PapaCambridge

Cambridge International AS & A Level

PHYSICS

Paper 4

Topical Past Paper Questions
+ Answer Scheme

2016 - 2021

PapaCambridge

Chapter 16

Particle and nuclear physics

397. 9702_s20_qp_41 Q: 11

An electron, at rest, has mass m_e and charge $-q$.

A positron is a particle that, at rest, has mass m_e and charge $+q$.

A positron interacts with an electron. The electron and the positron may be considered to be at rest.
The outcome of this interaction is that the electron and the positron become two gamma-ray (γ-ray) photons, each having the same energy.

(a) Calculate, for one of the γ-ray photons:

(i) the photon energy, in J

energy = ... J [2]

(ii) its momentum.

momentum = ... N s [2]

(b) State and explain the direction, relative to each other, in which the γ-ray photons are emitted.

....

....

....

.... [2]

[Total: 6]

398. 9702_s20_qp_42 Q: 12

(a) State what is meant by the *mass defect* of a nucleus.

....

....

.... [2]

(b) Some masses are shown in Table 12.1.

Table 12.1

	mass / u
proton $^1_1$p	1.007 276
neutron $^1_0$n	1.008 665
helium-4 ($^4_2$He) nucleus	4.001 506

Show that:

(i) the energy equivalence of 1.00 u is 934 MeV

[2]

(ii) the binding energy per nucleon of a helium-4 nucleus is 7.09 MeV.

[2]

(c) Isotopes of hydrogen have binding energies per nucleon of less than 3 MeV.

Suggest why a nucleus of helium-4 does not spontaneously break down to become nuclei of hydrogen.

....

....

.... [2]

[Total: 8]

399. 9702_s20_qp_43 Q: 11

An electron, at rest, has mass m_e and charge $-q$.

A positron is a particle that, at rest, has mass m_e and charge $+q$.

A positron interacts with an electron. The electron and the positron may be considered to be at rest.
The outcome of this interaction is that the electron and the positron become two gamma-ray (γ-ray) photons, each having the same energy.

(a) Calculate, for one of the γ-ray photons:

(i) the photon energy, in J

energy = ... J [2]

(ii) its momentum.

momentum = ... N s [2]

(b) State and explain the direction, relative to each other, in which the γ-ray photons are emitted.

....

....

....

.... [2]

[Total: 6]

400. 9702_m19_qp_42 Q: 12

The incomplete nuclear equation for one possible reaction that takes place in the core of a nuclear reactor is

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{139}_{57}\text{La} + {}^{95}_{42}\text{Mo} + 2{}^{1}_{0}\text{n} + \text{.................}$$

(a) **(i)** State the name given to this type of nuclear reaction.

.... [1]

(ii) Complete the nuclear equation. [2]

(b) The mass defect for the reaction is 0.223 u.

(i) Calculate the energy, in J, equivalent to 0.223 u.

energy = ... J [2]

(ii) Suggest **two** forms of the energy released in this reaction.

1. ....

....

2. ....

.... [2]

[Total: 7]

401. 9702_w19_qp_41 Q: 12

One possible nuclear reaction that takes place is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \longrightarrow ^{95}_{42}\text{Mo} + ^{139}_{57}\text{La} + 2^{1}_{0}\text{n} + 7^{\;0}_{-1}\text{e}$$

Data for nuclei in this reaction are given in Fig. 12.1.

nucleus	mass / u	total mass of separate nucleons / u	mass defect / u	binding energy per nucleon / MeV
$^{95}_{42}\text{Mo}$	94.906	95.765	0.859	8.443
$^{139}_{57}\text{La}$	138.906	140.125	1.219	8.189
$^{235}_{92}\text{U}$	235.044	236.909	1.865	....

Fig. 12.1

(a) Show that the energy equivalent to a mass of 1.00 u is 934 MeV.

[2]

(b) (i) Use data from Fig. 12.1 to calculate the binding energy per nucleon of a nucleus of uranium-235 ($^{235}_{92}\text{U}$). Complete Fig. 12.1.

[2]

(ii) The nucleon number of an isotope of the element rutherfordium is 267.

State whether the binding energy per nucleon of this isotope will be greater than, equal to or less than the binding energy per nucleon of uranium-235.

.... [1]

(c) Calculate the total energy, in MeV, released in this nuclear reaction.

energy = ... MeV [2]

(d) The nuclei in 1.2×10^{-7} mol of uranium-235 all undergo this reaction in a time of 25 ms.

