Delta Science Education

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HKDSE Physics

Core 5: Radioactivity and Nuclear Energy

Chapter 1: Radiation and Radioactivity

Part 2

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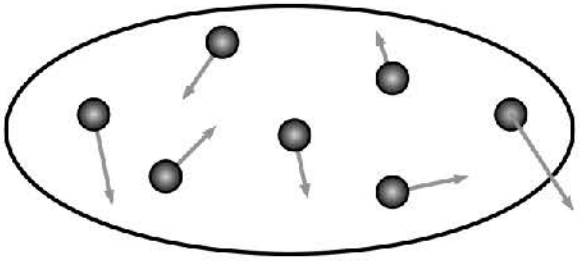
8. Characteristics of Radioactive Decay

(1) Random nature of decay

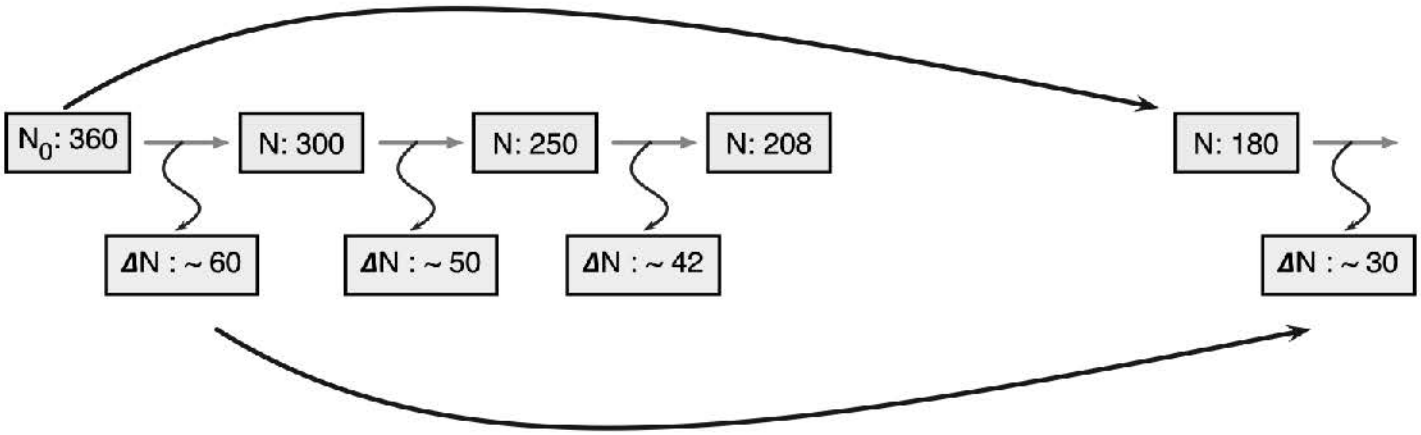
- **Radioactive nuclides**: unstable nuclei decay to give radiation particles.



- The emission of radioactive radiation occurs at **random**, i.e.
  - it is impossible to know [ ] **one particular nucleus will decay**; and
  - it is impossible to know [ ] **nucleus will decay in the next instant.**

(2) Dice decay analogue

- A large number of dice (N_0) is used to represent a sample of radioactive nuclides.
- The dice are shaken and thrown into a tray. Those with a '6' upwards are said to have 'decayed' (ΔN). These decayed dice are then removed and counted.
- The number of dice remaining in the try is N.



- The process is random in nature. It is not possible to know which die will be 'decayed' in the next throw. However, **if the number of dice is [ ], on average about [ ] of dice would be 'decayed' in each throw.**

(3) Definition of activity

- **Activity** A of a radioactive sample is
  - the number of radioactive particles emitted in a unit time; or
  - the number of radioactive nuclei decayed (ΔN) in a unit time.

➢ SI unit of activity: **Becquerel (Bq)**
>> 1 Bq = 1 count s^{-1} = 1 decay s^{-1} = 1 disintegration s^{-1}

➢ Assuming that the activity **remains** [ ] **during the time interval, t.**

(4) Decay constant

- As the number of radioactive nuclei decayed (ΔN) in a unit time is proportional to the number of undecayed nuclei (N), thus:

➢ k is called **decay constant**

➢ SI unit of k: s^{-1}

- Physical meaning of the decay constant:

Decay constant, k, is the probability of decay of the radioactive nuclei per unit time.

- The decay constant only depends on **the** [ ] and is **unaffected by any other environmental (including** [ ] **and pressure) or human factors**.

- Factors affecting the **activity** of a sample:
  - The type of radioactive nuclide
    different type of radioactive nuclides have different [ ]
  - The number of undecayed nuclei
    the activity is proportional to the number of [ ]

Examples that you must fully understand

1. A radioactive source undergoes beta decay. The activity of the source is 2500 Bq.

(a) Find the number of beta particles emitted by the source in 2 minutes, assuming that the activity remains unchanged in the time interval.

(b) Find the number of radioactive nuclides remaining in the sample after the 2 minutes in (a) if the decay constant of the radioactive source is 1.54×10^{10} yr^{-1}.

(c) If each beta particle carries an energy of 5.28×10^{-13}, calculate the average power emitted by the source during the 2 minutes.

(d) A GM tube is placed close to and facing the source. However, the correct count rate measured is only 250 counts per second. Give one reason why the GM tube cannot measure the activity of the source.

It is due to the random nature of radiation.
Since the beta particles are emitted in [ ], not all of the particles can [ ] [ ].

2. The decay constant of a radioisotope of an element

(1) is random.

(2) depends on pressure and temperature.

(3) is directly proportional to the number of nucleons in the isotope.

