is suitable. As the thickness of the iron is varied, the count rate will vary accordingly, giving a good indication of the thickness. (ans)

5. (a)

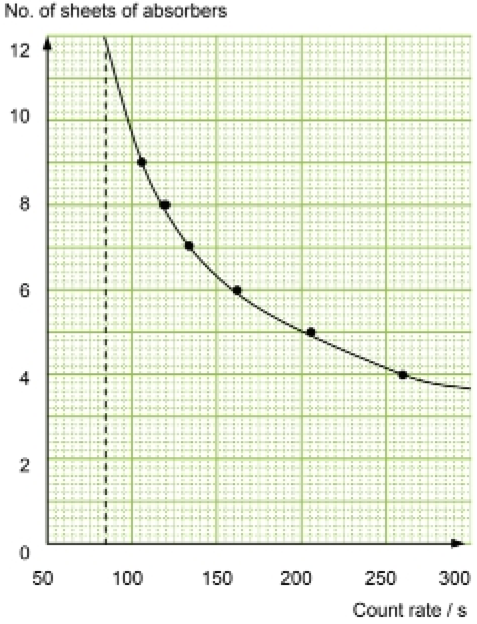


Place the detectors at equal distances from the source.

- Place four detectors at four different directions
- Measure the count rate after a certain period of time
- The reading would be slightly different, indicating the random nature of radioactive emission
- The readings at the detectors also indicate that emission is random with respect to direction (ans)

(b)(i) & (ii)

Graph of No. of sheets of absorbers against Count rate/s



(ans)

(b)(iii)

From the graph,

the smallest no. of absorbers = 12 (ans)

(c)(i)

To avoid frequent replacement. (ans)

(c)(ii)

So that it does not contaminate the water that runs through the pipe. If residual radioactive substances are present in the pipe, it could cause danger to people. (ans)

❷❺•❷ Characteristics of the three types of emission

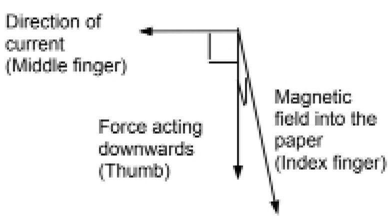
MCQs

1. D beta and gamma

All the alpha particles are absorbed by the cardboard. Beta and gamma radiations have relatively higher penetrating powers and are not stopped by the cardboard. (ans)

2. A β particles

Using Fleming's Left Hand Rule,



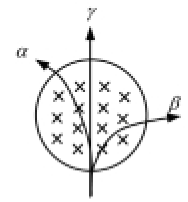
(ans)

☺ Note: Direction of current is opposite of direction of travel of β particles.

3. D α and β particles

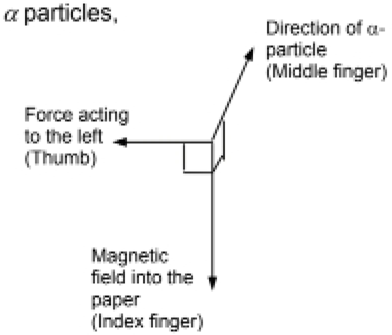
There are significant drops in count rates when a piece of paper and 5 mm aluminum sheet are inserted due to α and β particles being absorbed respectively. There is no significant change when a thick lead sheet is inserted, which means that the low count rate of around 28 is due to background radiation and no γ rays is emitted. (ans)

4. B

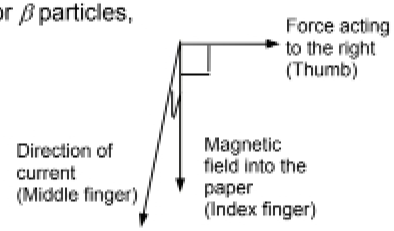


Using Fleming's Left Hand Rule,

For α particles,



For β particles,



α particles have greater mass than that of β particles, hence using F = ma, α particles will be deflected less than β particles.