Calculate the average power release during the time of 25 ms.

power = ... W [3]

[Total: 10]

402. 9702_w19_qp_43 Q: 12

One possible nuclear reaction that takes place is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \longrightarrow ^{95}_{42}\text{Mo} + ^{139}_{57}\text{La} + 2^{1}_{0}\text{n} + 7^{0}_{-1}\text{e}$$

Data for nuclei in this reaction are given in Fig. 12.1.

nucleus	mass / u	total mass of separate nucleons / u	mass defect / u	binding energy per nucleon / MeV
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$^{139}_{57}\text{La}$	138.906	140.125	1.219	8.189
$^{235}_{92}\text{U}$	235.044	236.909	1.865	....

Fig. 12.1

(a) Show that the energy equivalent to a mass of 1.00 u is 934 MeV.

[2]

(b) **(i)** Use data from Fig. 12.1 to calculate the binding energy per nucleon of a nucleus of uranium-235 ($^{235}_{92}\text{U}$). Complete Fig. 12.1.

[2]

(ii) The nucleon number of an isotope of the element rutherfordium is 267.

State whether the binding energy per nucleon of this isotope will be greater than, equal to or less than the binding energy per nucleon of uranium-235.

.... [1]

(c) Calculate the total energy, in MeV, released in this nuclear reaction.

energy = ... MeV [2]

(d) The nuclei in 1.2×10^{-7} mol of uranium-235 all undergo this reaction in a time of 25 ms.

Calculate the average power release during the time of 25 ms.

power = ... W [3]

[Total: 10]

403. 9702_m18_qp_42 Q: 3

(a) A mass is undergoing simple harmonic motion with amplitude x_0. The maximum velocity of the mass has magnitude v_0.

On Fig. 3.1, show the variation with displacement *x* of the velocity *v* of the mass.

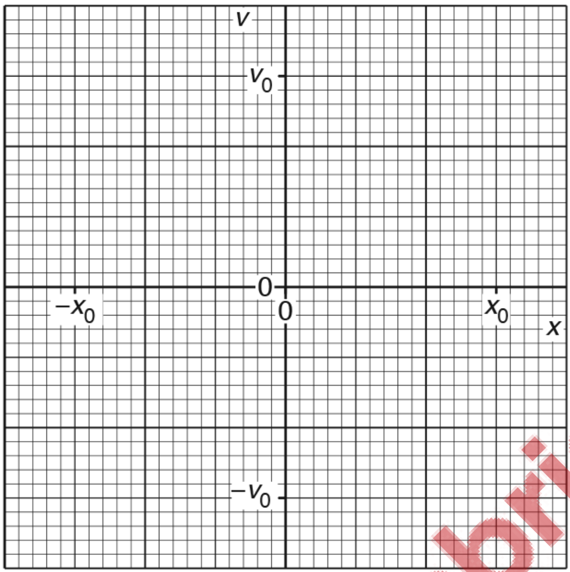

Fig. 3.1

[2]

(b) A straight stiff wire carries a constant current in a region of uniform magnetic flux density.

The angle θ between the direction of the current and the direction of the magnetic field is varied. The maximum force on the wire is F_0.

On Fig. 3.2, show the variation with angle θ of the force *F* on the wire for values of θ between 0° and 90°.

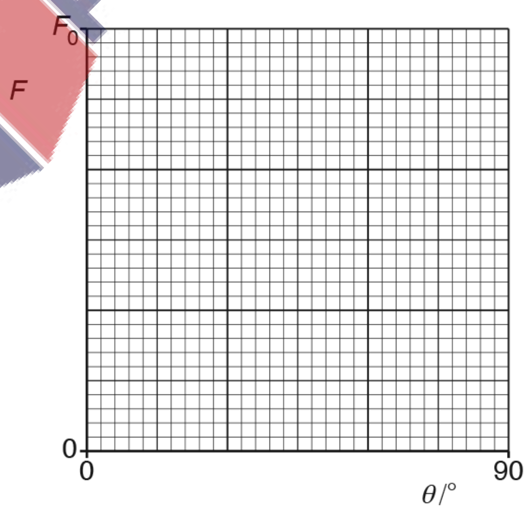

Fig. 3.2

[2]

(c) A sinusoidal supply has frequency 250 Hz and r.m.s. potential difference 2.8 V.

On the axes of Fig. 3.3, show quantitatively the variation with time *t* of the voltage *V* for one cycle of the varying voltage.