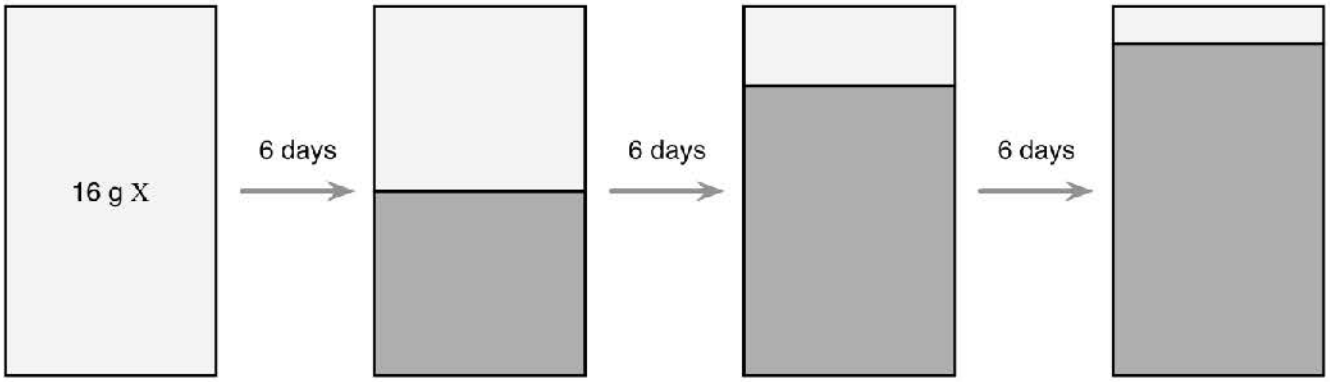
(4) is an identifying characteristic of that isotope.

(5) Half-life

Half-life is the time taken for the activity of a radioactive sample to decrease to half of its original value.

Half-life is the time taken for the number of radioactive nuclei to decrease to half of its original value.

- Suppose in a sample (specimen), nuclide X decays and changes into another stable nuclide Y with a half-life of 6 days. The sequence of the change of mass of the two nuclides is:



- Note that the **total mass of the sample (specimen or substance)** remains unchanged as the **radiation particles emitted are** ____ **in mass**.

- **Half-life is a constant depending on the** ____ **only.** It is **unaffected by any other environmental (including** ____ **and pressure) or human factors**.

Examples that you must fully understand

3. A radioactive substance has a half-life of **10 minutes**. Which of the following statements is / are correct?

(1) All atoms of the substance will decay within 10 minutes.
(2) All the atoms of the substance will split into 2 equal parts in 10 minutes.
(3) The substance will decay completely in 20 minutes.
(4) If the radioactive substance is heated to a very high temperature, the half-life would decrease.

4. Which of the following descriptions is / are correct? The half-life is

(1) The time taken for the mass of the sample to fall to half of its initial value.
(2) The time taken for the activity of the sample to fall to half of its initial value.
(3) Half of the time taken for the sample to decay completely.

Examples that you must fully understand

5. A radioactive substance decays into a stable nuclide. The activity is recorded as follows. What is the half-life of the substance?

Time / hour	0	1	2	3	4
Activity / count min^{-1}	460	320	225	163	118

6. In a beta-decay, element X decays into a stable element Y. The initial mass of X is 40 g while that of Y is 0 g. After 2 hours, the mass of Y is found to be 35 g. What is the half-life of X?

7. A sample of mass 64 g containing a radioactive substance X. X decays into stable Y with a half-life of 5 days. The initial activity of X is 4000 Bq.

(a) Find the mass of Y and the mass of the sample after 10 days.

(b) How long does it take for X to become 4 g?

(c) What is the activity of X when the mass of X is 4 g?

8. A radioactive source consists of a mixture of two radioisotopes P and Q. P has a half-life of 1 hour and Q has a half-life of 2 hours. Both P and Q have stable daughter nuclide. The initial activity recorded by a GM counter is 800 Bq. After 2 hours the counter registers an activity of 240 Bq. What is the initial activity of P?

(6) Calculation using half-life

- **The number of half-lives passed after certain time:**

- **Finding different quantities after certain time:**

Examples that you must fully understand

9. A radioactive nuclide has a mass of 40 g. It has a half-life of 5 years. The initial activity of the nuclide is 56000 Bq.

   (a) What is the activity of the nuclide after 50 years?

   (b) How long does it take for the activity to drop to 3500 Bq?

   (c) What is the mass of the radioactive nuclide when the activity has dropped to 10000 Bq?

10. A radioisotope X has a half-life of 2 days while another radioisotope Y has a half-life of 1 day. Initially there are N undecayed atoms of X and $8N$ undecayed atoms of Y. After how many days will X and Y have the same number of undecayed atoms?

Examples that you must fully understand

11. A radioactive substance X undergoes beta-decay and forms a stable product Y. If 16 g of X is present initially and its half-life is 2 years, calculate

(a) the mass of *X* and *Y* after 6 years

(b) the time taken when 0.5 g of *X* is left, and

(c) the time taken when 12 g of *Y* is formed.

12. A certain radioactive isotope X has a half-life of 20 hours. After a time interval of 10 hours, what is the approximate fraction (f) of a sample of the radioactive isotope X remaining?

