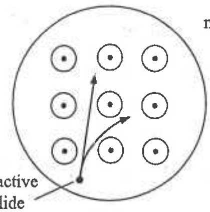
The following list of formulae may be found useful :

Law of radioactive decay	$N = N_0 e^{-kt}$
Half-life and decay constant	$t_{\frac{1}{2}} = \frac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$

Part A : HKCE examination questions

1. **< HKCE 1980 Paper II - 40 >**

A radioactive nuclide ${}^{A}_{Z}X$ undergoes radioactive decay inside a cloud chamber. The radiations emitted are subjected to a magnetic field and the resulting tracks are as shown in the figure. What are the atomic number and the mass number of the remaining nuclide ?



	Atomic Number	Mass Number
A.	$Z-2$	$A-4$
B.	$Z+1$	$A-4$
C.	$Z+1$	A
D.	$Z-1$	$A-4$

2. **< HKCE 1980 Paper II - 39 >**

The two isotopes ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ of chlorine have different
(1) numbers of protons
(2) number of neutrons
(3) chemical properties

A. (1) only
B. (2) only
C. (3) only
D. (1) & (2) only

3. **< HKCE 1981 Paper II - 31 >**

Which of the following statements concerning isotopes of an element is/are correct ?
(1) They have the same number of neutrons.
(2) They have the same chemical and physical properties.
(3) They have the same atomic number but different mass numbers.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

4. **< HKCE 1981 Paper II - 35 >**

Which of the following represents an alpha decay ?
(1) ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th$
(2) ${}^{215}_{85}At \rightarrow {}^{211}_{83}Bi$
(3) ${}^{210}_{81}Tl \rightarrow {}^{210}_{82}Pb$

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

5. < HKCE 1983 Paper II - 24 >

The atomic structure of isotopes of the same element differ from each other by having different numbers of
A. electrons.
B. neutrons.
C. electrons and protons.
D. electrons and neutrons.

6. < HKCE 1984 Paper II - 34 >

An ancient piece of wood was tested for its age by carbon-14 dating method. The normal emission rate from 2 g of carbon from a living plant is 20 counts per minute. If the rate from 2 g of carbon from the wood is 5 counts per minute, and the half life of carbon 14 is 5700 years, what is the approximate age of the wood in years ? (Background radiation may be neglected.)
A. 5700×4
B. 5700×2
C. 5700 / 2
D. 5700 / 4

7. < HKCE 1985 Paper II - 43 >

During radioactive decay, ${}^{230}_{90}X$ becomes ${}^{226}_{90}Y$. Which of the following statements would be correct ?
(1) The change would involve α decay only.
(2) One α particle and two β particles would be emitted.
(3) *X* and *Y* are two isotopes of the same element.
A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

8. < HKCE 1988 Paper II - 40 >

A U-235 nucleus would change to Ac-227 through a series of decay :

$${}^{235}_{92}U \xrightarrow{X} {}^{231}_{90}Th \xrightarrow{Y} {}^{231}_{91}Pa \xrightarrow{Z} {}^{227}_{89}Ac$$

What kind of particles are emitted at stages *X*, *Y* and *Z* in the radioactive decay chain shown above ?

	X	*Y*	*Z*
A.	α	α	β
B.	β	α	β
C.	β	β	α
D.	α	β	α

9. < HKCE 1988 Paper II - 38 >

The atomic number of Tin is 50 and its mass number is 112. Which of the following is an isotope of Tin ?
A. ${}^{112}_{51}X$
B. ${}^{114}_{50}X$
C. ${}^{112}_{49}X$
D. ${}^{112}_{62}X$

10. < HKCE 1989 Paper II - 39 >

${}^{235}_{92}U$ eventually decays to ${}^{207}_{82}Pb$. What is the number of α particles and β particles emitted during the decay ?

	α	β
A.	7	4
B.	7	10
C.	14	10
D.	28	4

11. < HKCE 1990 Paper II - 41 >

If the nucleus of an atom is represented by the symbol ${}^{214}_{83}X$, it means that this atom has
(1) 131 protons in its nucleus.
(2) 83 electrons outside its nucleus.
(3) 214 neutrons in its nucleus.
A. (1) only
B. (2) only
C. (3) only
D. (1) & (2) only

12. < HKCE 1992 Paper II - 39 >

${}^{238}_{92}U$ decays by emitting two α particles and two β particles. Which of the following represents the resulting nuclide ?
A. ${}^{234}_{90}Th$
B. ${}^{234}_{92}U$
C. ${}^{232}_{88}Ra$
D. ${}^{230}_{90}Th$

13. < HKCE 1994 Paper II - 39 >

Which of the following symbols represents a neutron ?
A. ${}^{0}_{0}n$
B. ${}^{1}_{0}n$
C. ${}^{0}_{1}n$
D. ${}^{1}_{1}n$

14. < HKCE 1995 Paper II - 40 >

A radioactive nuclide *W* decays to a nuclide *Z* by emitting one α-particle and two β-particles as shown below.

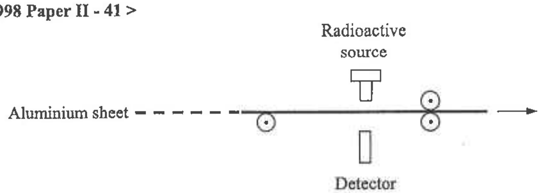
$$W \xrightarrow{\beta} X \xrightarrow{\alpha} Y \xrightarrow{\beta} Z$$

Which of the following statements about nuclides *W*, *X*, *Y* and *Z* is/are correct ?
(1) *W* and *Z* are isotopes.
(2) *X* has the greatest atomic number.
(3) *Y* has the greatest mass number.
A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

15. < HKCE 1997 Paper II - 40 >

Which of the following is **not** an application of radioactivity ?
A. Carbon-14 dating
B. Examination of foetuses (babies not yet born)
C. Killing cancer cells in human bodies
D. Sterilization of food

16. < HKCE 1998 Paper II - 41 >



In a factory producing aluminium sheets of 1 mm thickness, a thickness gauge is used to monitor the thickness of aluminium sheets. Which of the following states the correct radioactive source to be used in the thickness gauge and the reason behind ?

	Source	Reason
A.	α	The amount of α particles passing through aluminium depends on its thickness.
B.	β	The amount of β particles passing through aluminium depends on its thickness.
C.	β	β particles are less harmful to human beings.
D.	γ	γ radiation has the greatest penetrating power.

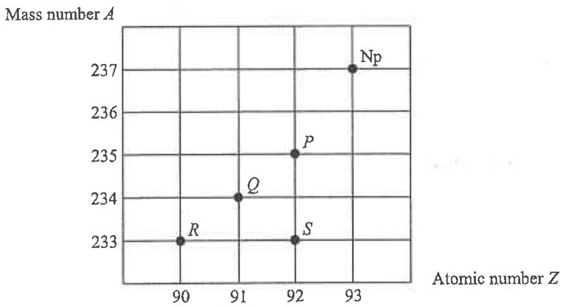
17. < HKCE 1998 Paper II - 39 >

A nucleus *X* emits a beta particle to form a daughter nucleus *Y*. Which of the following statements is/are correct ?

(1) *X* and *Y* have the same number of neutrons.
(2) The number of protons in *X* is greater than that in *Y* by 1.
(3) The total numbers of neutrons and protons in *X* and *Y* are equal.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

18. < HKCE 1999 Paper II - 39 >



The above diagram shows the mass number *A* and atomic number *Z* of a few nuclides. The isotope of neptunium (Np) shown decays by emitting an α particle and then a β particle.

Which of the following represents the resulting nuclide ?

A. *P*
B. *Q*
C. *R*
D. *S*

19. < HKCE 1999 Paper II - 40 >

Which of the following applications of radioactivity makes use of the fact that a radioactive nuclide has a constant half-life ?

A. Carbon-14 dating
B. Preservation of food
C. Smoke detectors
D. Thickness gauge

20. < HKCE 2001 Paper II - 41 >

The below shows part of a radioactive series.

$$P \xrightarrow{\alpha} Q \xrightarrow{\beta} R \xrightarrow{\beta} S$$

Which of the following nuclei are isotopes of the same element ?

A. *P* and *Q*
B. *P* and *R*
C. *P* and *S*
D. *Q* and *S*

21. < HKCE 2001 Paper II - 39 >

Radium $\left({}^{226}_{88}\text{Ra}\right)$ decays by emitting an α particle to form a product nucleus *X*. Which of the following shows the correct equation for this decay ?

A. ${}^{226}_{88}\text{Ra} + \alpha \longrightarrow {}^{230}_{90}\text{X}$
B. ${}^{226}_{88}\text{Ra} \longrightarrow {}^{224}_{84}\text{X} + \alpha$
C. ${}^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{X} + \alpha$
D. ${}^{226}_{88}\text{Ra} \longrightarrow {}^{226}_{89}\text{X} + \alpha$

22. < HKCE 2002 Paper II - 42 >

Which of the following is/are application(s) of radioactivity ?

(1) to estimate the age of ancient remains
(2) to kill bacteria in food
(3) to transmit signals over long distances

A. (2) only
B. (3) only
C. (1) & (2) only
D. (1) & (3) only

23. < HKCE 2002 Paper II - 40 >

A radioactive isotope ${}^{234}_{90}\text{Th}$ undergoes a series of decay processes to form a daughter ${}^{206}_{82}\text{Pb}$. How many α-particles and β-particles have been emitted in this decay process ?

	No. of α-particles	No. of β-particles
A.	6	7
B.	7	6
C.	7	8
D.	8	7

24. **< HKCE 2003 Paper II - 42 >**

Which of the following are essential criteria in choosing radioactive sources as medical tracers in human bodies ?
(1) The sources should have a short half-life.
(2) The radiation emitted should have a weak ionizing power.
(3) The radiation emitted should not be deflected by an electric field.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

25. **< HKCE 2004 Paper II - 42 >**

In order to detect cracks in an underground oil pipe, an engineer proposes adding a radioactive source to the oil. Which of the following sources is most suitable ?

A. a γ source with a half-life of a few hours
B. a γ source with a half-life of several years
C. an α source with a half-life of a few hours
D. an α source with a half-life of several years

26. **< HKCE 2005 Paper II - 25 >**

A thorium nucleus ($^{234}_{90}$Th) decays by emitting a β particle to form a daughter nucleus X. Which of the following equations represents this decay ?

A. $^{234}_{90}\text{Th} \longrightarrow\ ^{230}_{88}X + \beta$
B. $^{234}_{90}\text{Th} \longrightarrow\ ^{234}_{89}X + \beta$
C. $^{234}_{90}\text{Th} \longrightarrow\ ^{233}_{90}X + \beta$
D. $^{234}_{90}\text{Th} \longrightarrow\ ^{234}_{91}X + \beta$

27. **< HKCE 2006 Paper II - 43 >**

$$X \xrightarrow{\alpha} Y \xrightarrow{\beta} Z$$

$$P \xrightarrow{\beta} Q \xrightarrow{\beta} R \xrightarrow{\alpha} S$$

In the above two decay series, P and Y are two isotopes of the same element. Which of the following pairs of nuclides may be isotopes ?
(1) X and R
(2) Y and S
(3) Z and Q

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

28. **< HKCE 2006 Paper II - 27 >**

Some fresh foods are exposed to γ radiations from radioactive isotopes for a short time so that the micro-organisms in the foods can be killed. Why are the irradiated foods not harmful to people who eat them ?

A. γ radiation is an electromagnetic wave.
B. γ radiation has a high penetrating power.
C. γ radiation does not have a high ionizing power.
D. γ radiation does not make the foods radioactive.

29. **< HKCE 2007 Paper II - 25 >**

In the upper atmosphere, neutrons are produced by the action of cosmic rays. These neutrons interact with nitrogen nuclei as shown in the following reaction:

$$^{1}_{0}\text{n} + {}^{14}_{7}\text{N} \rightarrow X + {}^{1}_{1}\text{H}$$

Element X will then emit a β particle.

The nuclear reaction is as follows : $X \rightarrow Y + {}^{0}_{-1}\beta$.