γ rays have no charge, hence it will pass through the magnetic field undeflected. (ans)

Questions – 25.2

1. (a)

Air is an electrical insulator. Hence, a radioactive source ionizes the air and the ions carry charge, hence allowing a small charge to pass between X and Y. (ans)

(b)

Alpha radiation is absorbed by the aluminium can, hence the user's safety is ensured.

Alpha radiation is effective because it has great ionization ability and allows a large current to flow between the plates. (ans)

(c)

No, the smoke detector will be less effective since gamma radiation has low ionization ability and the current produced would be too weak. (ans)

(d)

Half-life is the time taken for half the number of radioactive atoms to decay. (ans)

(e)

Advantage:

Ionization will remain constant for a long time.

Disadvantage:

The smoke detector will remain radioactive long after it has been disposed. (ans)

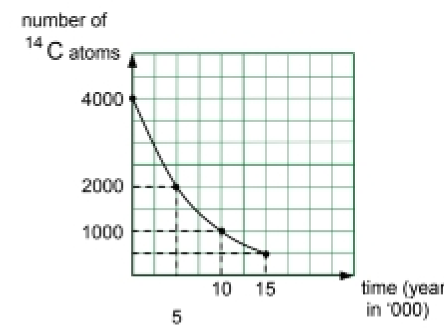
(f)

As a radioactive tracer which can be injected into the blood stream to allow the flow of the blood through the blood vessels to be monitored. (ans)

2. (a)(i)

The β-particle is a fast-moving electron. (ans)

(a)(ii)



(ans)

(b)

α-particles are positively charged and γ-particles contain no charge. (ans)

3. (a)

The purpose of L is to absorb most of the radiation and only allow radiation through the hole (focus). (ans)

(b)

The GM tube should be placed to the right of the magnet (looking from the side of L). According to Fleming's left hand rule, it will be deflected to the right. (ans)

(c)

Most of the alpha particles are absorbed by L. The range of alpha particles is also very short. (ans)

(d)

Remove the lead sheet.

Bring the GM tube closer and to the left of the magnet. (ans)

4. (a)

The count rate measured by the detector is proportional to the thickness of the steel plate. If the thickness of the plate is unusually high, the count rate will drop drastically. (ans)

(b)

The penetrative strength of alpha and beta particles is weak. (ans)

(c)

He can be working behind a lead barrier. (ans)

5. (a)

The engineer should use beta particles. Alpha particles cannot be used as the penetrative strength is very weak whereas gamma rays will be too strong. (ans)

(b)

If the half-life is too long, a change in readings cannot be noticed easily. If the half-life is too short, frequent replacement of the source is required. (ans)

(c)

C should be used. (ans)

(d)

If the cereal level is too high, the count-rate would be low and if the cereal level is too low, the count rate would be high. (ans)

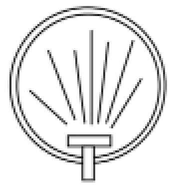
(e)

Light-dependent resistor (LDR). (ans)

6. (a)

When the radiation moves through the saturated air and vapour, tracks are created. If a particle is fast moving and very ionizing, the tracks will be continuous and straight. The tracks for gamma rays are short as they are weakly ionisng. (ans)

(b)



Alpha tracks

Beta tracks

Gamma tracks

(ans)

25•3 Nuclear reactions

MCQs

1. D $^{230}_{92}Y$

$^{234}_{92}X \rightarrow ^{4}_{2}\alpha + 2\,^{0}_{-1}\beta + ^{230}_{92}Y$ + energy (ans)

2. C 91

$^{238}_{92}U \rightarrow ^{4}_{2}\alpha + ^{234}_{90}Th$ + energy

$^{234}_{90}Th \rightarrow ^{0}_{-1}\beta + ^{234}_{91}Pa$ + energy

$\therefore$ proton number of protactinium = 91 (ans)

3. C $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$

4. D X – 2 Y – 8

Let the unstable nucleus by A.