A. $\frac{1}{4} \le f \le \frac{1}{2}$
B. $f = \frac{1}{2}$
C. $\frac{3}{4} > f > \frac{1}{2}$
D. $f > \frac{3}{4}$

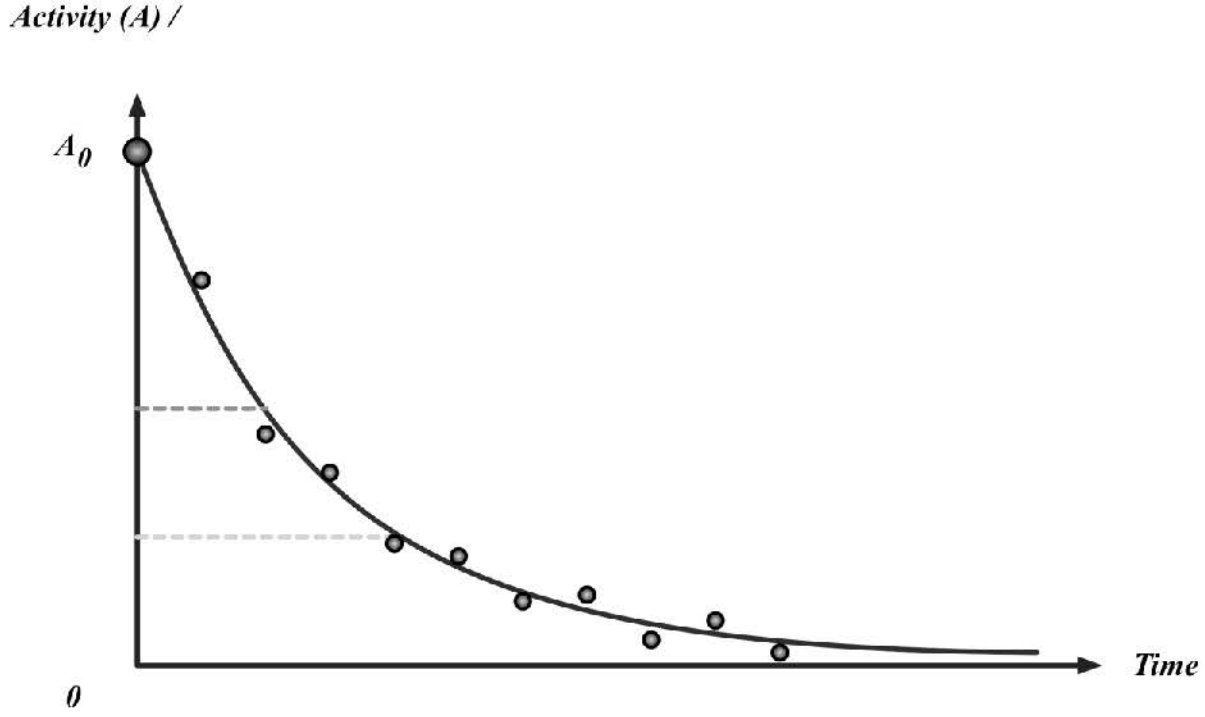
13. Radionuclide P decays into stable nuclide Q. The half-life of P is 5 days. Initially, the ratio of P to Q in a sample is $5 : 2$. Find the time taken for the ratio of P to Q to be $3 : 7$.

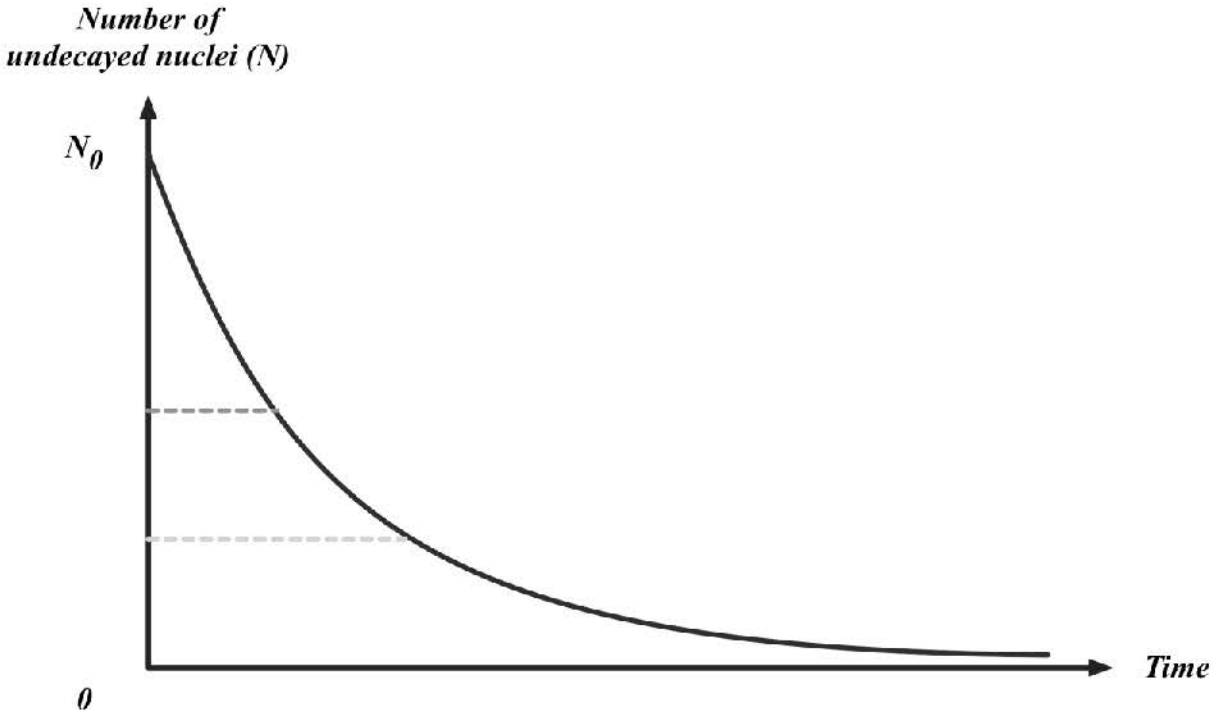
14. Two radioactive samples P and Q are freshly prepared. It is found that when $15/16$ of all the nuclei of P have decayed, $63/64$ of all nuclei of Q have also decayed. Find the ratio of half-life of P to half-life of Q.

10. Decay Curve

(1) Time variation of the activity

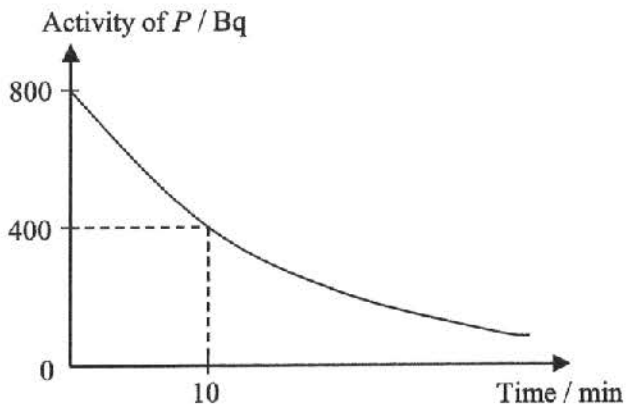
- A decay curve is obtained when the activity of a radioactive sample is plotted against the time.
- The points may be scattered at two sides of the curve due to the **random nature** of radiation.