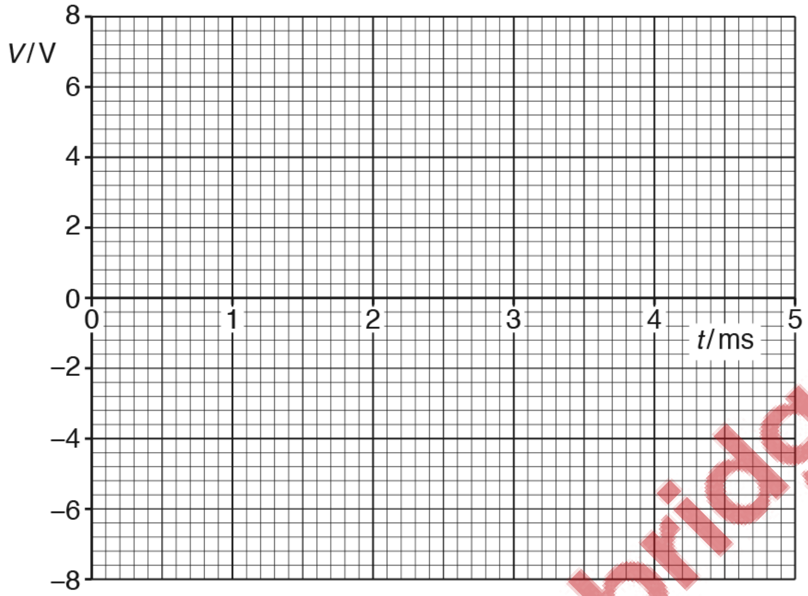

Fig. 3.3

[2]

(d) One particular fission reaction may be represented by the equation

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

The variation with nucleon number A of the binding energy per nucleon B_E is shown in Fig. 3.4.

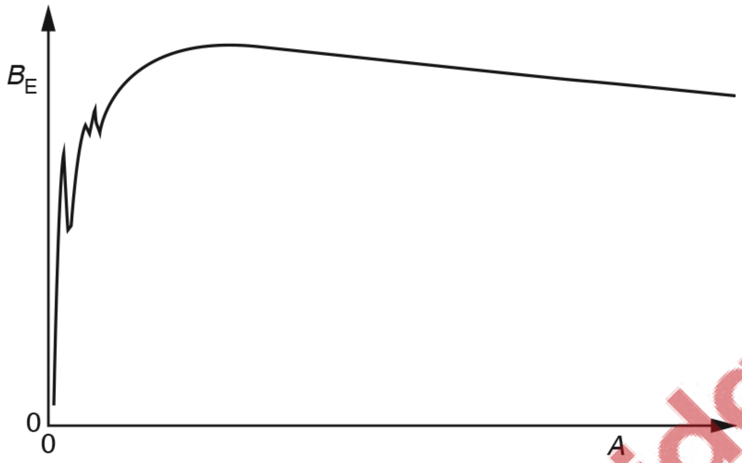

Fig. 3.4

On Fig. 3.4, mark on the line the position of

(i) the nucleus $^{235}_{92}\text{U}$ (label this point U),

(ii) the nucleus $^{141}_{56}\text{Ba}$ (label this point Ba),

(iii) the nucleus $^{92}_{36}\text{Kr}$ (label this point Kr).

[2]

[Total: 8]

404. 9702_w18_qp_41 Q: 11

A stationary isolated nucleus emits a γ-ray photon of energy 0.51 MeV.

(a) State what is meant by a *photon*.

....

....

....[2]

(b) For the γ-ray photon, calculate

(i) its wavelength,

wavelength = ... m [2]

(ii) its momentum.

momentum = ...N s [2]

(c) **(i)** For this nucleus, determine the change in mass Δm during the decay that gives rise to the energy of the γ-ray photon.

Δm = ... kg [2]

(ii) Explain why, after the decay, the nucleus is no longer stationary.

....

....

....[1]

[Total: 9]

---

405. 9702_w18_qp_42 Q: 12

(a) State what is meant by *nuclear fusion* and *nuclear fission*.

nuclear fusion: ....

....

....

nuclear fission: ....

....

....

[3]

(b) A nuclear reaction which may, in the future, be used for the generation of electrical energy is

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + x.$$

(i) Name the particle x.