What is the final product Y ?

A. $^{14}_{6}\text{C}$
B. $^{13}_{6}\text{C}$
C. $^{14}_{7}\text{N}$
D. $^{13}_{7}\text{N}$

30. **< HKCE 2009 Paper II - 25 >**

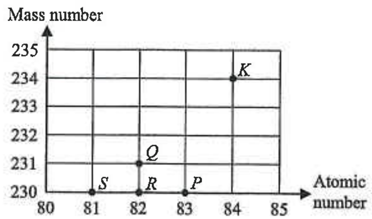
$$X \xrightarrow{\alpha} Y \xrightarrow{\beta} Z$$

The above shows part of a decay series. Which of the following deductions is/are correct ?
(1) X and Z are isotopes of the same element.
(2) X has two more neutrons than Z.
(3) Z has one more proton than Y.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

31. **< HKCE 2010 Paper II - 25 >**

The diagram shows the mass number and atomic number of a radioactive nuclide K. After undergoing the following decays, it becomes Z.



$$K \xrightarrow{\alpha} X \xrightarrow{\beta} Y \xrightarrow{\gamma} Z$$

Which of the following nuclides represents Z ?

A. P
B. Q
C. R
D. S

32. **< HKCE 2011 Paper II - 24 >**

A $^{238}_{92}$U nuclide undergoes a certain number of α and β decays and becomes $^{210}_{82}$Pb. Find the number of β particles emitted.

A. 2
B. 3
C. 4
D. 5

Part B : HKAL examination questions

33. < HKAL 1981 Paper I - 33 >

A stationary radioactive nucleus of mass number N emits an alpha particle, leaving a daughter nucleus of mass number $N - 4$. The ratio of the kinetic energy of the alpha particle to the kinetic energy of the daughter nucleus is

A. $(N - 4)/4$
B. $N^2/(N - 4)^2$
C. $(N - 4)^2/N$
D. $(N - 4)^2/4^2$

34. < HKAL 1994 Paper IIA - 45 >

A stationary U-238 nucleus undergoes α-decay. What is the ratio of the kinetic energy of the daughter nucleus to that of the α-particle ?

A. 238 : 4
B. 4 : 238
C. 234 : 4
D. 4 : 234

35. < HKAL 1995 Paper IIA - 44 >

$^{226}_{88}$Ra decays to $^{222}_{86}$Rn with a half-life of 1600 years. Which of the following statements is/are correct ?

(1) Alpha particle is given out in the decay.
(2) All $^{226}_{88}$Ra has decayed after 3200 years.
(3) The half-life of $^{226}_{88}$Ra can be shortened by heating.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

36. < HKAL 1997 Paper IIA - 43 >

$^{226}_{88}$Ra undergoes a series of decay to become the stable end-product $^{206}_{82}$Pb. What is the number of β-particles emitted in this series ?

A. 4
B. 6
C. 10
D. 14

37. < HKAL 2009 Paper IIA - 44 >

In β-decay, a neutron inside the nucleus changes into a proton and an electron, which is emitted as a β-particle. Radioactive nuclide plutonium $^{244}_{94}$Pu becomes lead $^{208}_{82}$Pb after a series of alpha and beta decays. Throughout the whole process, how many neutrons inside a $^{244}_{94}$Pu nucleus have undergone such change ?

A. 3
B. 6
C. 9
D. 12

38. < HKAL 2010 Paper IIA - 42 >

A radioactive source having a half-life of 5.3 years has an initial activity of 2500 Bq. A cancer treatment requires 10 seconds of irradiation of this source to give a certain number of radiation particles on a cancer site. If the same treatment is required after 2 years by this radioactive source, what should be the time of irradiation to give the same number of radiation particles ?

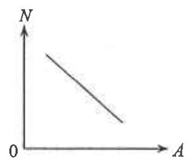
A. 13 s
B. 15 s
C. 18 s
D. 21 s.

Part C : HKDSE examination questions

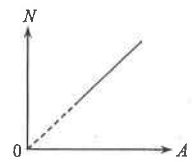
39. < HKDSE 2012 Paper IA - 36 >

Isotopes of an element have different mass number A and neutron number N. Which of the following $N - A$ plots correctly shows the relationship of N and A for any given element ?

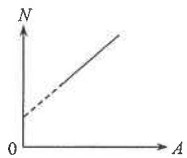
A.



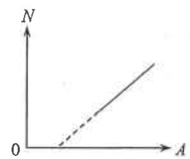
B.



C.



D.



40. < HKDSE 2013 Paper IA - 34 >

$^{238}_{92}$U undergoes α - β - β - α decay and becomes a nuclide X. What are the atomic number and mass number of X ?

	atomic number	mass number
A.	90	230
B.	90	234
C.	88	230
D.	88	234

41. < HKDSE 2014 Paper IA - 31 >

Nucleus W decays to nucleus Z as shown : $W \xrightarrow{\alpha} X \xrightarrow{\beta} Y \xrightarrow{\beta} Z$

Which of the following statements is/are correct ?

(1) Nucleus X has 1 more proton than nucleus Y.
(2) Nucleus W has 2 more neutrons than nucleus X.
(3) W and Z are isotopes of the same element.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

42. < HKDSE 2015 Paper IA - 33 >

A piece of ancient wood is dated using carbon-14 dating method. It registers a corrected count rate of 11.0 counts per minute while a fresh wood sample cut from the same kind of trees gives a corrected count rate of 15.6 counts per minute. What is the approximate age of the wood found in the archaeological site ? Given : half-life of carbon-14 is 5730 years.

A. 890 years
B. 1300 years
C. 2000 years
D. 2900 years

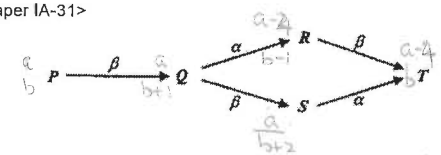
43. < HKDSE 2018 Paper IA - 32 >

X and *Y* are two radioactive nuclides. The ratio of the mass of an atom of *X* to that of an atom of *Y* is 1 : 2. The half-lives of *X* and *Y* are *T* and 2*T* respectively. If two samples consisting of purely *X* and *Y* respectively have the same initial mass, find the ratio of the number of undecayed nuclei of *X* to that of *Y* after a period of 4*T*.

A. 1 : 4
B. 1 : 2
C. 1 : 1
D. 2 : 1

44. <HKDSE 2019 Paper IA-32>

45. <HKDSE 2020 Paper IA-31>



Nuclide *P* can decay into nuclide *T* through either process *P* – *Q* – *R* – *T* or process *P* – *Q* – *S* – *T* as shown. Which deductions below are correct ?

(1) *P* and *T* are isotopes of the same element.
(2) *Q* and *S* have the same number of protons.
(3) *S* has one more neutron than *R*.

A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

There is question in next page

HKEAA's Marking Scheme is prepared for the markers' reference. It should not be regarded as a set of model answers. Students and teachers who are not involved in the marking process are advised to interpret the Marking Scheme with care.

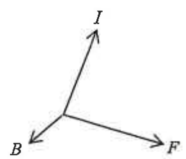
M.C. Answers

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

M.C. Solution

1. A

The magnetic field is directed out of paper.
The magnetic force is towards the right.
By using Left-hand rule, the direction of current is upwards, that is same as the direction of motion.
Thus the radiation carries (+) charge, it must be α-particle.



∴ $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$

2. B

× (1) Both have 17 protons.
✓ (2) No. of neutrons in $^{35}_{17}Cl = 35 - 17 = 18$
No. of neutrons in $^{37}_{17}Cl = 37 - 17 = 20$
× (3) Isotopes have identical chemical properties.

3. B

× (1) Isotopes have different number of neutrons but have same number of protons.
× (2) Different mass number represents different physical properties.
✓ (3) This is the definition of isotopes.

46. <HKDSE 2020 Paper IA-32>

The decay constant of a radioisotope of an element

A. is random.
B. depends on pressure and temperature.
C. is directly proportional to the number of nucleons in the isotope.
D. is an identifying characteristic of that isotope.

47. <HKDSE 2020 Paper IA-33>

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

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

4. C

✓ (1) ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$

✓ (2) ${}^{215}_{85}\text{At} \rightarrow {}^{211}_{83}\text{Bi} + {}^{4}_{2}\text{He}$

× (3) ${}^{210}_{83}\text{Tl} \rightarrow {}^{210}_{82}\text{Pb} + {}^{0}_{1}X$

5. B

Isotopes have different number of neutrons but have same number of protons, so as the electrons.

6. B

$20 \xrightarrow{5700\text{ years}} 10 \xrightarrow{5700\text{ years}} 5$

$\therefore$ Age of the wood $= 5700 \times 2$

7. D

× (1) ${}^{230}_{90}X \rightarrow {}^{4}_{2}\text{He} + {}^{226}_{88}A$; since the atomic number of Y is 90, there must be β-decay in the series.

✓ (2) ${}^{230}_{90}X \rightarrow {}^{4}_{2}\text{He} + {}^{226}_{88}A \rightarrow {}^{0}_{-1}e + {}^{226}_{89}B \rightarrow {}^{0}_{-1}e + {}^{226}_{90}Y$

✓ (3) Both X and Y have the same atomic number 90.

8. D

Balancing the equation : ${}^{235}_{92}\text{U} \xrightarrow{{}^{4}_{2}\text{He}} {}^{231}_{90}\text{Th} \xrightarrow{{}^{0}_{-1}e} {}^{231}_{91}\text{Pa} \xrightarrow{{}^{4}_{2}\text{He}} {}^{227}_{89}\text{Ac}$

$X = \alpha$

$Y = \beta$

$Z = \alpha.$

9. B

Isotopes have different mass number but same atomic number, i.e. 50.

$\therefore$ ${}^{114}_{50}\text{X}$ and Tin have the same atomic number and thus they are the same element.

10. A

${}^{235}_{92}\text{U} \rightarrow {}^{207}_{82}\text{Pb} + x\,{}^{4}_{2}\text{He} + y\,{}^{0}_{-1}e$

Balancing the mass, $235 = 207 + 4x$ $\therefore x = 7$

Balancing the charge, $92 = 82 + 2(7) + y(-1)$ $\therefore y = 4$

11. B

× (1) number of protons = atomic number = 83

✓ (2) number of electrons = number of protons = 83

× (3) number of neutrons = mass number − atomic number = 214 − 83 = 131

12. D

${}^{238}_{92}\text{U} \rightarrow {}^{A}_{Z}X + 2\,{}^{4}_{2}\text{He} + 2\,{}^{0}_{-1}e$

Balancing the mass number :

$238 = A + 2 \times 4$ $\therefore A = 230$

Balancing the atomic number :

$92 = Z + 2 \times 2 + 2 \times (-1)$ $\therefore Z = 90$

13. B

Upper number = Mass number of neutron = 1

Lower number = Charge of neutron = 0

14. C

Assume the mass number of W is 100 and the atomic number of W is 50. (OR any two arbitrary values)

$${}^{100}_{50}W \xrightarrow{{}^{0}_{-1}e} {}^{100}_{51}X \xrightarrow{{}^{4}_{2}\text{He}} {}^{96}_{49}Y \xrightarrow{{}^{0}_{-1}e} {}^{96}_{50}Z$$

✓ (1) W and Z have the same atomic number, thus they are isotopes.

✓ (2) The atomic number of X is 51, which is the greatest among the above 4 nuclides.

× (3) The mass number of Y is 96, which is less than that of W and X, not the greatest.