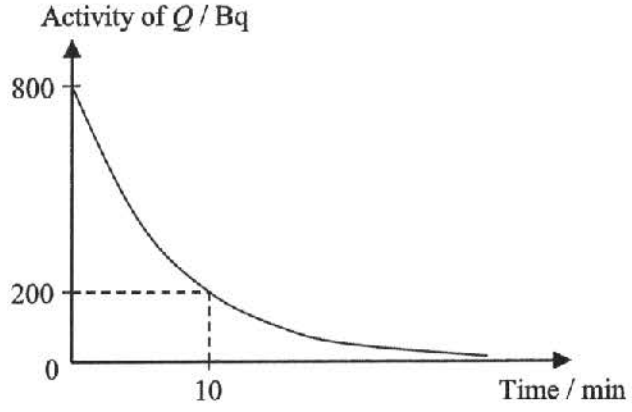




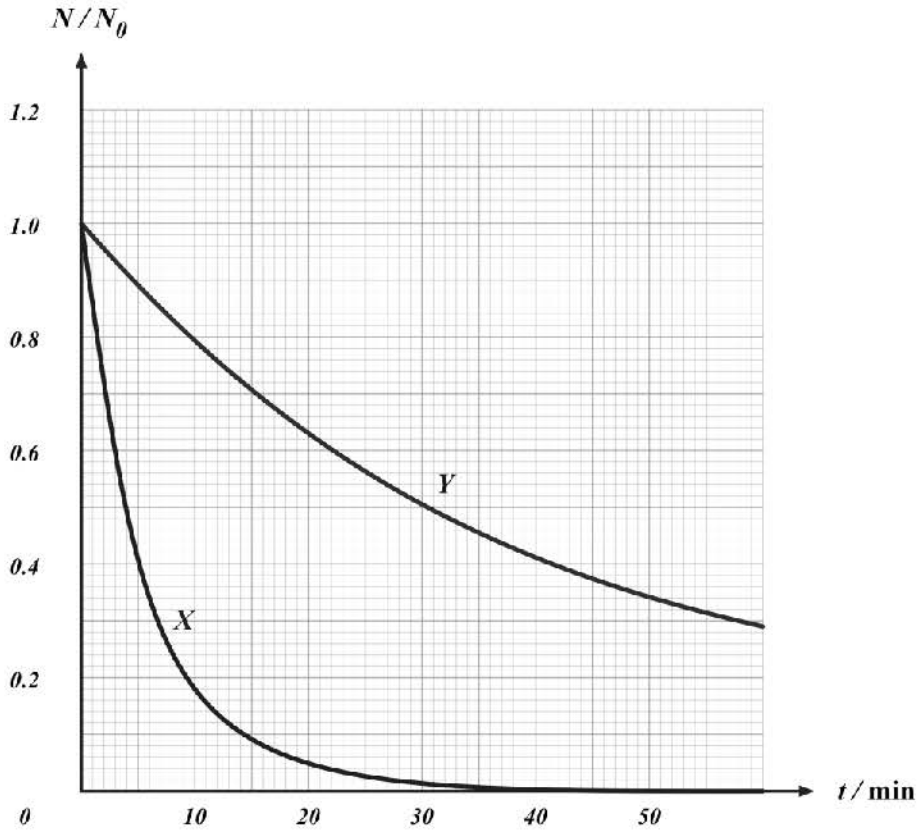
Examples that you must fully understand

15. The figures below show the variation of the activities of two radioactive sources P and Q with time. Find the ratio of half-life of P to that of Q.





16. The figure below shows the decay curves of two radioactive elements X and Y both emitting α-particles. N_0 is the number of radioactive atoms present at time $t = 0$ and N is the number at the end of t minutes.



(a) What are the half-lives of X and Y?

Half-life of X =

Half-life of Y =

(b) A mixture of X and Y is placed in front of a GM tube. Initially, they have the same number of radioactive atoms.

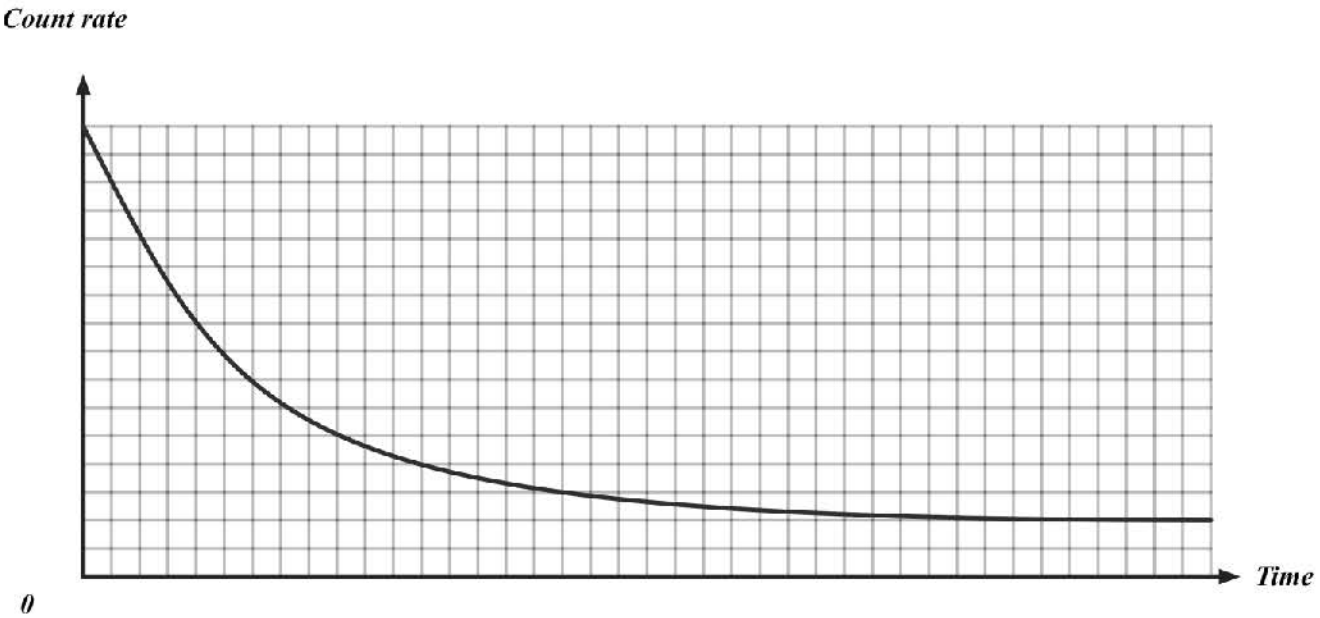
(i) Which element will be mainly responsible for the reading shown on the Geiger counter during the first four minutes?