....[1]

(ii) Data for the binding energy per nucleon E_B of some nuclei are given in Fig. 12.1.

		binding energy per nucleon $E_B / 10^{-13}$ J
deuterium	$^{2}_{1}H$	1.7813
tritium	$^{3}_{1}H$	4.5285
helium	$^{4}_{2}He$	11.3290

Fig. 12.1

1. State the binding energy per nucleon of x.

binding energy per nucleon = ... J

2. Calculate the energy change that takes place in this reaction.

energy change = ... J [3]

(iii) Use your answer in **(ii) part 2** to determine the energy release when 2.0 g of deuterium ($^{2}_{1}H$) reacts with 3.0 g of tritium ($^{3}_{1}H$).

energy = ... J [1]

[Total: 8]

406. 9702_w18_qp_43 Q: 11

A stationary isolated nucleus emits a γ-ray photon of energy 0.51 MeV.

(a) State what is meant by a *photon*.

....

....

....[2]

(b) For the γ-ray photon, calculate

(i) its wavelength,

wavelength = ... m [2]

(ii) its momentum.

momentum = ...N s [2]

(c) (i) For this nucleus, determine the change in mass Δm during the decay that gives rise to the energy of the γ-ray photon.

Δm = ... kg [2]

(ii) Explain why, after the decay, the nucleus is no longer stationary.

....

....

....[1]

[Total: 9]

407. 9702_m17_qp_42 Q: 12

(a) Define the *binding energy* of a nucleus.

....

....

....[2]

(b) A stationary nucleus of uranium-238 ($^{238}_{92}U$) decays to form a nucleus of thorium-234 ($^{234}_{90}Th$). An α-particle and a gamma-ray photon are emitted. The equation representing the decay is

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He + ^{0}_{0}\gamma$$

The masses of the nuclei are given in Fig. 12.1.

nucleus	mass / u
uranium-238	238.05076
thorium-234	234.04357
helium-4	4.00260

Fig. 12.1

(i) State the relationship between the binding energies of the nuclei that is consistent with this reaction being energetically possible.

....

....[1]

(ii) Calculate, for this reaction,

1. the change, in u, of the mass,

change of mass = ...u [1]

2. the total energy, in J, released.

energy = ...J [2]

(iii) State and explain whether the energy of the gamma-ray photon is equal to the energy released in the reaction.

....

....

....[2]

[Total: 8]

---

408. 9702_s17_qp_41 Q: 12

One possible nuclear reaction that takes place in a nuclear reactor is given by the equation

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{95}_{42}\text{Mo} + ^{139}_{57}\text{La} + 2^{1}_{0}\text{n} + x^{0}_{-1}\text{e}$$

Data for the nuclei and particles are given in Fig. 12.1.

nucleus or particle	mass / u
$^{235}_{92}$U	235.123
$^{95}_{42}$Mo	94.945
$^{139}_{57}$La	138.955
$^{1}_{0}$n	1.00863
$^{0}_{-1}$e	5.49×10^{-4}

Fig. 12.1

(a) Determine, for this nuclear reaction, the value of *x*.

x = ...[1]

(b) **(i)** Show that the energy equivalent to 1.00 u is 934 MeV.

[3]

(ii) Calculate the energy, in MeV, released in this reaction. Give your answer to three significant figures.

energy = ... MeV [3]

(c) Suggest the forms of energy into which the energy calculated in **(b)(ii)** is transformed.

....

....

....

....[2]

[Total: 9]

409. 9702_s17_qp_42 Q: 12

One nuclear reaction that can take place in a nuclear reactor may be represented, in part, by the equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2^{1}_{0}n + \ldots\ldots\ldots\ldots + \text{energy}$$

Data for a nucleus and some particles are given in Fig. 12.1.

nucleus or particle	mass / u
$^{139}_{57}La$	138.955
$^{1}_{0}n$	1.00863
$^{1}_{1}p$	1.00728
$^{0}_{-1}e$	5.49×10^{-4}

Fig. 12.1

(a) Complete the nuclear reaction shown above. [1]

(b) **(i)** Show that the energy equivalent to 1.00 u is 934 MeV.

[3]

(ii) Calculate the binding energy per nucleon, in MeV, of lanthanum-139 ($^{139}_{57}La$).

binding energy per nucleon = ... MeV [3]

(c) State and explain whether the binding energy per nucleon of uranium-235 ($^{235}_{92}U$) will be greater, equal to or less than your answer in **(b)(ii)**.

....

....

....

....[3]

[Total: 10]

---

410. 9702_s17_qp_43 Q: 12

One possible nuclear reaction that takes place in a nuclear reactor is given by the equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2^{1}_{0}n + x^{\;0}_{-1}e$$

Data for the nuclei and particles are given in Fig. 12.1.

nucleus or particle	mass / u
$^{235}_{92}U$	235.123
$^{95}_{42}Mo$	94.945
$^{139}_{57}La$	138.955
$^{1}_{0}n$	1.00863
$^{0}_{-1}e$	5.49×10^{-4}

Fig. 12.1

(a) Determine, for this nuclear reaction, the value of x.

x = ...[1]

(b) **(i)** Show that the energy equivalent to 1.00 u is 934 MeV.