15. B

✓ A. Carbon-14 dating makes use of the detection of β-radiation emitted by carbon for archaeological study

× B. Examination of fetuses makes use of ultrasound

✓ C. Killing cancer cells makes use of γ-rays

✓ D. Sterilization of food makes use of γ-rays

16. B

β particles are only partly absorbed by thin sheet of aluminium

$\therefore$ amount of β particles passing through depends on its thickness

$\therefore$ β can be used to check thickness of aluminium sheets

17. B

${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$

× (1) Number of neutron in $X = A - Z$
Number of neutron in $Y = A - (Z + 1)$

× (2) The number of protons in Y is greater than that in X by 1

✓ (3) Same mass number ⇒ same total numbers of neutrons and protons

18. D

$^{237}_{93}\text{Np} \xrightarrow{^4_2\text{He}} {}^{233}_{91}X \xrightarrow{^{0}_{-1}e} {}^{233}_{92}S$

19. A

✓ A. Age of ancient findings can be found by C-14 that emit β radiation with a constant half-life
× B. Use γ-rays to kill bacteria and germs
× C. Use α-radiation to ionize the air
× D. Use β-radiation to check thickness of aluminium sheets

20. C

Assume the atomic number of P is Z
Atomic number of $Q = Z - 2$
Atomic number of $R = Z - 2 + 1 = Z - 1$
Atomic number of $S = Z - 2 + 1 + 1 = Z$
Thus, P and S have the same atomic number, they are isotopes of the same element.

21. C

$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{X} + {}^{4}_{2}\alpha$

22. C

✓ (1) carbon 14 dating is used to estimate the age of ancient remains
✓ (2) gamma rays are used to kill bacteria in food
× (3) microwaves are used to transmit signals over long distances

23. B

Balancing the equation : $^{234}_{90}\text{Th} \longrightarrow {}^{206}_{82}\text{Pb} + x\ {}^{4}_{2}\alpha + y\ {}^{0}_{-1}\beta$

$234 = 206 + 4x$ $\therefore\ x = 7$

$90 = 82 + 2(7) + (-1)y$ $\therefore\ y = 6$

24. A

✓ (1) The sources should have a short half-life so as to reduce the harmful effect to human bodies
✓ (2) The radiation should have a weak ionizing power so that it can cause less harmful effect to human bodies
× (3) β-radiation, which can be deflected by an electric field, can be used as medical tracers.
Since human bodies do not have electric field, this is not a criterion in choosing medical tracers.

25. A

γ source should be used

since it has great penetrating power to pass through the pipe wall and the ground to be detected.

The half life should be short in order to reduce the harmful effect to the environment.

26. D

The symbol of β is $^{0}_{-1}\beta$.

Thus the mass number of X is unchanged and the atomic number of X should be 91.

27. D

Since P and Y are two isotopes, they must have the same atomic number but different mass number.

Assume the atomic number of P and Y are both equal to n.

$_{n+2}X \xrightarrow{^4_2\alpha} {}_{n}Y \xrightarrow{^{0}_{-1}\beta} {}_{n+1}Z$

$_{n}P \xrightarrow{^{0}_{-1}\beta} {}_{n+1}Q \xrightarrow{^{0}_{-1}\beta} {}_{n+2}R \xrightarrow{^4_2\alpha} {}_{n}S$

✓ (1) Both X and R have the same atomic number of $n + 2$.
✓ (2) Both Y and S have the same atomic number of n.
✓ (3) Both Z and Q have the same atomic number of $n + 1$.

28. D

After the foods have been exposed to γ radiations,

the foods will not become radioactive,

since there is no radioactive source in the foods.

29. C

The neutron interacts with nitrogen :

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

The equation for the nuclear reaction :

$$^{14}_{6}X \rightarrow {}^{14}_{7}Y + {}^{0}_{-1}\beta$$

The final product Y is $^{14}_{7}\text{N}$

30. B

Assume the atomic number of X is 50 and the mass number of X is 100 :

$$^{100}_{50}X \xrightarrow{^4_2\alpha} {}^{96}_{48}Y \xrightarrow{^{0}_{-1}\beta} {}^{96}_{49}Z$$

× (1) Since the atomic numbers of X and Z are not equal, they are not isotopes of the same element.
× (2) The number of neutrons of X is 50 and the number of neutrons of Z is $96 - 49 = 47$
Thus X should have 3 more neutrons than Z.
✓ (3) The number of protons of Y is 48 and that of Z is 49,
thus Z has one more proton than Y.

31. A

Mass number of K is 234 and atomic number of K is 84.

$${}^{234}_{84}K \xrightarrow{{}^{4}_{2}\alpha} {}^{230}_{82}X \xrightarrow{{}^{0}_{-1}\beta} {}^{230}_{83}Y \xrightarrow{\gamma} {}^{230}_{83}Z$$

The final product is P which has the mass number of 230 and atomic number of 83.

32. C

$238 = 210 + 4\alpha$ $\therefore \alpha = 7$

$92 = 82 + 2 \times 7 - \beta$ $\therefore \beta = 4$

33. A

$$KE = \frac{1}{2}mv^2 = \frac{(mv)^2}{2m}$$

since the daughter nucleus and the α particle must have the same magnitude of momentum after the explosion

$$\therefore KE \propto \frac{1}{m}$$

$$\frac{KE_\alpha}{KE_{\text{nucleus}}} = \frac{m_{\text{nucleus}}}{m_\alpha} = \frac{N-4}{4}$$

34. D

$$KE = \frac{1}{2}mv^2 = \frac{(mv)^2}{2m}$$

since the daughter nucleus and the α particle must have the same magnitude of momentum after the explosion

$$\therefore KE \propto \frac{1}{m} \quad \therefore \frac{KE_{\text{nucleus}}}{KE_\alpha} = \frac{m_\alpha}{m_{\text{nucleus}}} = \frac{4}{238-4} = \frac{4}{234}$$

35. A

✓ (1) Balancing the equation : ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$.

× (2) It takes infinite time for all ${}^{226}_{88}\text{Ra}$ to decay.

× (3) Nuclear change cannot be changed by the surrounding temperature.

36. A

$${}^{226}_{88}\text{Ra} \rightarrow {}^{206}_{82}\text{Pb} + x\,{}^{4}_{2}\text{He} + y\,{}^{0}_{-1}e$$

Balancing the mass number,

$226 = 206 + 4x$ $\therefore x = 5$

Balancing the atomic number,

$88 = 82 + 2(5) + y(-1)$ $\therefore y = 4$

$\therefore$ 4 β-particles are emitted.

37. B

Consider the mass number : $244 = 208 + a(4)$ $\therefore a = 9$

There are 9 alpha particles emitted in the series.

Consider the atomic number : $94 = 82 + 9 \times (2) + b(-1)$ $\therefore b = 6$

There are 6 beta particles emitted in the series.

As each emission of beta particle involves a decay of neutron, there are 6 neutrons having such change.

38. A

The initial activity : $A_o = 2500$ Bq.

After two years, the activity A becomes : $A = (2500)\left(\frac{1}{2}\right)^{2/5.3} = 1925$ Bq

By $\Delta N = A\,\Delta t$ and same treatment needs the same number of radiation particles ΔN

$\therefore \Delta N = (2500) \times 10 = (1925) \times t$ $\therefore t = 13$ s

39. D

Let Z be the atomic number, which is equal to the number of protons.

$A = Z + N$ $\therefore N = A - Z$

Compared with $y = mx + c$, the graph is a straight line with slope +1 and with a negative y-intercept.

40. A

Atomic number of $X = 92 - 2 + 1 + 1 - 2 = 90$

Mass number of $X = 238 - 4 - 0 - 0 - 4 = 230$

41. D

$${}^{100}_{50}W \xrightarrow{\alpha} {}^{96}_{48}X \xrightarrow{\beta} {}^{96}_{49}Y \xrightarrow{\beta} {}^{96}_{50}Z$$

Assume that the atomic mass and atomic number of W is 100 and 50 respectively.

× (1) Nucleus X should have 1 less proton than nucleus Y.

✓ (2) Nucleus W has 2 more neutrons and 2 more protons than nucleus X.

✓ (3) Since W and Z have the same number of protons, they are isotopes of the same element.

42. D

Method ① : $C = C_o\left(\frac{1}{2}\right)^{t/t_{1/2}}$

$\therefore (11.0) = (15.6)\left(\frac{1}{2}\right)^{t/5730}$ $\therefore \log\left(\frac{11.0}{15.6}\right) = \log\left(\frac{1}{2}\right) \times \frac{t}{5730}$ $\therefore t = 2888 \approx 2900$ years

Method ② : $k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{5730} = 1.21 \times 10^{-4}\ \text{year}^{-1}$

By $C = C_o e^{-kt}$ $\therefore (11.0) = (15.6)\, e^{-(1.21\times10^{-4})\cdot t}$ $\therefore t = 2887 \approx 2900$ years

43. B

Initial number of atoms (nuclei) = $\dfrac{\text{Initial mass}}{\text{Mass of one atom}}$

Since the initial mass of X and Y are equal, initial number of undecayed nuclei $\propto \dfrac{1}{\text{Mass of one atom}}$

Since mass of one atom of X : mass of one atom of Y = 1 : 2

$\therefore$ initial number of nuclei of X : initial number of nuclei of Y = 2 : 1

Let the initial number of nuclei of X and Y be $2N_o$ and N_o respectively.

After a period of $4T$:

$$N_X = 2N_o \times \left(\frac{1}{2}\right)^{4T/T} = \frac{1}{8}N_o$$

$$N_Y = N_o \times \left(\frac{1}{2}\right)^{4T/2T} = \frac{1}{4}N_o$$

$\therefore N_X : N_Y = 1 : 2$

Use the following data wherever necessary :

Avogadro constant $N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$

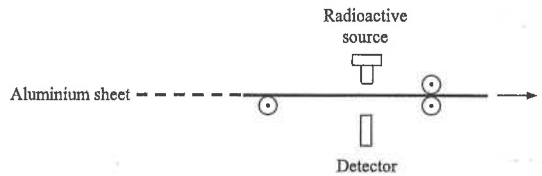
The following list of formulae may be found useful :

Law of radioactive decay	$N = N_0 e^{-kt}$
Half-life and decay constant	$t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$

Part A : HKCE examination questions

1. **< HKCE 1980 Paper I - 9 >**

(a) A factory aims at producing aluminium sheets of 1 mm thickness. A radioactive source and a detector is used to monitor the thickness of the aluminium sheet manufactured as shown in the figure below.



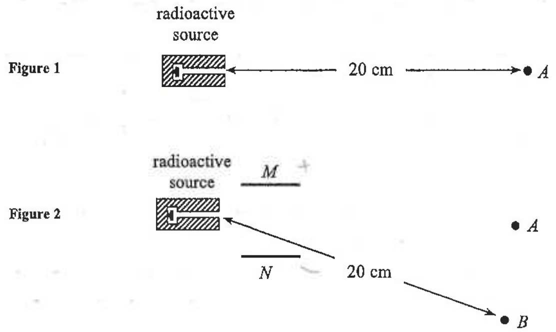
(i) State what type of source (α, β or γ) should be used. (1 mark)

(ii) Explain briefly why the other two types of source are not used. (2 marks)

(b) Give TWO other applications of radioactivity. (2 marks)

2. < HKCE 1981 Paper I - 9 >

(a)



$^{238}_{92}U$ is a radioactive source giving α, β and γ radiations.