$^{Y}_{X}A \rightarrow 2\,^{0}_{-1}\beta + 2\,^{4}_{2}\alpha + ^{Y-8}_{X-2}A$ (ans)

Questions – 25.3

1. (a)

β-particles are deflected to the positive plate, hence charges flow. (ans)

(b)

Change in nucleon number = 218 – 210 = 8

Assume that $^{218}_{84}Po$ emits 2 α-particles:

$^{218}_{84}Po \rightarrow 2\left(^{4}_{2}He\right) + n\left(^{0}_{-1}e\right) + ^{210}_{82}Pb$

84 = 4 + (- n) + 82

n = 2

$\therefore$ 2 α-particles and 2 β-particles have been emitted. (ans)

2. (a)

Mass number = 43

Proton number = 21 (ans)

(b)

$^{43}_{21}Z \rightarrow ^{39}_{19}X + ^{4}_{2}\alpha$ (ans)

3. Summarizing the information on the decays of the isotopes,

$^{228}_{88}Ra \rightarrow ^{4}_{2}\alpha + ^{224}_{86}Rn$

$^{224}_{86}Rn \rightarrow ^{4}_{2}\alpha + ^{220}_{84}Po$

$^{224}_{86}Rn \rightarrow 2\,^{4}_{2}\alpha + ^{216}_{82}Pb$

$^{216}_{82}Pb \rightarrow ^{0}_{-1}\beta + ^{216}_{83}Bi$

Isotope	Nucleon number	Proton number	Neutron number
Radium	228	88	140
Radon	224	86	138
Polonium	220	84	136
Lead	216	82	134
Bismuth	216	83	133

(ans)

4. (a)(i)

A neutron enters a U-235 nucleus making it unstable. The U-235 nucleus then breaks up into two lighter nuclei of approximately equal mass and 3 neutrons. The neutrons can continue the same nuclear reaction to produce a chain reaction. (ans)

(a)(ii)

In fusion, lighter nuclei combine to form a heavier nucleus. In fusion, neutrons are not required to start the reaction and the reaction occurs only at very high temperatures. (ans)

(b)(i)

The U-235 nucleus produces fission products which decay in a series to form the isotopes. (ans)

(b)(ii)

A nucleus is radioactive if the nucleus is unstable and undergoes transformation in its proton-neutron ratio by the emission of radiation. (ans)

(b)(iii)

The highly radioactive waste products produce a lot of heat which can be lost easily if the waste products are placed in a metal can since metal is a good conductor of heat. The water can act as a good coolant since it has a high specific heat capacity. (ans)

---

5. (a)

D has the longest half-life. It takes 3 minutes for the count rate to drop from 1000 to about 500. The drop is more drastic for the others. (ans)

(b)(i)

Alpha particles. (ans)

(b)(ii)

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$ (ans)

25•4 Half-life

MCQs

1. D 48 hours

Let x be the number of half-life to reach 75 counts per second

$600 \times (\frac{1}{2})^x = 75$

$2^{-x} = 75 \div 600 = 0.125 = 2^{-3}$

$\therefore x = 3$

$T = 3 \times 16 = 48$ hours (ans)

---

2. B 20 counts per second

No. of half life past $= 10 \div 5 = 2$

Rate recorded after 10 min

$= 80 \times (\frac{1}{2})^2 = 20$ counts per second (ans)

---

3. C 11400

Count rate for 10 g of another living sample $= 800 \div 2 = 400$ counts min^{-1}

Let x be the number of half lives that have past

$100 = 400 \times (\frac{1}{2})^x$

$\therefore x = 2$

No. of years the fossil has been dead $= 2 \times 5700 = 11400$ (ans)

---

4. B 2 hours

Let x be the number of half-life that past.

$1\,000 = 16\,000 \times (\frac{1}{2})^x$

$\therefore x = 4$

Half-life of the isotope $= 8 \div 4 = 2$ hours (ans)

---

5. D $\frac{1}{32}$

Number of half-lives $= 25 \div 5 = 5$

Fraction of material left $= (\frac{1}{2})^5 = \frac{1}{32}$ (ans)

---

6. A 10 days

Time/ days	Count-rate due only to source
10	40
30	10
90	0

Let x be the number of half lives that have past

$10 = 40 \times (\frac{1}{2})^x$

$\therefore x = 2$

Half-life source $= (30 - 10) \div 2 = 10$ days (ans)

---

7. D 18

Let Z be the number of days for the number of radioactive atoms in the two sources be equal.