Element: ☐

(ii) Estimate the fraction of the total number of counts due to that element in the first four mins.

(2) Curve of count rate against time

■ The **total count rate includes the count rate of** ☐ **radiation.**



Examples that you must fully understand

17. In an experiment to measure the half-life of a radioactive isotope, the following results are recorded:

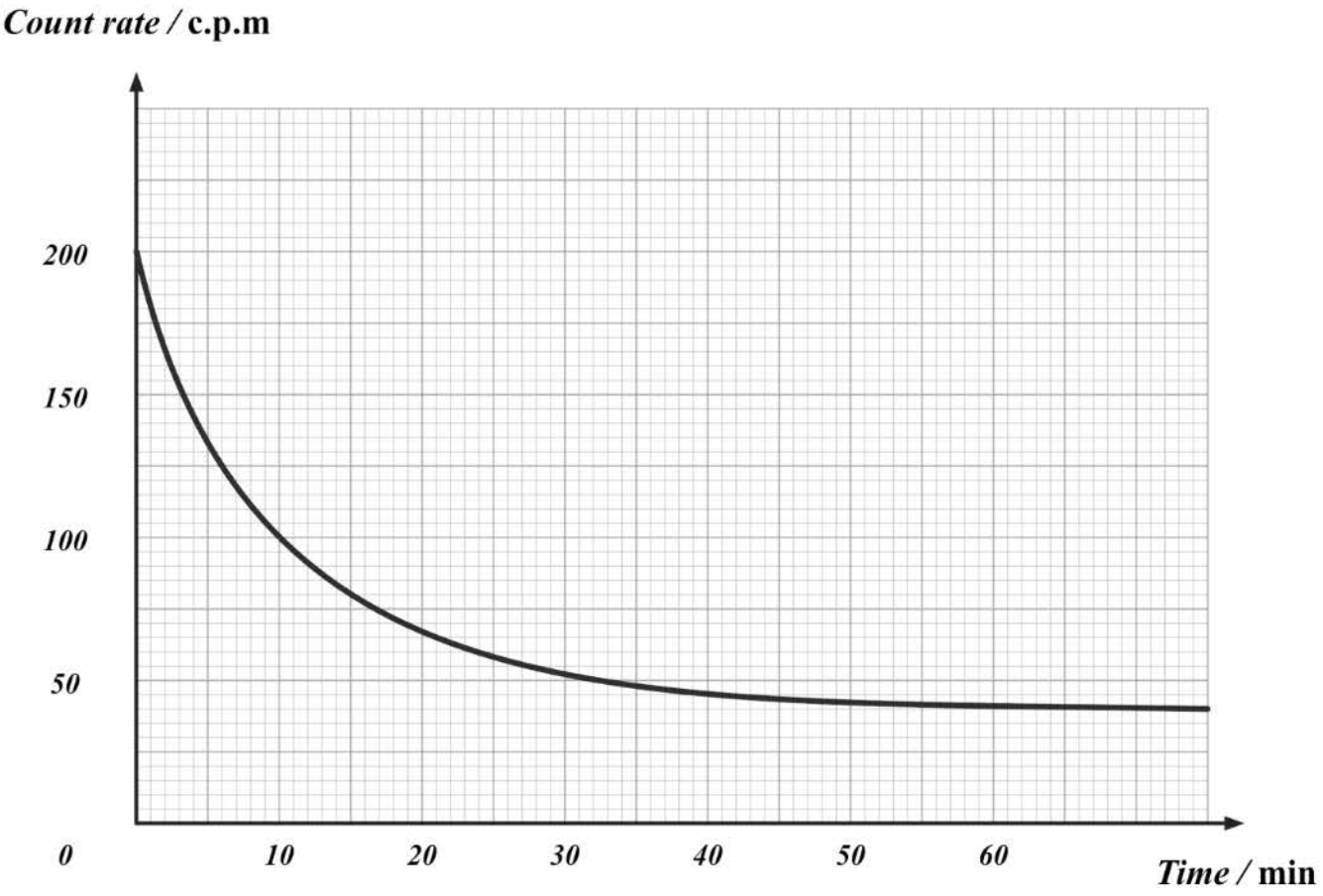
Time / hour	0	2	4	6	8	10	100
Count rate / count min^{-1}	116	96	80	69	58	50	20

What is the half-life of the isotope?

Half-life =

Examples that you must fully understand

18. The radioactivity in a room containing a radioactive source is measured by a GM counter. The figure below shows the variation of count rate with time.



(a) Find the background count rate of the room.

Background count rate =

(b) Find the count rate due only to the radioactive source at the time of 10 minutes.

Count rate =

(c) From the figure, find the half-life of the radioactive source.

Half-life =

(d) Suggest three sources of the background radiation.