(i) If $^{238}_{92}U$ decays by emitting four α-particles and two β-particles, what will be the atomic number and mass number of the resulting nucleus ? (6 marks)

(ii) A GM counter is placed at *A* as shown in the Figure 1 about 20 cm from the source. What types of radiation can be received by the counter at *A* ? (2 marks)

(iii) An electric field is applied across the metal plates *M* and *N* as shown in the Figure 2 so that *M* is connected to the positive terminal and *N* is connected to the negative terminal of a voltage supply. The GM counter is now moved to *B* about 20 cm from the source. Describe and explain what happens to the count-rate. (2 marks)

(b) A volume of solution containing a radioactive isotope with an activity of 4400 Bq is now injected into the blood stream of a patient. After 20 hours the activity of 10 cm³ of blood becomes 2 Bq. If the half-life of the isotope is 10 hours, estimate the volume of blood inside the person. (3 marks)

(c) If an α-particle is emitted from an atom of $^{224}_{88}Ra$ during the decay process, what will be the mass number and the atomic number of the daughter atom ? (2 marks)

3. < HKCE 1982 Paper I - 8 >

(a) What are the mass numbers of

(i) α-particles,

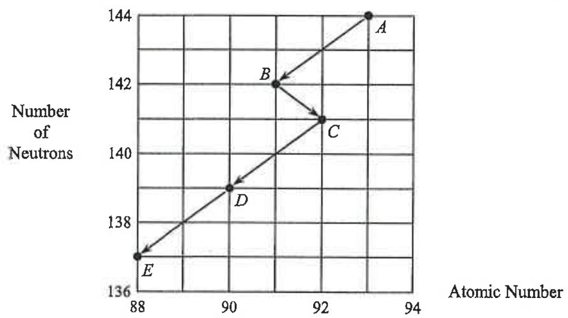
(ii) β-particles, and

(iii) neutrons ? (3 marks)

(b) The parent α source is $^{226}_{88}Ra$. If the daughter nucleus of Ra after α decay is *X*, write down the equation of the α-decay. (3 marks)

(c) If $^{234}_{91}X$ decays by emitting one α particle and one β particle to form a stable product nucleus *Y*, what will be the atomic number and mass number of *Y* ? (2 marks)

(d)



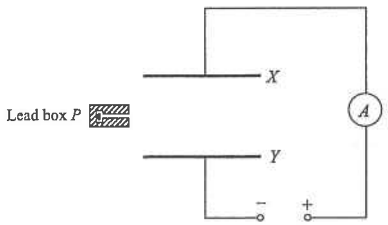
The above figure shows a radioactive decay series : *A* → *B* → *C* → *D* → *E*

(i) State what particles are emitted at each stage. (4 marks)

(ii) What is the mass number of *C* ? (1 mark)

4. **< HKCE 1991 Paper I - 7 >**

(a) Two metal plates X and Y are connected to a sensitive ammeter and an extra high tension supply (E.H.T.). A lead box P is placed near the metal plates as shown in the below figure.



(i) Sketch the electric field pattern between X and Y. The direction of the field should be shown. (2 marks)

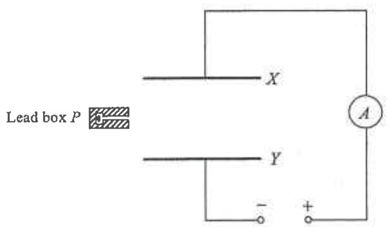
(ii) If a radioactive source emitting α particles is placed in P, the ammeter shows that a current is flowing. Explain why there is a current. (2 marks)

(iii) Explain what happens to the ammeter reading if the source in (ii) is replaced by one emitting γ rays ? (2 marks)

(iv) Suppose now a radioactive source $^{234}_{91}Pa$ is placed in P. $^{234}_{91}Pa$ decays by emitting a β particle and γ rays to form a daughter nucleus U.

(1) Write down an equation for the decay. (1 mark)

(2) On the below figure, sketch and label the paths of the radiation emitted by the source. (2 marks)



(b) Leaks in underground oil pipes can be detected by adding a small amount of radioactive source into the oil being pumped. Oil flows out from the leaks and radioactivity is detected on the ground around the leaks.

(i) Which type of source (α, β or γ) is suitable ? Explain briefly. (2 marks)

(ii) Two sources emitting the suitable type of radiation of half-lives 50 years and 10 hours are available. Which one should be used ? Explain briefly. (3 marks)

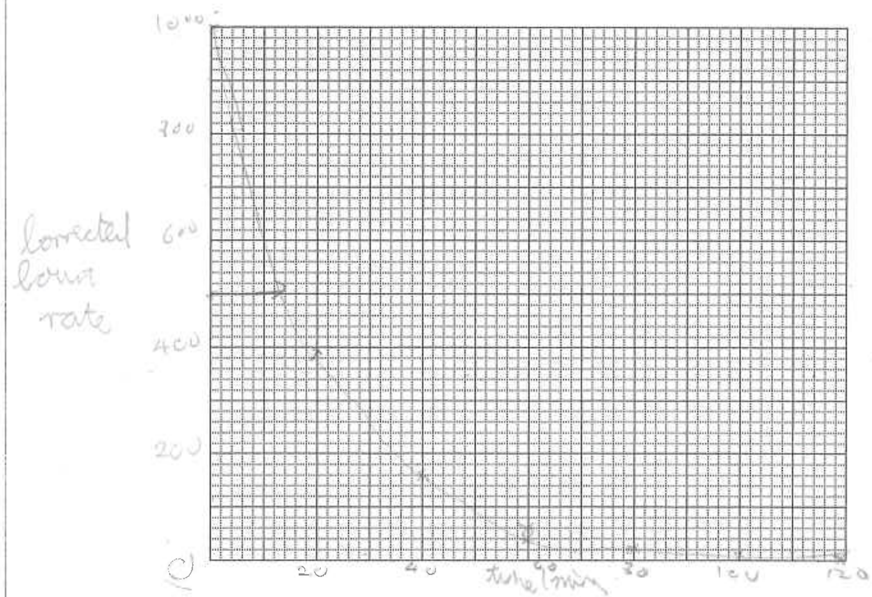
5. **< HKCE 1993 Paper I - 7 >**

In an experiment to measure the half-life of a radioactive isotope of sodium in a place where the background count rate is 100 counts per minute, the following result is obtained :

Time / hour	0	20	40	60	80	100	120
Total count rate/counts per min.	1100	498	259	161	125	110	104

(a) Suggest TWO major sources of background radiation. (2 marks)

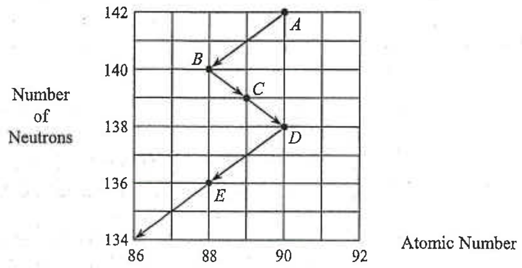
(b) Plot the graph of the CORRECTED count rate against time on graph paper. Hence find the half-life of the isotope. (6 marks)



(c) By considering its half-life, state whether the isotope is suitable to be used for injecting into a patient's vein so as to investigate his blood circulation. Give your reason. (3 marks)

6. **< HKCE 1994 Paper I - 6 >**

The below figure shows part of a decay series.



(a) From the figure, name the particle which is emitted in each of the following changes :

(i) $A \rightarrow B$

(ii) $B \rightarrow C$ (2 marks)

(b) State two nuclides in the series which are isotopes of each other. (1 mark)

(c) The final stable nuclide of the series is X, whose atomic number is 82 and the number of neutrons is 126.

(i) Find the mass numbers of A and X. (2 marks)

(ii) Find the total number of α particles emitted from A to X. (2 marks)

(d) Some of the nuclides in the figure also emit γ-radiation when they decay. However, it is impossible to identify these nuclides from the figure. Explain briefly. (2 marks)

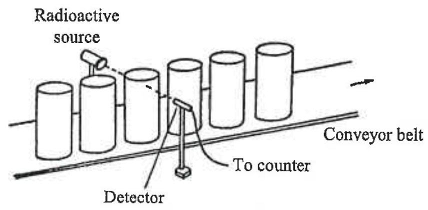
(e) A GM counter is placed 20 cm from a radioactive source which undergoes the decay as shown in the above figure. The corrected count rates obtained in three consecutive minutes are 1027, 1011 and 1018 counts per minute respectively.

(i) What type(s) of radiation emitted by the source can reach the counter ? Explain briefly. (2 marks)

(ii) Explain what is meant by a CORRECTED count rate. (2 marks)

(iii) Explain briefly why the three readings differ from each other. (2 marks)

7. **< HKCE 1996 Paper I - 6 >**



A factory produces detergent contained in plastic bottles. The following method is used to monitor the amount of detergent contained in each bottle : a radioactive source is placed on one side of the conveyor belt at the level to which the detergent is expected to fill and a detector is placed at the same level on the other side as shown in the figure above.

(a) Which type of radioactive source (α, β or γ) should be used ? Explain briefly why the other two types are not suitable. (3 marks)

(b) Suggest one suitable detector for the above system. (1 mark)

(c) Explain how the monitoring system can detect bottles of detergent that have not been filled up to the required level. (3 marks)

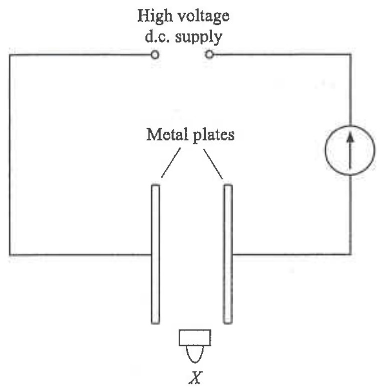
(d) Two sources emitting the suitable type of radiation of half-lives 10 minutes and 5 years are available.

(i) Explain what is meant by the half-life of a radioactive source. (2 marks)

(ii) Which source should be used ? Explain briefly. (3 marks)

(e) State two safety precautions that factory workers should take when handling radioactive sources. (2 marks)

8. < HKCE 1997 Paper I - 6 >



Two metal plates are connected to a high voltage d.c. supply and a galvanometer as shown in the Figure above. When a radioactive source X emitting α particles is placed very near the metal plates, the galvanometer shows that a current is flowing. When X is moved a small distance away from the two plates, the galvanometer reading quickly drops to zero.

(a) Explain why there is a current and why it is present only when X is very near the metal plates. (3 marks)

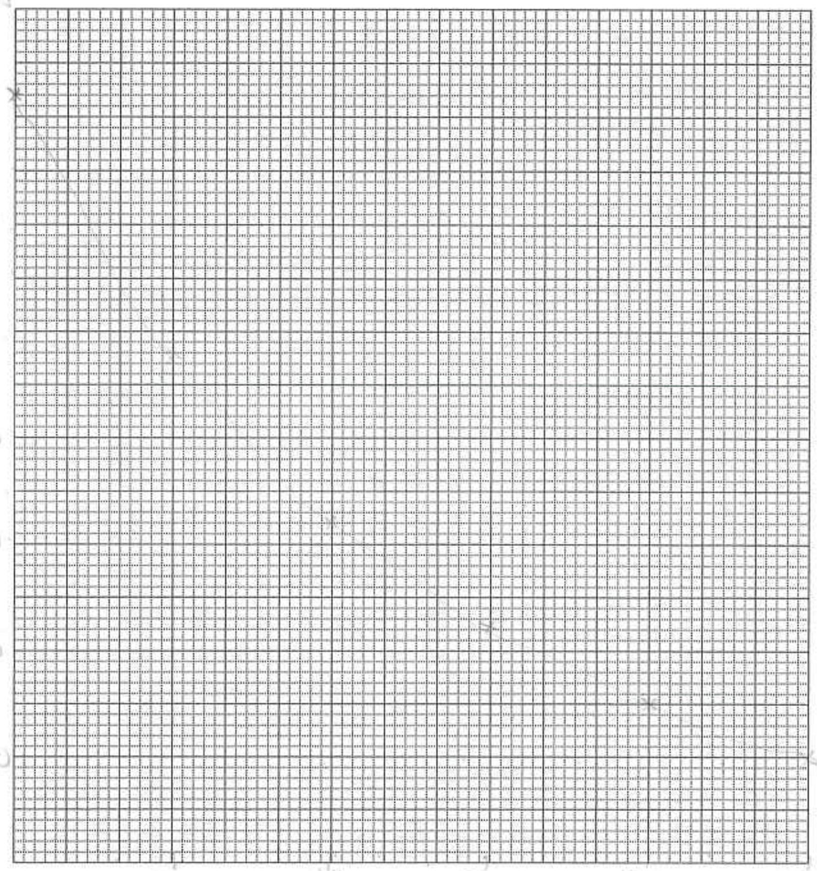
(b) ${}^{220}_{86}X$ decays by emitting an α particle to form a stable nucleus Y. Write down an equation for the decay. What is the neutron number of Y? (3 marks)

(c) How would the galvanometer reading be affected if X is replaced by a β source ? Explain briefly. (2 marks)

8. (d) X is placed very near the metal plates and the galvanometer reading is recorded every 30 seconds. The results obtained are shown below :

Time / s	0	30	60	90	120	150
Current / μA	72	48	32	22	15	10

(i) Plot a graph of current against time on graph paper. (4 marks)



(ii) Hence find the half-life of X.