$6.4 \times 10^{11} \times (\frac{1}{2})^{Z \div 2} = 8.0 \times 10^{10} \times (\frac{1}{2})^{Z \div 3}$

$8 = (\frac{1}{2})^{\frac{Z}{3} - \frac{Z}{2}} = (\frac{1}{2})^{\frac{2Z - 3Z}{6}} = (\frac{1}{2})^{-\frac{Z}{6}} = 2^{\frac{Z}{6}}$

$\ln 8 = \frac{Z}{6} \ln 2$

$\frac{Z}{6} = \frac{\ln 8}{\ln 2} = 3$

$\therefore Z = 3 \times 6 = 18$ (ans)

---

8. D 12 000 years

16 → 8 → 4

Age of remains $= 2 \times 6000 = 12\,000$ years (ans)

---

9. C $\frac{1}{64}$

The half-life is 4 days if only $\frac{1}{8}$ is left after 12 days. $\frac{1}{64}$ of the radioactive element remains after 24 days. (ans)

Questions – 25.4

1. (a)(i)

α -particles are helium nuclei.

β -particles are fast-moving electrons.

γ -particles are electromagnetic waves with high frequency. (ans)

(a)(ii)

	mass	charge	penetrative power	ionisation strength
α - particles	4u	+2e	weak	strong
β - particles	$\frac{u}{1840}$	–e	medium	medium
γ - particles	none	none	strong	weak

u = mass of one nucleon , e – electronic charge

(b)(i)

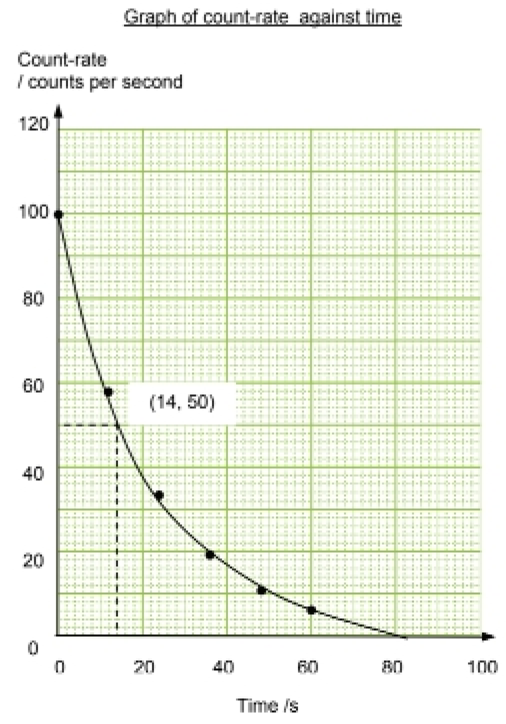
The half-life of radioactive sample is the time required for half the atoms of a radioactive isotope of an element to decay. (ans)

(b)(ii)

Number of half-lives elapsed after 20 days
$= \left(\frac{20}{5}\right) = 4$ half-lives

Fraction of initial sample $= \left(\frac{1}{2}\right)^4 = \frac{1}{16}$ (ans)

2. (a)



(ans)

(b)

The half-life can be determined by finding the mean tine taken for the activity to decrease to half its initial value. The first pair of readings are shown on the graph as an example.