[3]

(ii) Calculate the energy, in MeV, released in this reaction. Give your answer to three significant figures.

energy = ... MeV [3]

(c) Suggest the forms of energy into which the energy calculated in **(b)(ii)** is transformed.

....

....

....

....[2]

[Total: 9]

411. 9702_m16_qp_42 Q: 9

A particle of charge $+q$ and mass m is travelling with a constant speed of $1.6 \times 10^5\,\mathrm{m\,s^{-1}}$ in a vacuum. The particle enters a uniform magnetic field of flux density $9.7 \times 10^{-2}\,\mathrm{T}$, as shown in Fig. 9.1.

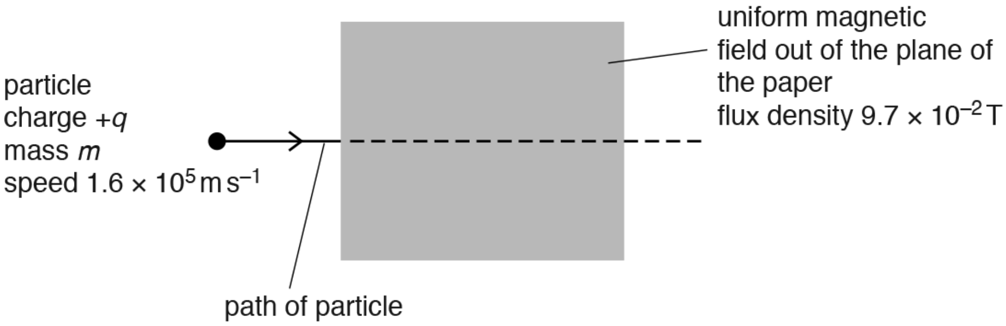

Fig. 9.1

The magnetic field direction is perpendicular to the initial velocity of the particle and perpendicular to, and out of, the plane of the paper.

A uniform electric field is applied in the same region as the magnetic field so that the particle passes undeviated through the fields.

(a) State and explain the direction of the electric field.

....

....

....[2]

(b) Calculate the magnitude of the electric field strength.

Explain your working.

electric field strength = ... $\mathrm{V\,m^{-1}}$ [3]

(c) The electric field is now removed so that the positively-charged particle follows a curved path in the magnetic field. This path is an arc of a circle of radius 4.0 cm.

Calculate, for the particle, the ratio $\frac{q}{m}$.

ratio = ... C kg^{-1} [3]

(d) The particle has a charge of 3*e* where *e* is the elementary charge.

(i) Use your answer in **(c)** to determine the mass, in u, of the particle.

mass = ... u [2]

(ii) The particle is the nucleus of an atom. State the number of protons and the number of neutrons in this nucleus.

number of protons = ...

number of neutrons = ...
[1]

[Total: 11]

412. 9702_w16_qp_42 Q: 14

Phosphorus-30 ($^{30}_{15}P$) was the first artificial radioactive nuclide to be produced in a laboratory. This was achieved by bombarding aluminium-27 ($^{27}_{13}Al$) with α-particles.

A partial nuclear equation to represent this reaction is

$$^{27}_{13}Al + \alpha \rightarrow {}^{30}_{15}P + \Phi$$

(a) State the full nuclear notation for

(i) the α-particle,

....[1]

(ii) the particle represented by the symbol Φ.

....[1]

(b) Data for the rest masses of the particles in the reaction are given in Fig. 14.1.

particle	mass / u
$^{27}_{13}Al$	26.98153
α	4.00260
$^{30}_{15}P$	29.97830
Φ	1.00867

Fig. 14.1

Calculate, for this reaction,

(i) the change in the total rest mass of the particles,

mass change = ... u [2]

(ii) the energy, in joule, equivalent to the mass change calculated in **(i)**.

energy = ... J [2]

(c) With reference to your answer in **(b)(i)**, comment on the energy of the α-particle such that the reaction can take place.

....

....

....

....[2]

[Total: 8]

413. 9702_m21_qp_42 Q: 12

(a) Radioactive decay is both spontaneous and random.

State what is meant by:

1. *spontaneous decay* ....

....

2. *random decay.* ....

.... [2]

(b) Strontium-90 ($^{90}_{38}Sr$) is an unstable nuclide.