(Note : You may assume that the activity of the source is directly proportional to the current.) (1 mark)

(e) Explain why X is **not** suitable for use as tracers. (1 mark)

9. **< HKCE 1998 Paper I - 6 >**

The radioactive isotope of sodium, $^{24}_{11}\text{Na}$, decays by emitting a β particle to form a stable isotope of magnesium (Mg).

(a) Write down an equation for the decay. (2 marks)

(b) Suppose you are given the following apparatus :

a GM counter, a sheet of paper and a 5 mm thick aluminium sheet.

Describe how you can demonstrate that $^{24}_{11}\text{Na}$ emits β particles and does not emit α particles. (4 marks)

(c) The half-life of $^{24}_{11}\text{Na}$ is 15 hours. A sample of $^{24}_{11}\text{Na}$ with an activity of 32×10^3 disintegrations per second is injected into the blood stream of a patient. After 45 hours, 6 cm^3 of blood is taken out from the patient's body and its activity is found to be 5 disintegrations per second.

(i) How many half-lives of $^{24}_{11}\text{Na}$ will have elapsed after 45 hours ? (1 mark)

(ii) Estimate the volume of blood in the patient's body. (3 marks)

(iii) Suggest **two** reasons for using $^{24}_{11}\text{Na}$ in this dilution test. (2 marks)

(d) State an application of radioactive isotopes, other than tracers, in each of the following fields :

(i) Medicine (1 mark)

(ii) Industry (1 mark)

10. **< HKCE 2000 Paper I - 11 >**

(a) *X* and *Y* are two radioactive nuclides with half lives of 12 hours and 2.6 years respectively. Both two nuclides decay by emitting a β particle to form stable product nuclides.

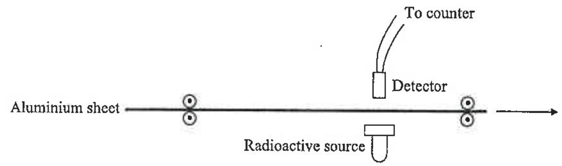
(i) After emitting a β particle, how would the atomic number and mass number of nuclide *X* be changed ? (2 marks)

(ii) Describe the changes in activity (in disintegrations per second) of a specimen of nuclide *X* and a specimen of *Y* after one day. (2 marks)

(iii) Comment on the following statement :

The mass of the specimen containing nuclide *X* will be reduced by approximately half in 12 hours. (2 marks)

(b) A factory produces aluminium sheets 1 mm in thickness. The thickness of the sheets is monitored by a gauge as shown in the figure below. A β source is used in the gauge.



(i) Explain why α and γ sources are not used in the gauge. (2 marks)

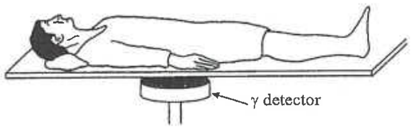
(ii) Which of the nuclides (*X* or *Y*) is more suitable to use as the radioactive source ? Explain your answer. (2 marks)

(iii) The count rate recorded should be around 90 counts per second when the thickness of the aluminium sheet is 1 mm. On a certain day when the gauge is operating properly, the following data are recorded :

Time / s	0	10	20	30	40	50	60	70	80	90	100
Recorded count rate / counts per s	90	89	91	90	90	88	66	64	90	89	89

Describe and explain the variation in the readings in the above table. (4 marks)

11. **< HKCE 2002 Paper I - 10 >**



Iodine-131 ($^{131}_{53}I$) is a radioisotope which decays by emitting a β-particle and γ rays. It is used in hospitals to test the kidneys of patients. During the test, an iodine-131 solution is injected into the bloodstream of a patient. As the blood passes through the kidney, iodine-131 will be absorbed by the kidney and eventually excreted out of the body with urine. If the kidney is not functioning properly, both the absorption and excretion rates of iodine-131 will decrease. A γ-detector is placed near the kidneys of the patient to detect the activity of the radiation coming from the kidneys as shown in the above figure.

(a) Using *X* to denote the daughter nucleus, write down an equation for the decay of an iodine-131 nucleus. (2 marks)

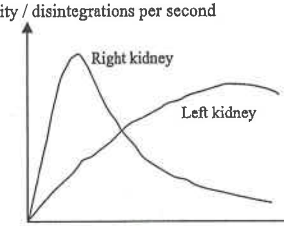
(b) Explain why the β-particles emitted by iodine-131 fail to reach the detector. (1 mark)

(c) The half-life of iodine-131 is 8 days.

(i) State the meaning of 'half-life'. (2 marks)

(ii) For safety purposes, the activity of iodine-131 solution in the test should not exceed 1.5×10^8 disintegrations per second. When an iodine-131 solution is prepared, its activity is 6×10^8 disintegrations per second. How many days after preparation would the solution be suitable for the test ? (2 marks)

(iii)



The above graph shows the variation of the activities of the radiation detected from the right and left kidneys of a patient with time. Which kidney do you think is **not** functioning properly ? Explain your answer. (3 marks)

(iv) Besides iodine-131, technetium-99*m* is another radioisotope that can be used in the kidney test. Technetium-99*m* emits γ radiation only and its half-life is 6 hours. Which of these two sources do you think is more preferable for use in the kidney test ? Explain your answer. (4 marks)

12. **< HKCE 2004 Paper I - 9 >**

slot

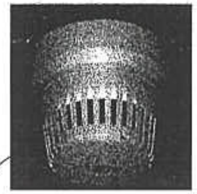


Figure 1

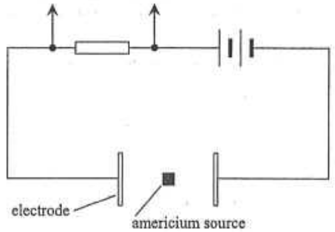


Figure 2

Figure 1 shows a smoke detector. The circuit inside the detector is shown in Figure 2. A small amount of the radioisotope americium-241 ($^{241}_{95}Am$) is placed between two electrodes. The two electrodes are connected to a battery and an alarm circuit. The detector has slots in it to allow air flow.

(a) An americium-241 nucleus decays by emitting an *α*-particle to form a daughter nucleus neptunium (Np), with a half-life of 432 years.

(i) Write down an equation for the decay of an americium-241 nucleus. (2 marks)

(ii) Find the number of neutrons in the daughter nucleus. (1 mark)

(b) Under normal conditions, a small current flows in the circuit inside the detector. However, when smoke particles enter the detector, the current drops significantly. This triggers the alarm to sound.

(i) Explain why a current flows between the electrodes under normal conditions. (3 marks)

(ii) Suggest one possible reason why the current drops when smoke particles enter the detector. (2 marks)

(c) Explain why it is preferable for the radioactive source used in smoke detectors to have a long half-life. (2 marks)

(d) Carbon-14 ($^{14}_{6}C$) is a radioisotope which decays by emitting *β* particles and has a half-life of 5700 years. Explain whether this source is suitable for use in smoke detectors or not. (2 marks)

(e) People are concerned about the biological hazards of radiation. If you are the manufacturer of the above described smoke detector, how would you explain to the public that using the detector will not pose any health hazard ? (2 marks)

13. < HKCE 2005 Paper I - 7 >

Read the following passage about Iodine-131 therapy and answer the questions that follow.

> Iodine-131 is a radioisotope which emits β and γ radiation. It can be used for thyroid cancer treatment.
>
> A patient suffering from thyroid cancer will first undergo an operation to have the thyroid gland removed. However, some thyroid tissue may remain in the neck of the patient or may be carried in the blood stream to other parts of the body. Iodine-131 is then used to trace and get rid of the remaining thyroid tissue in the body.
>
> Iodine-131 therapy consists of two stages. In Stage 1, the patient will take a low dose of Iodine-131 to trace the remaining thyroid tissue. A detector is placed near the patient to monitor the activity of the radiation coming from the patient.
>
> In case any remaining thyroid tissue is spotted in Stage 1, the patient will then take a higher dose of Iodine-131 in Stage 2. The iodine will be absorbed by the thyroid tissue and the radiation emitted can kill the cancer cells.
>
> Special hospital rooms are designed for patients who receive Stage 2 of the therapy. The rooms have metallic shielding in the doors and reinforced walls. Inside the rooms, there are plastic covers on the furniture, doors, handles and switches.

Source : *Iodine-131 Therapy,* The Ohio State University Medical Center, 2003.

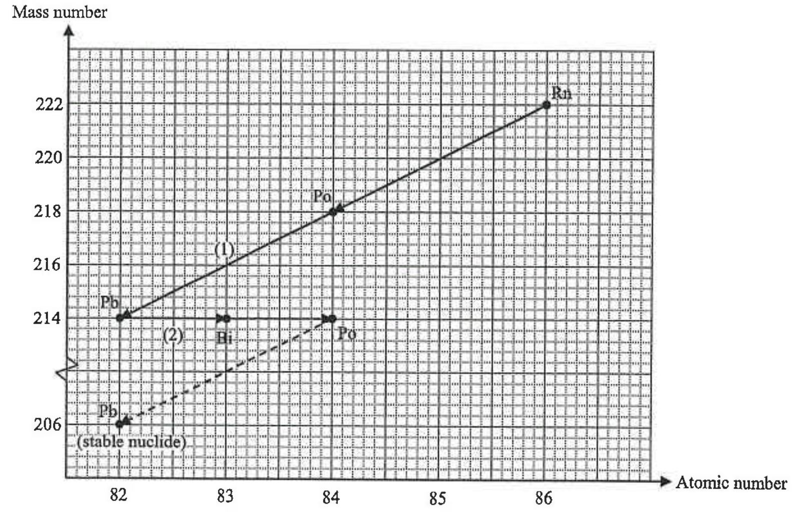
(a) Explain why, in Stage 1, β radiation from the patient cannot be detected by the detector. (1 mark)

(b) In Stage 2, which kind of radiation is more effective in killing cancer cells ? Explain your answer. (2 marks)

(c) State one special feature of the hospital rooms designed for patients receiving Stage 2 of the therapy and explain its function. (2 marks)

14. < HKCE 2009 Paper I - 7 >

Radon-222 (Rn-222) has a half-life of 3.8 days and undergoes a radioactive decay series as shown in the Figure below to become a stable nuclide Lead-206 (Pb-206).



(a) Estimate the mass of undecayed Rn-222 after 15.2 days if its initial mass is 1×10^{-5} g. (2 marks)

(b) State the nuclear radiation emitted in process (1) indicated in the above Figure. (1 mark)

(c) Write down a nuclear equation for process (2) indicated in the above Figure. (2 marks)

(d) Determine the total number of α particles and the total number of β particles emitted in the radioactive decay series from Rn-222 to Pb-206. (4 marks)

15. **< HKCE 2010 Paper I - 8 >**

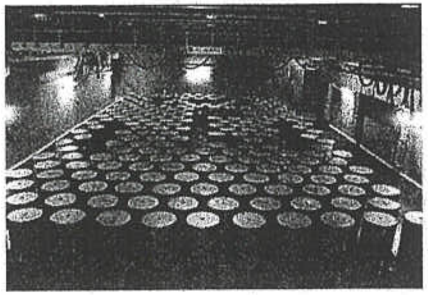
Read the following passage about low-level radioactive waste and answer the questions that follow.

Low-level Radioactive Waste

Industrial, medical and educational institutions in Hong Kong generate small amounts of low-level radioactive waste. Such waste produces no detectable heat output and is of low radioactive level. Weakened radiation sources from hospitals and educational institutions are examples of low-level radioactive waste.

For many years, most of the waste had been stored in disused tunnels and hospitals. The Government considers that in the long run the low-level radioactive waste should be stored in a purpose-built facility. After about two years of construction, the Low-level Radioactive Waste Storage Facility (the Facility) (see the Figure below) at Siu A Chau, an uninhabited island to the southwest of Lantau Island, was successfully commissioned and began its operation in July 2005. It comprises a shielded waste storage vault, a fully equipped laboratory. an automatic control room, an advanced wastewater treatment plant and specially designed waste reception and processing area. The radiation levels inside and outside the Facility are continuously monitored to ensure safe operation.