Change in activity / counts per second	Time Period
100 to 50	14 – 0 = 14
80 to 40	19 – 4 = 15
60 to 30	24 – 10 = 14
40 to 20	35 – 19 = 16
20 to 10	50 – 35 = 15
Average	15.25 ≈ 15 s

(ans)

3. (a)(i)

Alpha particle – helium nucleus

Beta particle – high energy electron

Gamma rays – high energy electromagnetic radiation (ans)

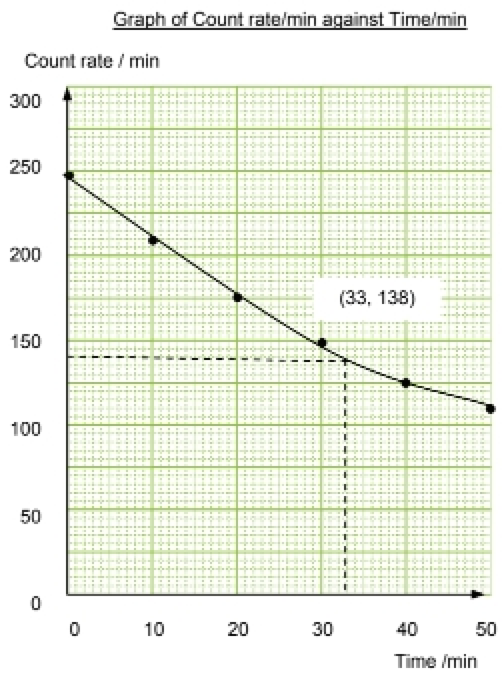
(a)(ii)

α particle → +2

β particle → -1

γ ray → no charge (ans)

(b)



(ans)

(b)(i)

From the graph,

when count-rate = [(248 – 28) ÷ 2] + 28 = 138,
time = 33 min

∴the half-life is 33 min. (ans)

(b)(ii)

Background radiation is partly due to the presence of radioactive material in the earth and nearby surroundings.

It is partly due to cosmic rays that penetrate the earth's atmosphere from outer space. (ans)

(c)(i)

$^{14}_{6}C \rightarrow {}^{0}_{-1}e + {}^{14}_{7}N$ (ans)

(c)(ii)

$15 \xrightarrow{5000} \frac{15}{2} \xrightarrow{5000} \frac{15}{4}$

Estimated age = 5000 × 2 = 10 000 years (ans)

(d)

The fluctuation is due to background radiation and also due to the random nature of radioactive emission. (ans)

❷❺•❺ Uses of radioactive isotopes including safety precautions

MCQs

1. C It prevents much of the radiation from escaping into the surroundings

Lead is able to absorb all α and β radiations as well as most of the γ radiation if it is thick enough. (ans)

2. B short half-life and emit beta particles

The tracer should have short half-life so that radiation will not irradiate the body for a long time and damage the tissues. Beta particles have relatively smaller ionization power. Hence the damage to the cells will be lesser. Also, beta particles are able to penetrate the body and be detected. (ans)

Questions – 25.5

1. (a)

The right kidney is not working properly. More radiation is still present in the right kidney after 10 minutes. This shows that it cannot pass the gamma source to the bladder properly. (ans)

(b)(i)

Number of half-lives = 24 ÷ 4 = 6

Count –rate = $800 \times \left(\frac{1}{2}\right)^6 = 125$ counts min^{-1} (ans)

(b)(ii)

Source Y. (ans)

(c)

The radiation cannot penetrate through the body for detection. Also, it has high ionizing power thus it is harmful to the body cells. (ans)

(d)

The film under the 3 mm thick aluminium window and that under the 1 mm thick lead window will not be affect because beta particles will be absorbed by them. (ans)

2. (a)(i)

"Radioactive" means the ability to emit α, β and γ radiation in a random and spontaneous manner.

"Half-life" is the time taken for half the number of radioactive atoms to decay. (ans)

(a)(ii)

Put an aluminium sheet of a few mm thick between the source and a GM tube connected to a ratemeter. The ratemeter shows a great drop in reading. (ans)

(a)(iii)

The radiation has to drop to $\frac{1}{8}$ of the initial reading.