The activity of a sample of 1.0×10^{-9} kg of strontium-90 is 5.2 MBq.

(i) Determine the decay constant λ of strontium-90.

λ = ... s^{-1} [3]

(ii) The activity of the sample after a time of 1.0 half lives is found to be greater than the expected 2.6 MBq.

Suggest a possible reason for this.

....

.... [1]

[Total: 6]

414. 9702_s21_qp_41 Q: 6

(a) An isolated metal sphere of radius r is charged so that the electric field strength at its surface is E_0.

On Fig. 6.1, sketch the variation of the electric field strength E with distance x from the centre of the sphere. Your sketch should extend from $x = 0$ to $x = 3r$.

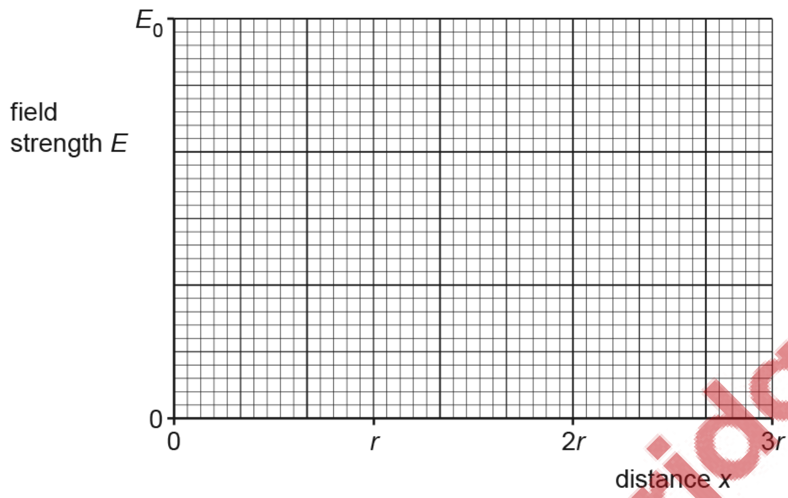

Fig. 6.1

[3]

(b) The de Broglie wavelength of a particle is λ_0 when its momentum is p_0.

On Fig. 6.2, sketch the variation with momentum p of the de Broglie wavelength λ of the particle for values of momentum from $\frac{p_0}{2}$ to p_0.

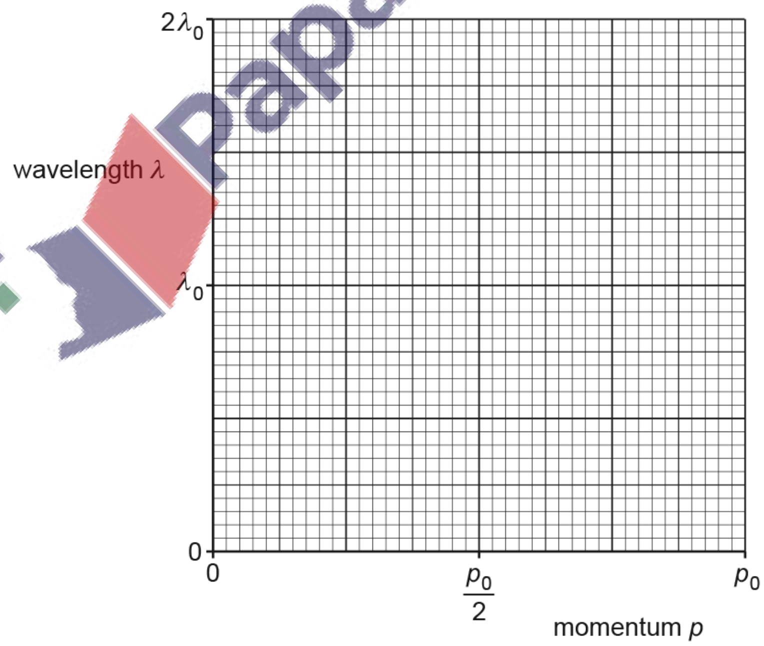

Fig. 6.2

[2]

(c) A radioactive isotope decays with a half-life of 15 s to form a stable product.

A fresh sample of the radioactive isotope at time $t = 0$ contains N_0 nuclei and no nuclei of the stable product.

On Fig. 6.3, sketch the variation with t of the number n of nuclei of the stable product for time $t = 0$ to time $t = 45$ s.