The Low-level Radioactive Waste Storage Facility at Siu A Chau - Storage Vault



(a) State **one** characteristic of low-level radioactive waste. (1 mark)

(b) Explain why Siu A Chau is suitable for the storage of low-level radioactive waste. (1 mark)

(c) Suggest an instrument to monitor the radiation levels inside and outside the Facility. (1 mark)

(d) In hospitals, radioactive sources are used as tracers. The radioactive source is injected into a patient's body and the radiation level is monitored with detectors outside the body. Explain why γ source is suitable for using as tracers. (2 marks)

16. **< HKCE 2010 Paper I - 7 >**

Carbon-14 dating can be used to identify the age of some objects. Living organisms contain a constant proportion of carbon-14. After an organism dies, the amount of carbon-14 in it decreases due to decays. We can estimate the age of an object by measuring the activity of carbon it contains.

(a) Carbon-14 undergoes decay as shown in the following nuclear equation, where D denotes the daughter nucleus.

$$^{14}_{6}C \rightarrow ^{y}_{x}D + \beta$$

Find the values of x and y. (2 marks)

(b) In a piece of wood found, the activity of 10 g of carbon is 35 disintegrations per minute. It is known that the activity due to 10 g of carbon in a living plant is 140 disintegrations per minute. Estimate the age of this piece of wood. Given that the half-life of carbon-14 is 5700 years. (3 marks)

17. **< HKCE 2011 Paper I - 7 >**

It is known that plutonium-238 ($^{238}_{94}Pu$) decays by emitting one α particle.

(a) Write a nuclear equation for the decay of plutonium-238. Use the symbol Y as the daughter nucleus. (2 marks)

(b) A sample of plutonium-238 is put in a cloud chamber. Some tracks are seen.

(i) Describe the tracks that are seen. (1 mark)

(ii) No tracks can be seen when the sample is covered by a piece of paper. Explain. (2 marks)

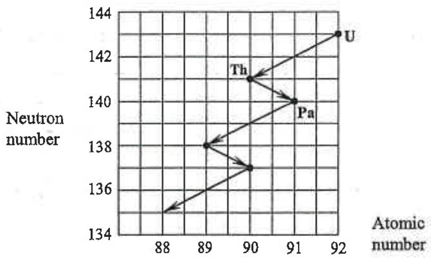
(c) Plutonium-238 can be used in heater units in spacecrafts for outer space missions. It is known that the power of the heater unit is directly proportional to the activity of plutonium-238 contained. Each heater unit has a power of 2 W when it is newly manufactured. How long can a newly manufactured heater unit last if the minimum power output required is 0.25 W ?

Given : half-life of plutonium-238 = 87.7 years (3 marks)

Part B : HKAL examination questions

18. **< HKAL 1993 Paper IIB - 12 >**

The figure below shows the decay series for an isotope of uranium : ${}^{235}_{92}U$.



(a) Name the particles emitted when

(i) Uranium (U) decays to Thorium (Th); and (1 mark)

(ii) Thorium (Th) decays to Protactinium (Pa). (1 mark)

(b) Given that the half-life of ${}^{235}_{92}U$ is 7.1×10^8 years, what would be the percentage of ${}^{235}_{92}U$ left in a sample after a period of 10^8 years ? (3 marks)

19. **< HKAL 1995 Paper I - 10 >**

The age of a sample of rock containing potassium-40 can be estimated by observing its activity. Potassium-40 decays to give the stable isotope of Argon. The activity of a sample is found to be 1.6 Bq while the original activity of a similar rock having the same mass is 4.8 Bq. The half-life of potassium-40 is 1.3×10^9 years.

(a) (i) Find the decay constant of potassium-40. (2 marks)

(ii) Give the physical meaning of the decay constant of a radioactive isotope. (2 marks)

19. (b) Find the age of the rock sample. (2 marks)

(c) Give **two** factors that determine the activity of a radioactive source. (2 marks)

20. **< HKAL 2009 Paper I - 8 >**

Carbon-14 dating is used in archaeological study to determine the age of an ancient sample.

(Given : mass of one mole of carbon-12 = 12.0 g and half-life of carbon-14 = 5730 years)

(a) (i) Calculate the decay constant k, in s^{-1}, of carbon-14. (2 marks)

(ii) The relative abundance of carbon-14 in living things is only one carbon-14 atom for every 7.2×10^{11} atoms of carbon-12. Calculate the activity for 1 g of carbon in living things. (3 marks)

(b) (i) Explain the origin of carbon-14 in the atmosphere and why the abundance of carbon-14 in living things, such as plants, remains more or less constant. (3 marks)

(ii) An archaeologist measured an activity of 2 Bq from 60 g of carbon in a piece of ancient bone. Use the result in (a), estimate the age of the bone. (3 marks)

Part C : HKDSE examination questions

21. **< HKDSE 2013 Paper IB - 9 >**

Carbon-14 dating can be used to identify the age of some objects which have the ^{14}C isotope, as it is radioactive and decays by emitting a β-particle. A piece of wood sample is examined using carbon-14 dating and its activity is 0.2 Bq. The half-life of ^{14}C is 5730 years. Given : 1 year = 3.16×10^7 s

(a) Calculate the decay constant of ^{14}C in s^{-1}. Hence find the number of ^{14}C nuclei in this wood sample. (3 marks)

Assume that living organisms contain a constant proportion of carbon-14 in the ratio of ^{14}C / ^{12}C = 1.3×10^{-12} during its life time via intake of carbon dioxide (CO_2) from the atmosphere.

(b) The carbon content of this wood sample is found to contain a total of 1×10^{23} carbon nuclei. Estimate the number of ^{14}C nuclei in the sample originally when it died. (1 mark)

(c) Estimate the age of this wood sample in years using the results found in (a) and (b). (2 marks)

22. **< HKDSE 2016 Paper IB - 9 >**

Part of the decay series of uranium-238 (U-238) is shown below. The end product lead-206 (Pb-206) is stable.

$$^{238}_{92}U \xrightarrow[4.5 \times 10^9 \text{ years}]{\alpha} Th \xrightarrow[21 \text{ days}]{\beta} Pa \longrightarrow \ldots \longrightarrow \, ^{206}_{82}Pb$$

(a) When a U-238 nucleus decays to a Pb-206 nucleus, how many α-particle(s) and β-particle(s) are emitted ? (2 marks)

(b) As the first decay in the above chain from U to Th has a half-life much longer than those of subsequent decays, the decay from U-238 to Pb-206 can be simplified to a *single decay* with half-life 4.5×10^9 years :

$$^{238}_{92}U \xrightarrow[4.5 \times 10^9 \text{ years}]{} \, ^{206}_{82}Pb$$

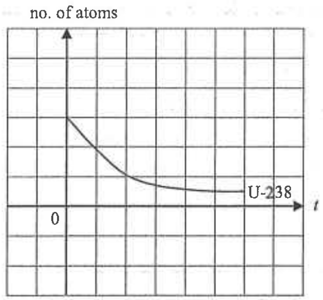
Suppose that a uranium-bearing rock contains only U-238 and no Pb-206 at the time when it was formed long ago by solidification of molten material. In a particular sample of the rock, it is found that *at present*, the ratio :

$$\frac{\text{number of Pb-206 atoms}}{\text{number of U-238 atoms}} = \frac{2}{3}$$

(i) Estimate the age of the rock. Assume that all Pb-206 atoms come from the decay of U-238 originally present in the sample and ignore the small number of U-238 atoms which have decayed but have not yet become Pb-206. (2 marks)

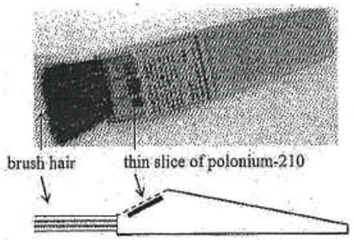
(ii) State, with a reason, whether the answer in (b) (i) is an overestimate or underestimate of the age of the rock if some Pb-206 atoms have actually been lost. (2 marks)

(iii) The graph in the Figure below shows how the number of U-238 atoms in the sample varies with time t subsequently while t = 0 denotes the present time. On the same Figure, sketch a graph to show the variation of the number of Pb-206 atoms in the sample with time. (2 marks)



23. **< HKDSE 2017 Paper IB - 10 >**

Dust may adhere to the surfaces of photos and films due to electrostatic attraction. To remove the dust effectively, a special brush with a thin slice of polonium-210 ($^{210}_{84}Po$) fixed near the brush hair as shown in the below Figure may be used. Polonium-210 undergoes α decay and the daughter nucleus lead (Pb) is stable.



(a) Write a nuclear equation for the decay of polonium-210. (2 marks)

(b) Briefly explain how the α particles help clean the charged dust. (2 marks)

(c) Briefly explain why the polonium-210 slice must be fixed near to the brush hair. (1 mark)

(d) The manufacturer recommends that the brush should be returned to the factory for replacement of the polonium-210 slice every year. Taking the activity of a newly replaced polonium-210 slice as 1 unit, find its activity after one year (365 days). Given: half-life of polonium-210 is 138 days. (2 marks)

24. **< HKDSE 2018 Paper IB - 10 >**

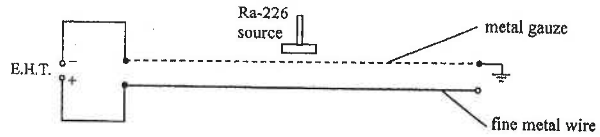
(a) Part of the decay series of radium-226 (Ra-226) is shown below. Ra-226 decays to radon (Rn) by emitting an α particle with half-life 1600 years. The end product in the series is lead (Pb), which is stable.

$$^{226}_{88}Ra \xrightarrow{\alpha} Rn \longrightarrow \dots \longrightarrow Pb$$

(i) $^{206}_{82}Pb$, $^{207}_{82}Pb$ and $^{208}_{82}Pb$ are three stable isotopes of lead. State, with a reason, which isotope can be the end product in this series. (2 marks)

(ii) In a certain laboratory, a Ra-226 source has been used for 50 years. Estimate the percentage of undecayed Ra-226 left after this period. (2 marks)

(b) Spark counter can show the ionizing power of radiations. The Figure indicated the main features of a type of spark counter in school laboratories.



A spark counter consists of a fine metal wire mounted a few mm beneath an earthed metal gauze. The wire is connected to the positive terminal of an E.H.T. (Extra High Tension) supply so that a very intense electric field is set up between the wire and the metal gauze. When a Ra-226 source is brought near the gauze, sparks giving out flashes of light and crackling sound are produced at irregular intervals.

(i) Explain why the sparks occur at **irregular** intervals. (1 mark)

A Ra-226 source used in school laboratories is usually said to emit α, β as well as γ radiations.

(ii) Explain why β radiation is also emitted even though the source is primarily an α-emitter. (1 mark)

(iii) Why is the sparking mainly caused by α radiation rather than β or γ radiation ? Suggest a simple way to verify this. (2 marks)

HKEAA's Marking Scheme is prepared for the markers' reference. It should not be regarded as a set of model answers. Students and teachers who are not involved in the marking process are advised to interpret the Marking Scheme with care.

Question Solution

1. (a) (i) β should be used. [1]

(ii) α is not used because it is totally absorbed by the aluminium sheet [1]

OR

α is not used because its penetrating power is too weak that it cannot pass through aluminium sheet. [1]

γ is not used because the count rate would not be affected significantly by the aluminium sheet. [1]

OR

γ is not used because its penetrating power is too strong that almost all γ will pass through the sheet. [1]

(b) Any **TWO** of the following : [2]

* radiotherapy
* estimate the age of archaeological samples
* medical tracer
* sterilization
* leakage test of underground oil pipes
* smoke detection

[Note : Thickness gauge is NOT acceptable since it is the application in part (a).]