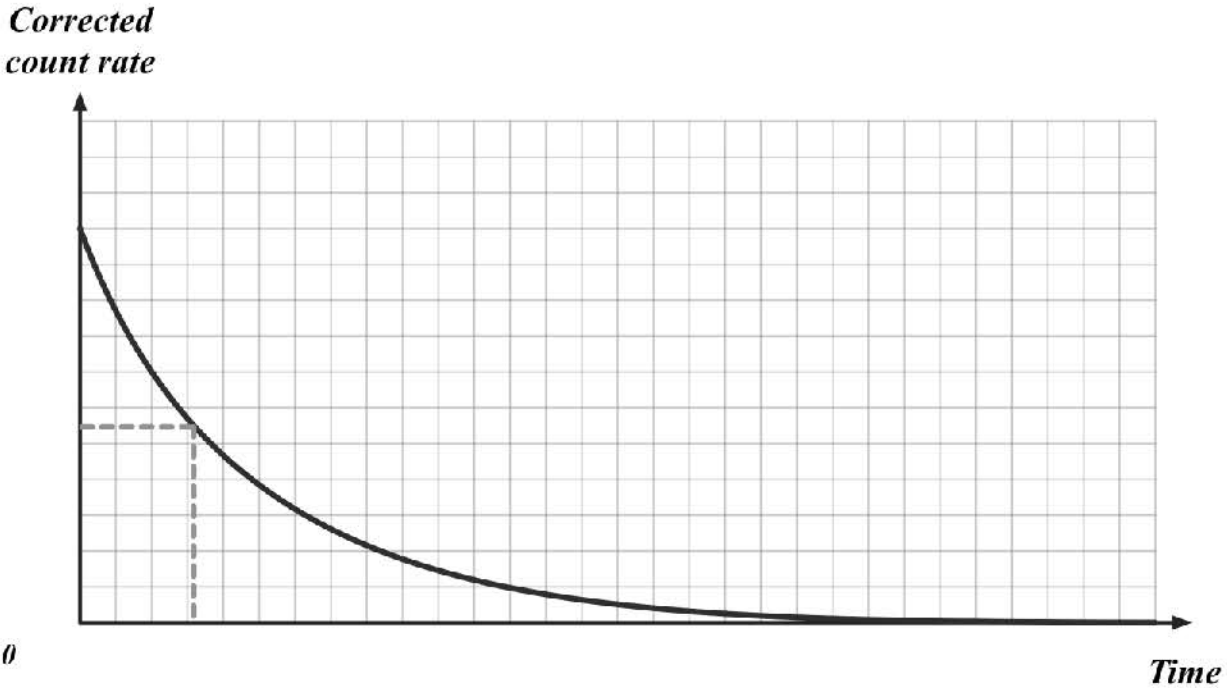
(i) Radiation from

(ii) Radiation from

(iii) Radiation from

(3) Curve of corrected count rate against time

- The corrected count rate is the count rate of a radioactive sample that has **deducted** the background count rate.
- The **corrected count rate** then represents the [ ] of the sample.

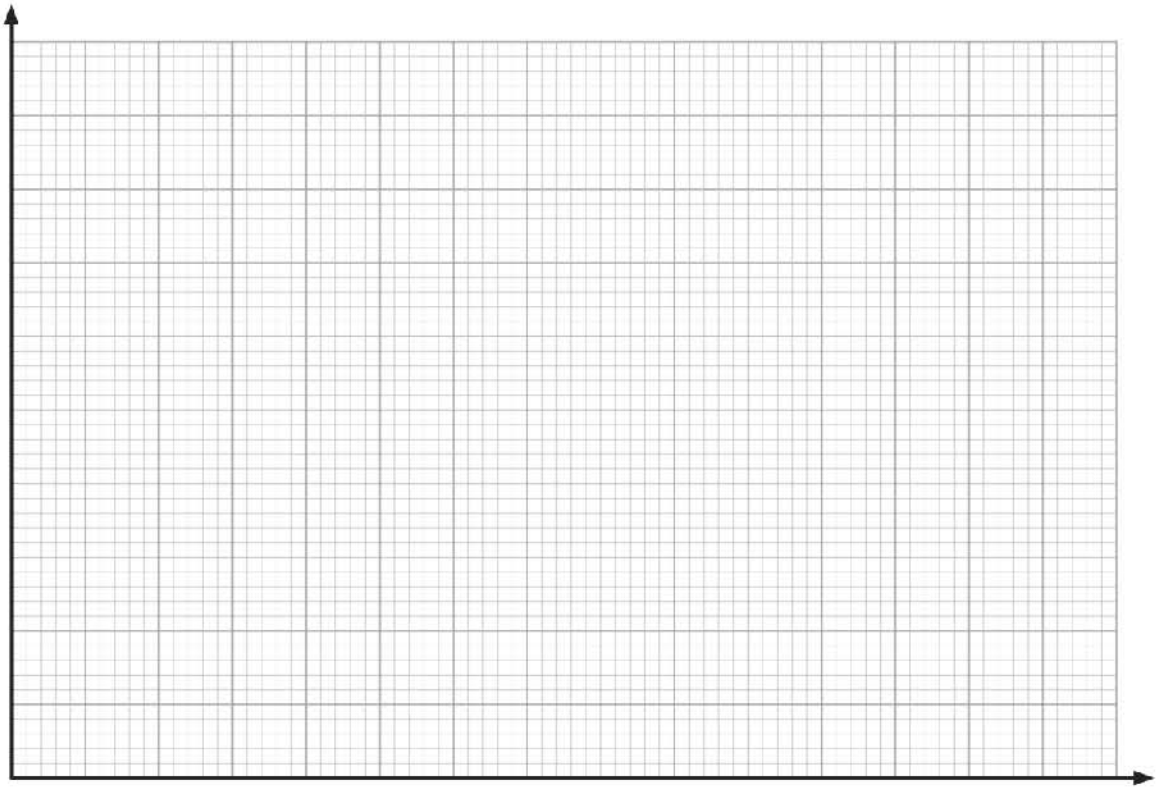


Examples that you must fully understand

19. In an experiment to measure the half-life of a radioactive isotope in a place where the background count rate is **50 counts per minute**, the following results are recorded:

Time / hour	0	10	20	30	40	50	60
Count rate / count min^{-1}	1050	448	209	111	75	60	54

(a) Plot the graph of the corrected count rate against time on a graph paper.

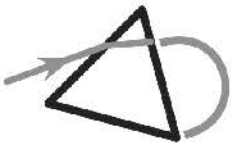


(b) Find the half-life of the radioisotope.

Half-life =

(c) What is the count rate after 200 hours?

Count rate =



(4) Exponential law of decay

- Number of undecayed nuclei N follows the exponential law:

where N_o is the original number of undecayed nuclei

and k is the decay constant, with unit

- Decay constant k depends on the type of radioactive nuclide. Different radioactive nuclides have different values of decay constant.