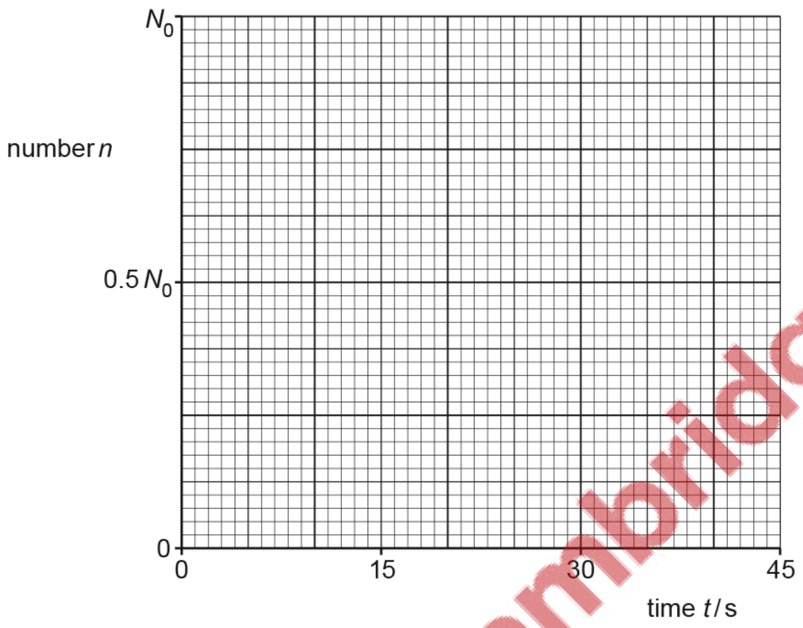

Fig. 6.3

[3]

[Total: 8]

415. 9702_s21_qp_42 Q: 5

(a) An isolated metal sphere of radius r is charged so that the electric potential at its surface is V_0.

On Fig. 5.1, sketch the variation with distance x from the centre of the sphere of the electric potential. Your graph should extend from $x = 0$ to $x = 3r$.

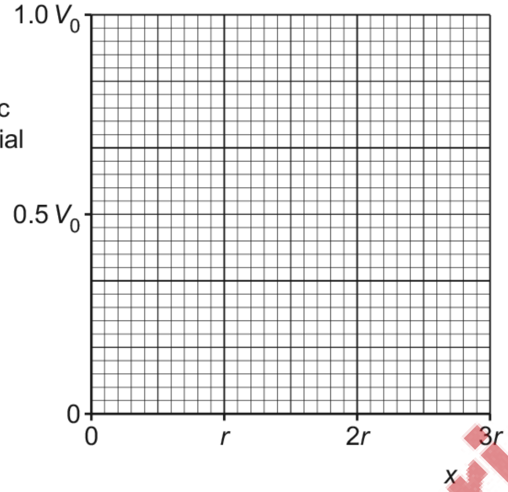

Fig. 5.1

[3]

(b) Photons having wavelength λ are incident on a metal surface.
The maximum wavelength for which there is emission of electrons is λ_0.
For photons of wavelength $\frac{\lambda_0}{2}$, the maximum kinetic energy of the emitted electrons is E_{MAX}.

On Fig. 5.2, sketch the variation with wavelength λ of the maximum kinetic energy for values of wavelength between $\lambda = \frac{\lambda_0}{3}$ and $\lambda = \lambda_0$.

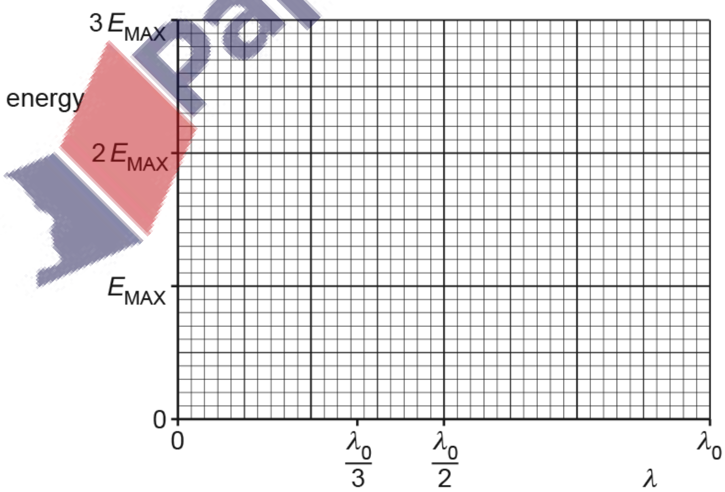

Fig. 5.2

[3]

(c) A pure sample of a radioactive isotope contains N_0 nuclei. The half-life of the isotope is $T_{\frac{1}{2}}$. The product of the radioactive decay is stable.