2. (a) (i) Atomic number of resulting nucleus $= 92 - 4 \times 2 + 2$ [2]

$= 86$ [1]

Mass number of resulting nucleus $= 238 - 4 \times 4$ [2]

$= 222$ [1]

(ii) β and γ [2]

(iii) Count-rate decreases [1]

since only background radiation can be detected at point B [1]

(b) After 20 hours : $A = 4400 \times \left(\frac{1}{2}\right)^2 = 1100$ [1]

By $\frac{10}{V} = \frac{2}{1100}$ [1]

$\therefore$ Volume of blood $= 5500$ cm^3 [1]

(c) Mass number $= 224 - 4 = 220$ [1]

Atomic number $= 88 - 2 = 86$ [1]

3. (a) (i) mass number of $\alpha = 4$ [1]

(ii) mass number of $\beta = 0$ [1]

(iii) mass number of neutron $= 1$ [1]

(b) ${}^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}X + {}^{4}_{2}\alpha$ [3]

(c) atomic number $= 91 - 2 + 1 = 90$ [1]

mass number $= 234 - 4 = 230$ [1]

(d) (i) $A \longrightarrow B$: α particle [1]

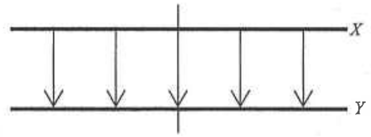
$B \longrightarrow C$: β particle [1]

$C \longrightarrow D$: α particle [1]

$D \longrightarrow E$: α particle [1]

(ii) Mass number of $C = 141 + 92 = 233$ [1]

4. (a) (i)



< Direction of electric field lines is downwards > [1]

< The electric field lines are parallel and evenly spaced > [1]

(ii) Air molecules are ionized by α particles. [1]

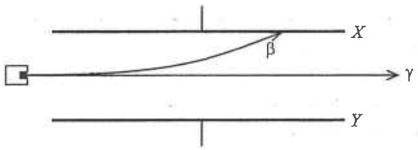
The ions then move to the metal plates to conduct a current. [1]

(iii) The ammeter reading decreases ; (OR becomes zero) [1]

since the ionizing power of γ radiation is very weak. [1]

(iv) (1) ${}^{234}_{91}\text{Pa} \longrightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\beta + \gamma$ [1]

(2)



< β is deflected upwards > [1]

< γ is not deflected > [1]

4. (b) (i) A γ source should be used. [1]
Since the penetrating power of γ is high enough to reach the ground. [1]

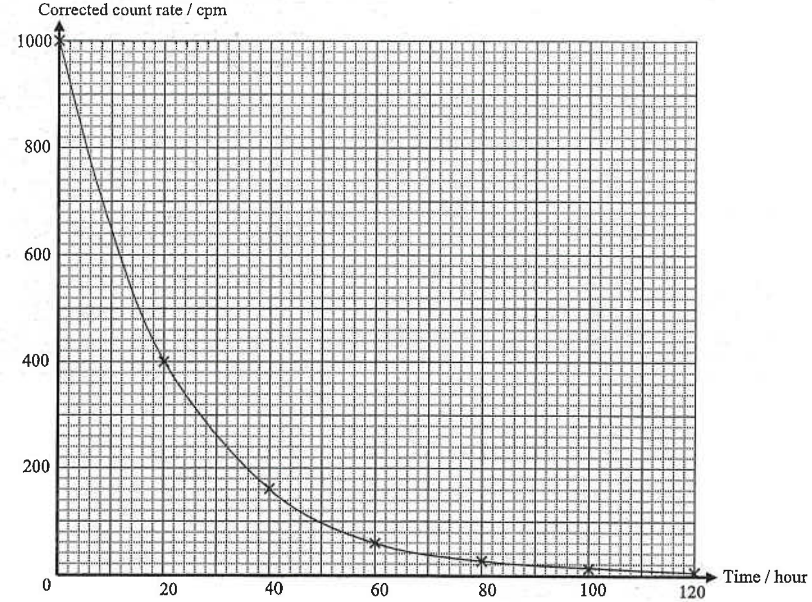
(ii) The source with half life 10 hours should be used. [1]
Reason : (Any **ONE** of the following) [2]
* It gives less pollution to the environment as its activity disappears quickly
* It causes less harmful effect to the environment as its activity disappears quickly

5. (a) Any **TWO** of the following : [2]
* Cosmic radiation from the space
* Radiation from the rocks
* Radiation from air
* Radiation from food

(b)

Time / hour	0	20	40	60	80	100	120
Corrected count rate / cpm	1000	398	159	61	25	10	4

[1]



< Two axes labelled correctly > [1]
< Suitable scales chosen > [1]
< At least 5 points plotted correctly > [1]
< Smooth curve drawn > [1]

5. (b) Half-life = 15 hours < 14 – 16 hours is acceptable > [1]

(c) Yes, it is suitable [1]
The half-life is long enough for the doctor to diagnose the patient. [1]
The half-life is short enough to cause less harmful effect on the patient. [1]
OR
The half-life is not too short [1]
and not too long. [1]

6. (a) (i) α particle [1]
(ii) β particle [1]

(b) A and D are isotopes of each other. (**OR** B and E) [1]

(c) (i) Mass number of A = 142 + 90 = 232 [1]
Mass number of X = 126 + 82 = 208 [1]

(ii) Total number of α particles emitted $= \dfrac{232-208}{4}$ [1]
$= 6$ [1]

(d) γ emission does not change the atomic number and mass number of the nuclide. [2]

(e) (i) β and γ radiation can reach the counter because their ranges in air are longer than 20 cm. [2]
(ii) A corrected count rate is equal to the recorded count rate minus the background count rate. [2]
(iii) The readings differ due to the random nature of radiation. [2]

7. (a) A β source should be used. [1]
An α source is not suitable because α particles cannot pass through the container. [1]
A γ source is not suitable because γ radiation is too penetrating. [1]
(**OR** cannot be absorbed by the container)

(b) A GM tube (**OR** Geiger Muller tube) (**OR** GM counter) can be used. [1]

(c) If a bottle not filled up to the required level passes the source,
the counter will record a much higher reading than that when an acceptable bottle passes the source, [2]
since the β radiation does not pass through the detergent and hence is not absorbed. [1]

7. (d) (i) The half-life is the time taken for half of the number of undecayed nuclei in the source to decay. [2]

OR

The half-life is the time taken for the activity of the source to fall to half of its initial value. [2]

OR

The half-life is the time taken for the mass of the undecayed nuclei in the source to decay. [2]

(ii) The source with half-life 5 years should be used. [1]

Reason : (ANY ONE) [2]

* The source will decay slowly and can be used for a long time.
* The activity of the source will be very stable to be used for a long time.
* The source with half-life 10 minutes will decay rapidly and the registered count rate is unstable even when no bottles are present.

(e) Any **TWO** of the followings : [2]

* Wearing film badges or other detecting devices
* Working behind lead-glass windows
* Handling radioactive sources using special forceps (**OR** remote controlled robots)
* Wearing protective coveralls
* Radioactive sources should not be pointed towards human bodies
* Radioactive sources should be stored in lead castles and returned to the storage box after use
* Workers should wear disposable gloves to handle the radioactive sources

8. (a) Some air molecules are ionized by the α-particles. [1]

The ions then move to the two respective plates to form a current. [1]

As α-particles have a very short range in air, the source must be placed very close to the plates. [1]

(b) $^{220}_{86}X \longrightarrow {}^{216}_{84}Y + {}^{4}_{2}\alpha$

< Mass number and atomic number of Y are correct > [1]

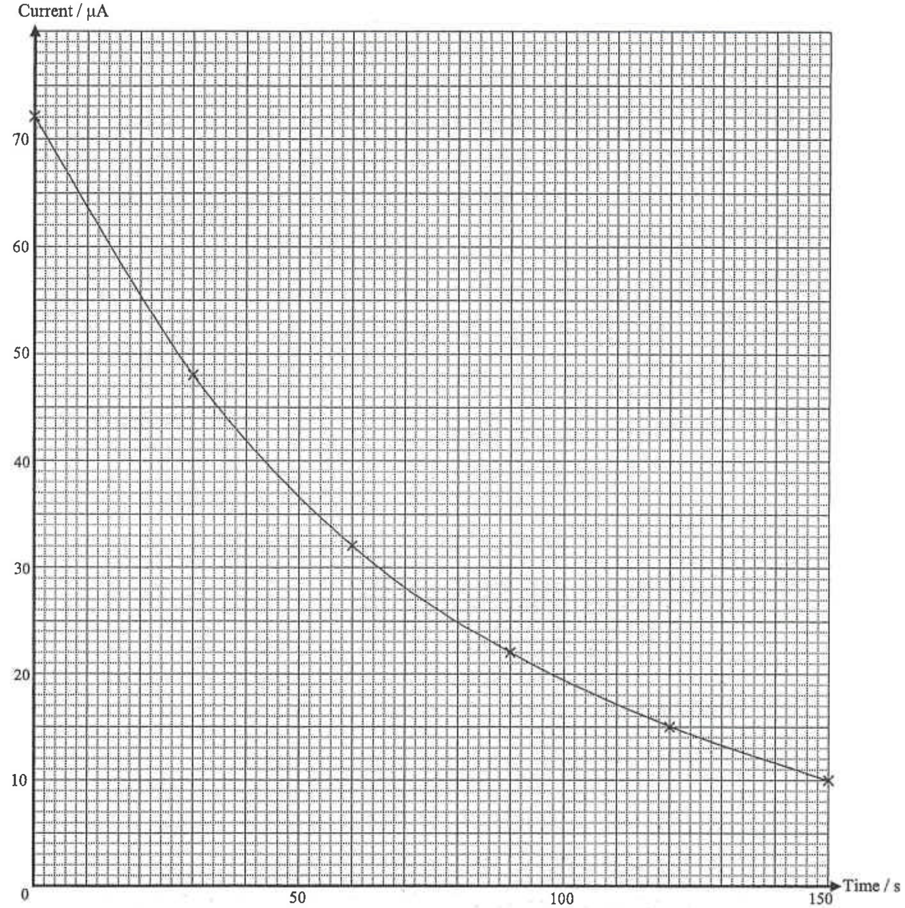
< Equation is correct > [1]

The neutron number of Y is 132. [1]

(c) The galvanometer reading decreases (**OR** becomes very small) [1]

because the ionizing power of β-particles is weaker. [1]

8. (d) (i)



< Labelled axes with units > [1]

< An appropriate scale > [1]

< Correct points plotted > [1]

< Smooth curve > [1]

(ii) From the graph, the half-life of the source is 52 s. [1]

< from 50 s to 54 s is acceptable >

(e) Any **ONE** of the following : [1]

* The penetrating power of α-particles is too low to be used as tracers.
* The half-life of X is too short to be used as tracers.

9. (a) $^{24}_{11}\text{Na} \longrightarrow {}^{24}_{12}\text{Mg} + {}^{0}_{-1}\beta$ [2]

(b) The GM tube is held close from the source and its reading is noted. [1]
Insert a piece of paper between the GM tube and the source. [1]
The count rate would remain unaffected. This shows that the source does not emit α particles. [1]
Insert the aluminium sheet between the tube and the source. The count rate would drop significantly. [1]
This shows that the source emits β particles.

(c) (i) Number of half-lives elapsed $= \dfrac{45}{15} = 3$ [1]

(ii) Total activity in the blood of the patient after 45 hours $= 32 \times 10^3 \times \left(\dfrac{1}{2}\right)^3 = 4000$ [1]

$\therefore \dfrac{V}{6} = \dfrac{4000}{5}$ [1]

$\therefore V = 4800 \text{ cm}^3$ [1]

(c) (iii) Any **TWO** of the following : [2]
* The half-life is long enough for medical diagnosis.
* The half-life is short enough to reduce the harmful effect to the human body.
* The daughter nuclei Mg is stable and has no harmful effect.
(**OR** Sodium and magnesium have no harmful chemical effects on human body.)