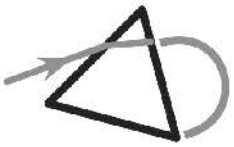
- Since the activity A is proportional to the undecayed nuclei N:

Examples that you must fully understand

20. The activity of a radioactive sample is **8500 Bq**. The decay constant of the sample is **9.6×10^{-5} s^{-1}**. What is the activity of the sample after **3 hours**?

21. A radioactive sample contains **6×10^{22}** undecayed nuclei. The decay constant of the sample is **0.025 min^{-1}**. What is the number of nuclei decayed after **1 hour**?

22. The activity of a radioisotope is **250 Bq** at time t = 0 and **54 Bq** at t = **30 min**. Estimate its activity at t = **10 min**.



Examples that you must fully understand
23. The activity of a radioisotope was **70 Bq** at **5 pm** and **49 Bq** at t = **10 pm**. Estimate its activity at noon the same day.
24. A radioactive sample originally consists entirely of an element X, after the emission of a single α-particle, each atom of X would become an atom of element Y. After **10 days**, the source was found to contain 45% X and 55% Y. What is the composition after a further of **5 days**?

(5) Relate the decay constant and the half-life

- When $t = t_{1/2}$ the activity must drop to half of the initial value, i.e.

 or 

- Since decay constant and half-life are inter-related, exponential decay is described by:

 or 

Examples that you must fully understand

25. The half-lives of some radioisotopes are tabulated below:

Radioisotope	Half-life
Carbon-11	20.3 minutes
Phosphorus-32	14.3 days
Sodium-22	2.60 years

Which of the following statements is / are correct?

(1) The activity of carbon-11 must be the highest.

(2) The decay constant of phosphorus-32 is larger than that of carbon-11.

(3) If the initial activity of sodium-22 is 1520 Bq, its activity would be lower than 380 Bq after 6 years.

26. The activity of a radioactive sample is 1.0×10^6 Bq. The half-life of the sample is 5.3 years. Estimate the number of nuclei in the sample that decay in the first day.

Since the time of 1 day is

27. The activity of a radioactive sample is 1.0×10^6 Bq. The half-life of the sample is 5.3 days. Estimate the number of nuclei in the sample that decay in the first day.

Examples that you must fully understand

28. The table gives the corrected count rate (in counts per minute) from three samples of radioisotopes at three different times.

Isotopes	0 min	20 min	40 min
X	480	243	119
Y	135	32	9
Z	168	118	93

From the result, it can be concluded that

(1) X produces the most penetrating radiation.

(2) Y has the largest decay constant.

(3) Z has the longest half-life.

29. A counter is placed near a radioactive source which has a half-life of **1 hour**. The counter registers **840 counts / min** at noon and **540 counts / min** at 1 p.m. What is the total count rate at 3 p.m. on the same day?

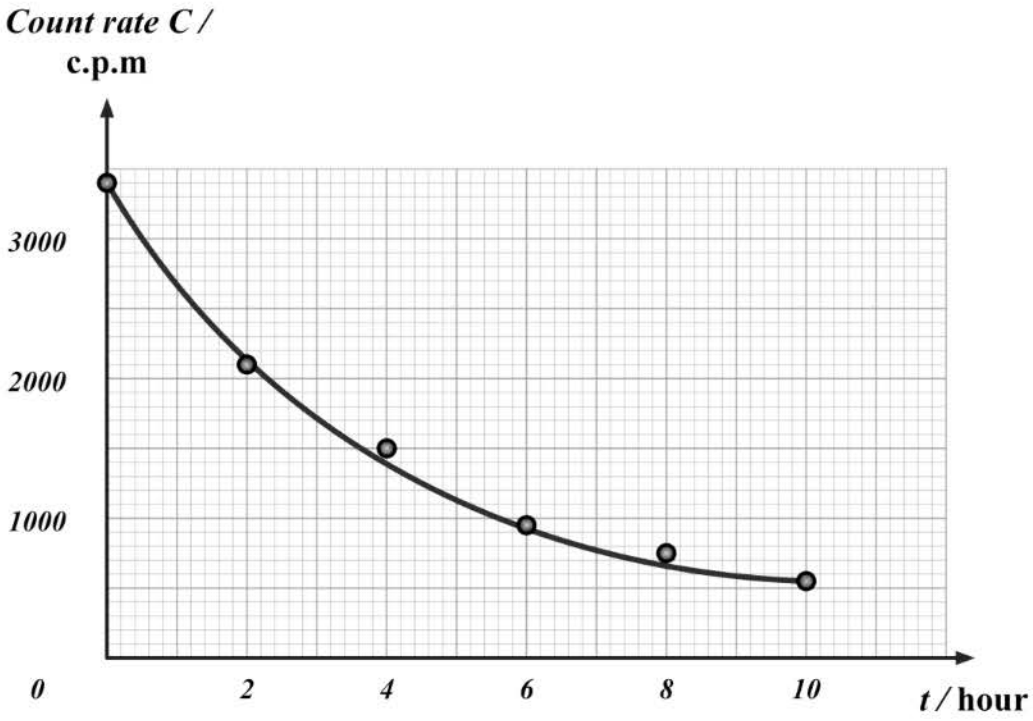
30. A radioactive sample initially contains 3.2×10^{25} plutonium-238 atoms. The sample can be used to generate a certain amount of energy in a certain period of time, t. You can assume the time, t, is much shorter than the half-life of plutonium-238. It is given the half-life of plutonium-238 to be **87.74 years**. You can take **1 year** to be 3.16×10^7 **s**.

(a) Find the initial activity in Bq of the radioactive sample.

(b) After 36 years, if the same source is used to generate the same amount of energy, calculate the radiation time required, in terms of t.

Examples that you must fully understand

31. The graph below shows the correct count rate C, measured in counts per minute, of a radioactive sample of X varied with time. It is known that α-particle are emitted by the sample.



(c) Explain why the points on the graph do not fit exactly into the smooth curve.

It is due to the [ ] [ ] of radiation.