$\therefore$ Time taken = 3 half lives = 3 × 15 = 45 hours (ans)

(b)(i)

With a short half-life, the radiation will not irradiate the body for a long time and damage the tissues. (ans)

(b)(ii)

When the flow of blood increases, the intensity of radiation drops (as shown in the first part and last part of the graph). The peak in the graph shows the accumulation of radiation due to the slowing down in the rate of flow of blood. (ans)

3. (a)(i)

Reading off from the graph,

When time = 8 min, number of nuclei left = 140 (ans)

(a)(ii)

Estimated half life of polonium = 2.0 min (ans)

(b)(i)

No, polonium cannot be used as a tracer. The half life of polonium is too short for a proper tracing to be done. (ans)

(b)(ii)

Alpha emitters emit helium nucleus which has strong ionizing power that cause more serious damage to the body.

Alpha emitters have weak penetrating power and may not pass through the body to be detected. (ans)

4. (a)

β-particles have weaker penetrative powers as compared to γ-particles. Hence they would be unable to pass through the body to reach the detector. (ans)

(b)(i)

The half-life of radioactive sample is the time required for half the atoms of a radioactive isotope of an element to decay. (ans)

(b)(ii)

Half-lives that need to elapse before the iodine is usable:

$$\left(\frac{1}{2}\right)^x = \left(\frac{1.5\times10^8}{12\times10^8}\right)$$

$$\left(\frac{1}{2}\right)^x = \left(\frac{1}{8}\right)$$

$\therefore x = 3$

Total no of days that the sample has to be left $= 3 \times 8 = 24$ days (ans)

(b)(iii)

The right kidney is not functioning normally. Instead of the rate of disintegration decreasing over time, it is increasing, which is abnormal implying that the right kidney is not functioning normally. (ans)

(b)(iv)

Iodine-131 is more suitable. Technetium has a relatively short half-life that disintegrate too quickly for any reasonable results to be tabulated. (ans)

5. Radioisotopes can be used as medical tracers. A patient can be given a solution of iodine-131 to drink. The isotope is then absorbed by the thyroid gland of the body. Using a detector outside the body to measure the amount of γ-rays from the thyroid gland we can determine the amount of iodine absorbed by the gland and this information can help us to evaluate if the thyroid gland is functioning normally. A short half-life should be used since radiation is harmful to the body. (ans)

6. (a)(i)

If the electrostatic charge is not removed, there is a tendency for the layers of film o stick together. (ans)

(a)(ii)

The 'active bar' is placed at C so that all the excess charges are neutralized. If it is at A or B, there is still a chance for the rollers to produce charges on the film due to friction after the neutralization has been done. (ans)

(b)(i)

Alpha particles are helium nuclei ${}^4_2He^{2+}$. (ans)

(b)(ii)

Alpha radiation has the ionizing power as it is massive and has a charge of +2. (ans)

(b)(iii)

A gamma emitter is not suitable as it is not charged. It is unable to deionise the film. (ans)

(b)(iv)

The positively charged alpha particles given off by cobalt-60 neutralizes the excess charge on the film by deionization process. (ans)

(c)(i)

$$800 \xrightarrow{138} 400 \xrightarrow{138} 200 \xrightarrow{138} 100$$

Time taken $= 138 \times 3 = 414$ days (ans)

(c)(ii)

The mass or the count rate of the 'active bar' would have decreased appreciably by one year. Therefore they are replaced. (ans)

(d)

The used 'active bars' still have residual radioactive cobalt-60 on it, thus it cannot be thrown away with other factory waste. (ans)

7. (a)(i)

P: thin aluminium (5 mm)

Q: thick lead (2 cm) (ans)

(a)(ii)

X will be black. (ans)

(b)(i)

It is the time taken for the count rate to drop to half its initial value. (ans)

(b)(ii)

The radiation would be in the body for too long if the half-life is 6 days. 6 minutes is too short for any proper investigation to be done. (ans)

(b)(iii)

$$6400 \xrightarrow{6} 3200 \xrightarrow{6} 1600 \xrightarrow{6} 800 \xrightarrow{6} 400$$

Count rate = 400 counts per minute (ans)

(b)(iv)

It is due to background radiation and also due to the random nature of radioactive emission. (ans)