(d) (i) Any **ONE** of the followings : [1]
* Radiotherapy
* Medical tracer
* Sterilization of medical equipment

(ii) Any **ONE** of the followings : [1]
* Thickness gauge
* Food preservation (Sterilization of beef)
* Leakage detection
* Radioactive lightning conductor
* Smoke detector

10. (a) (i) The atomic number increases by one. [1]
The mass number remains unchanged. [1]

(ii) The activity of specimen *X* will fall to a quarter of its original value. [1]
The activity of specimen *Y* will remain approximately unchanged. [1]

(iii) As the mass of β particles emitted is very small, [1]
the mass of the specimen would almost remain unchanged after 12 hours. [1]

10. (b) (i) α source is not used because the penetrating power of α particles is too low. [1]
γ source is not used because the penetrating power of γ radiation is too high. [1]

(ii) Nuclide *Y* is more suitable. [1]
As nuclide *Y* has a longer half-life, its activity remains stable over a longer period of time. [1]

(iii) The reading remains steady from $t = 0$ to 50 s and from $t = 80$ to 100 s. [1]
The small variation within this period is due to the random nature of radioactive decay. [1]
The reading drops significantly from $t = 60$ to 70 s. [1]
The aluminium sheet in this period is thicker than the normal value. [1]

11. (a) $^{131}_{53}\text{I} \longrightarrow {}^{131}_{54}\text{X} + {}^{0}_{-1}\beta$ **OR** $^{131}_{53}\text{I} \longrightarrow {}^{131}_{54}\text{X} + {}^{0}_{-1}\beta + \gamma$ [2]

(b) The β particles fail to pass through the human body. [1]

OR

The β particles are absorbed by the human body. [1]

(c) (i) The half-life is the time taken for the activity of the source to drop to half of its initial value. [2]

(ii) No. of half-life = 2 [1]
The solution is suitable after $2 \times 8 = 16$ days [1]

(iii) The left kidney is not functioning properly [1]
since the activity in the left kidney increases at a lower rate. [2]

(iv) Technetium-99*m* is more preferable than iodine-131 for use in the test. [1]
Since technetium-99*m* has a shorter half-life [1]
and does not emit β particles, [1]
so it causes less harmful effect to the patient. [1]

12. (a) (i) $^{241}_{95}\text{Am} \longrightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\alpha$ [2]

(ii) Number of neutrons = 237 – 93 = 144 [1]

(b) (i) The α-particles will ionize the air to give ions. [2]
The ions then move to the electrodes to give a current. [1]

(ii) The smoke particles block the movement of the charged particles. [1]
As a result, fewer ions reach the electrodes, so the current drops. [1]

12. (c) The activity of the source will remain stable for a long period of time. (**OR** decay very slowly) [1]
So the detector can be used for a longer timer. (**OR** The source needs not be replaced frequently.) [1]

(d) As β particles have a weaker ionizing power, [1]
the current flowing between the electrodes will be extremely small. [1]
So Carbon-14 is not suitable.

(e) Any **ONE** of the following : [2]
* The radiation dose from the smoke detector is very small.
* The radiation from the smoke detector is much less than the background radiation.
* The source used in the smoke detector is a very weak source.
* α-particles have a very short range in air.

13. (a) The penetrating power of β radiation is too low. [1]
OR
β radiation cannot penetrate through human body. [1]

(b) β radiation is more effective in killing cancer cells. [1]
Since the ionizing power of β is higher than that of γ radiation. [1]

(c) The rooms have metallic shielding in the doors and walls. [1]
They can prevent radiation from leaking out of the rooms. [1]
OR
Inside the rooms, there are plastic covers on the furniture, doors, handles and switches. [1]
This prevents other persons using the room from being contaminated. [1]

14. (a) Number of half-lives = $\dfrac{15.2}{3.8} = 4$ [1]

Mass of Rn-222 left = $1 \times 10^{-5} \times (\frac{1}{2})^4 = 6.25 \times 10^{-7}$ g [1]

(b) α [1]

(c) ${}^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}\beta$ [2]

(d) Let a and b be the number of α particles and β particles respectively.
$222 - 206 = 4a$ [1]
$a = 4$ [1]
$86 - 82 = 4 \times 2 - b$ [1]
$b = 4$ [1]

15. (a) It produces no detectable heat output. [1]
OR
It has a low radioactive level. [1]

(b) It is because it is an uninhabited place. [1]

(c) GM counter (**OR** GM tube) [1]
OR
photographic film [1]

(d) It has weak ionizing power [1]
and causes less harmful effect to the human body. [1]
OR
It has strong penetrating power [1]
and can pass through the body to be detected outside the body. [1]

16. (a) $x = 7$ [1]
$y = 14$ [1]

(b) $35 = 140 \left(\dfrac{1}{2}\right)^n$ **OR** $140 \rightarrow 70 \rightarrow 35$ [1]

$\therefore\ n = 2$ [1]

The age of the wood = $2 \times 5700 = 11400$ years [1]

17. (a) ${}^{238}_{94}\text{Pu} \rightarrow {}^{234}_{92}\text{Y} + {}^{4}_{2}\text{He}$ (OR ${}^{4}_{2}\alpha$) [2]

(b) (i) The tracks are straight. [1]
OR
The tracks are thick. [1]

(ii) As α radiation has weak penetrating power, [1]
they are stopped by the paper. [1]

(c) 2 W → 1 W → 0.5 W → 0.25 W [1]
OR
$\dfrac{0.25}{2} = \left(\dfrac{1}{2}\right)^n \quad \therefore n = 3$ [1]

Hence, the heater can last 3 half-lives. [1]

Time = $3 \times 87.7 = 263.1$ years < accept 263 years > [1]

18. (a) (i) α particle [1]

(ii) β particle [1]

(b) $k = \frac{\ln 2}{7.1\times10^8} = 9.76\times10^{-10}$ year^{-1} [1]

$\frac{N}{N_o} = e^{-kt} = e^{-(9.76\times10^{-10})\times(10^8)} = 0.907$ [1]

∴ percentage left = 90.7% [1]

OR

$\frac{N}{N_o} = \left(\frac{1}{2}\right)^{t/t_{1/2}}$ [1]

$= \left(\frac{1}{2}\right)^{(10^8)/(7.1\times10^8)} = 0.907$ [1]

∴ percentage left = 90.7% [1]

19. (a) (i) $k = \frac{\ln 2}{1.3\times10^9}$ **OR** $\frac{\ln 2}{1.3\times10^9\times365\times24\times3600}$ [1]

$= 5.33\times10^{-10}$ year^{-1} **OR** 1.69×10^{-17} s^{-1} [1]

(ii) The decay constant of a radioactive isotope is the probability of decay of the nuclei present [1]
per unit time. [1]

(b) ∵ $A = A_o e^{-kt}$

∴ $(1.6) = (4.8)\,e^{-5.33\times10^{-10}t}$ **OR** $(1.6) = (4.8)\,e^{-1.69\times10^{-17}t}$ [1]

∴ $t = 2.06\times10^9$ years **OR** $t = 6.50\times10^{16}$ s [1]

(c) ① The number of undecayed nuclei present [1]

② The decay constant of the radioactive source < **OR** The half-life of the radioactive source > [1]

20. (a) (i) $k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{(5730\times365\times24\times3600)}$ [1]

$= 3.84\times10^{-12}$ s^{-1} [1]

(ii) Number of carbon-14 atoms in 1 g of carbon :

$N = \frac{1}{12}\times6.02\times10^{23}\times\frac{1}{7.2\times10^{11}} = 6.97\times10^{10}$ [1]

$A = kN = (3.84\times10^{-12})\times(6.97\times10^{10})$ [1]

$= 0.268$ Bq < accept 0.267 Bq > [1]

20. (b) (i) Carbon-14 is formed when neutrons produced by cosmic rays collide with nitrogen.

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

Carbon-14 forms radioactive carbon dioxide and is taken up by plants for photosynthesis.
(**OR** Carbon-14 is taken up by animals through eating.) [1]

This exchange maintains the same abundance inside a living thing until it dies. [1]

(ii) Activity of the bone per gram : $A = \frac{2}{60} = 0.0333$ Bq [1]

By $A = A_o e^{-kt}$ ∴ $(0.0333) = (0.268)\,e^{-(3.84\times10^{-12})t}$ [1]

∴ $t = 5.43\times10^{11}$ s = 17200 years [1]

OR

By $A = A_o\left(\frac{1}{2}\right)^{t/t_{1/2}}$ ∴ $(0.0333) = (0.268)\left(\frac{1}{2}\right)^{t/5730}$ [1]

∴ $t = 17200$ years [1]

21. (a) $k = \frac{\ln 2}{5730\times3.16\times10^7} = 3.83\times10^{-12}$ s^{-1} [1]

By $A = kN$

∴ $(0.2) = (3.83\times10^{-12})\,N$ [1]

∴ $N = 5.22\times10^{10}$ [1]

(b) $N_o = (1\times10^{23})\times(1.3\times10^{-12}) = 1.3\times10^{11}$ [1]

(c) $N = N_o e^{-kt}$

$(5.22\times10^{10}) = (1.3\times10^{11})\,e^{-(3.83\times10^{-12})t}$ [1]

∴ $t = 2.38\times10^{11}$ s = 7540 years < accept 7500 to 7600 years > [1]

22. (a) $238 = 206 + 4\,n_\alpha$ ∴ $n_\alpha = 8$ [1]

$92 = 82 + 8\times(2) + n_\beta(-1)$ ∴ $n_\beta = 6$ [1]

(b) (i) $N = N_o\left(\frac{1}{2}\right)^{t/t_{1/2}}$ [**OR** $N = N_o e^{-kt}$ and $k = \frac{\ln 2}{t_{1/2}}$] [1]

∴ $\left(\frac{3}{5}\right) = \left(\frac{1}{2}\right)^{t/(4.5\times10^9)}$

∴ $t = 3.32\times10^9$ years < accept 3.3×10^9 years > [1]

22. (b) (ii) Answer in part (i) is underestimate. [1]

The original number of U-238 should be greater.

The ratio $\dfrac{\text{present number of U-235 atoms}}{\text{original number of U-238 atoms}}$ is in fact smaller than $\dfrac{3}{5}$ [1]

thus, longer time should have been elapsed.

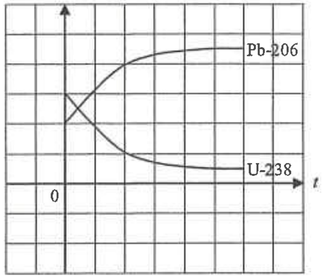
OR

Answer in part (i) is underestimate. [1]

Since more U-235 should have been decayed, [1]

thus longer time should have been elapsed.

(iii)



< Initial no. of Pb-206 is at 2 units as U : Pb = 3 : 2 initially > [1]

< Final no. of Pb is at 4.5 units since U + Pb = 5 and finally U has 0.5 unit > [1]

23. (a) ${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$ < accept ${}^{4}_{2}\alpha$ > [2]

(b) The α particles ionize the air molecules. [1]

The ions neutralize the charges on the dust (**OR** film surface). [1]

(c) This is because α has a short range of a few centimetre in air. [1]

(d) $A = (1) \times \left(\dfrac{1}{2}\right)^{365/138}$ [1]

$= 0.160$ unit [1]

OR

$k = \dfrac{\ln 2}{(138)} = 0.005023$ [1]

$A = (1)\ e^{-(0.005023)(365)} = 0.160$ unit [1]

24. (a) (i) 226 − 206 = 20 which is a multiple of 4 (for α) [1]

$\therefore\ {}^{206}_{82}\text{Pb}$ is the end product [1]

(ii) $\dfrac{N}{N_o} = \left(\dfrac{1}{2}\right)^{t/t_{1/2}} = \left(\dfrac{1}{2}\right)^{(50)/(1600)}$ [1]

$= 97.9\ \%$ < accept 98 % > [1]

OR

$k = \dfrac{\ln 2}{1600} = 4.33 \times 10^{-4}$

$\dfrac{N}{N_o} = e^{-kt} = e^{-(4.33\times10^{-4})\times(50)}$ [1]

$= 97.9\ \%$ < accept 98 % > [1]

(b) (i) Due to random nature of radiation [1]

(ii) Some of the daughter products of Ra-226 may emit β particles [1]

(iii) Since the ionizing power of β and γ are weaker than that of α [1]

Any **ONE** of the following : [1]

* Raise the source to a distance greater than the range of α, sparks will cease.
* Insert a paper between the source and the gauze, sparks will cease.