(d) What is the decay constant of X?

Half-life: Decay constant:

(e) How long would it take for the corrected count rate to drop to 100 cpm?

(f) The corrected count rate cannot represent the actual activity of the radioactive source X. Give two reasons.

(i) Since the alpha particles are emitted in [ ] [ ], not all the emitted alpha particles can enter the GM tube to be measured.

(ii) Some α-particles cannot be detected as they may be internally [ ] by the sample.

11. Radiation hazard

(1) Harmful effect of ionizing radiation on human

- Harmful effect of ionizing radiation:
  - Radiation can [ ] and tissue in human;
  - Radiation can cause [ ] in human; and
  - Radiation can cause [ ] of body cells and this can affect off springs.
- Effect of radiation is [ ] in human.

Examples that you must fully understand

32. If the human body is exposed to radioactive sources emitting nuclear radiation, explain which type of source (alpha, beta or gamma) is the most dangerous.

The source emitting [ ] radiation is the most dangerous since [ ] has the [ ] [ ] [ ], and thus [ ].

33. If a radioactive source is injected into the human body, explain which type of source (alpha, beta or gamma) is the most dangerous.

The source emitting [ ] radiation is the most dangerous since [ ] has the [ ] [ ] [ ], thus causes [ ].

(2) Radiation dose

- The extent of radiation effects on a human body varies according to factors including:
  - [ ] of the radioactive source;
  - the [ ]; and
  - which [ ] **of human body is exposed** to that radiation
- **Radiation dose** is used to measure the **amount of** [ ] **caused by the radiation on human body.** The radiation dose is measured in **Sievert (Sv).**
- <u>**The following activities may lead to greater radiation dose:**</u>
  - Cigarette smoking
  - Long distance travelling by air
  - Medical examination

(3) Radiation dose in everyday life

- **Different effects of dose level on human bodies:**
  - A large dose of 10 Sv or above is fatal
  - A dose of 1 to 10 Sv causes acute radiation sickness
  - A dose of 0.1 to 1 Sv may cause cancer
  - A dose below 0.1 Sv (100 mSv) has no clear health effect
- The average annual dose from background radiation is about 2 mSv.
- Maximum annual dose for a person in public is 5 mSv.
- Maximum annual dose for a person employed in radiation industry is 20 mSv.

Examples that you must fully understand

34. Some typical radiation equivalent doses are tabulated as follows:

	Radiation dose
Watching television	0.005 mSv / hr for watching every day in a year
Flying in an aircraft	0.0028 mSv / hr
X-ray check	0.05 mSv each time
Cigarette smoking	0.15 mSv per pack

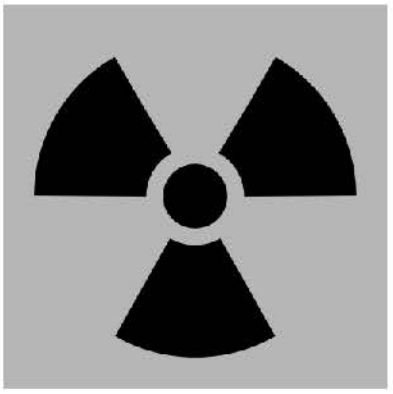
(a) Mary watches television for 8 hours every day on average. Calculate the radiation equivalent dose received by Mary in one year.

(b) A pilot drives aircraft for 10 trips every month. Each trip lasts for 8 hours on average. Calculate the radiation equivalent dose received by him in one year.

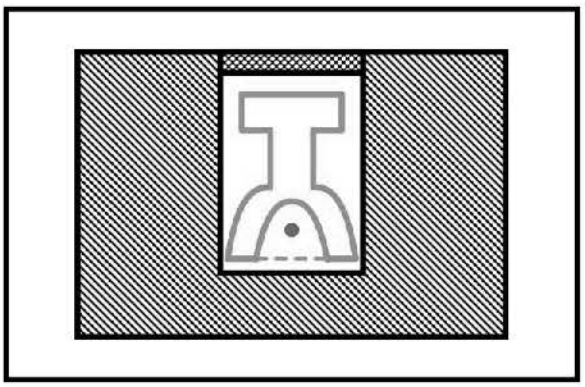
(c) A man smokes three packs of cigarette each day. What is the total radiation dose absorbed by the man in 1 year?

(d) What is the number of X-ray checks in one year that receives the equivalent dose as the man in part (c)?

(4) Warning sign of radiation



(5) Laboratory safety on use of radioactive source



- Use long forceps to handle a radioactive source.
- Keep the exposure time to radioactive source as short as possible.
- Wear disposable gloves and protective clothing in handling.
- Never point a source towards human bodies.
- No eating, drinking and smoking during the handling.
- Store the radioactive source in lead containers.

Examples that you must fully understand

35. The radiation sources in the school are stored in a castles inside a wooden box. What is the material that the castle made of?

    The castle is made of [ ].

36. Suppose Mary receives a dose of 0.2 mSv consisting of α radiation and Lily receives a dose of 0.1 m mSv consisting of γ radiation. Who has received greater harmful effect on the human body?

    [ ] has received greater harmful effect.

37. State the unit of measurement for the following quantities:

    (i) Activity [ ]; (ii) Frequency [ ]; (iii) Radiation dose [ ]; (iv) Loudness level [ ]

(6) Ways to minimize the radiation dose absorbed

- Workers working in radioactive environment should wear protective clothing.
- Workers monitor the total radiation dose by wearing film-badge. If the dose is too high, they would leave the job for a period of time.
- Remote-controlled robots are used to handle highly radioactive source.
- If possible, workers should work behind lead-glass windows.

Examples that you must fully understand

38. State three safety precautions that a factory worker should take when handling radioactive sources.

(1) He should wear a [ ] [ ] to monitor the radiation dose.
(2) He should handle the sources with [ ] [ ].
(3) He should not direct the sources towards [ ] [ ].

39. State three safety measures to minimize the radiation dose received by a factory worker.

(1) He should work behind [ ] [ ].
(2) He may use [ ] [ ] [ ] to handle the sources.
(3) He would wear [ ] [ ].