The variation with time t of the number N of nuclei of the radioactive isotope is shown in Fig. 5.3.

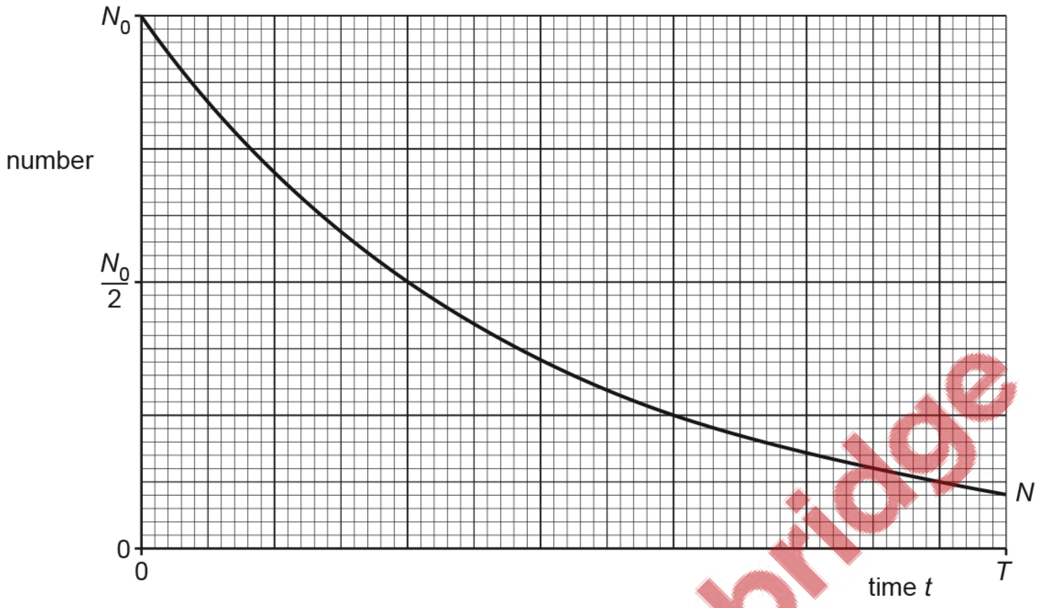

Fig. 5.3

On Fig. 5.3:

- label, on the time axis, the time $t = 1.0T_{\frac{1}{2}}$ and the time $t = 2.0T_{\frac{1}{2}}$
- sketch the variation with time t of the number of nuclei of the decay product for time $t = 0$ to time $t = T$.

[3]

[Total: 9]

416. 9702_s21_qp_43 Q: 6

(a) An isolated metal sphere of radius r is charged so that the electric field strength at its surface is E_0.

On Fig. 6.1, sketch the variation of the electric field strength E with distance x from the centre of the sphere. Your sketch should extend from $x = 0$ to $x = 3r$.

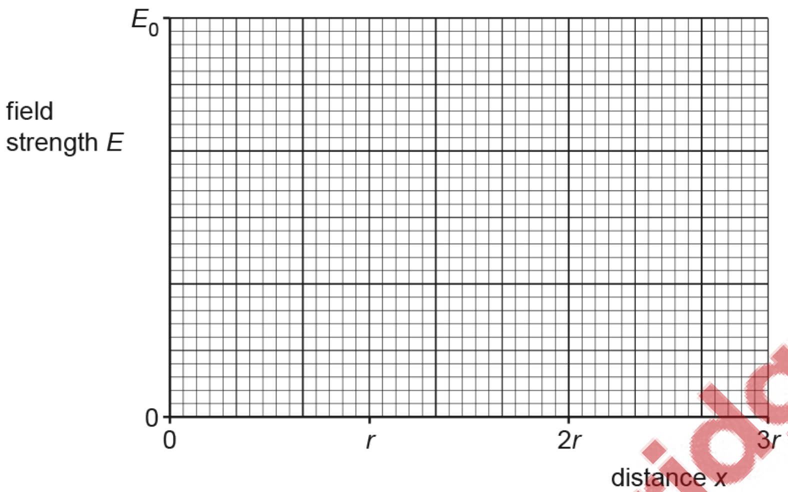

Fig. 6.1

[3]

(b) The de Broglie wavelength of a particle is λ_0 when its momentum is p_0.

On Fig. 6.2, sketch the variation with momentum p of the de Broglie wavelength λ of the particle for values of momentum from $\frac{p_0}{2}$ to p_0.

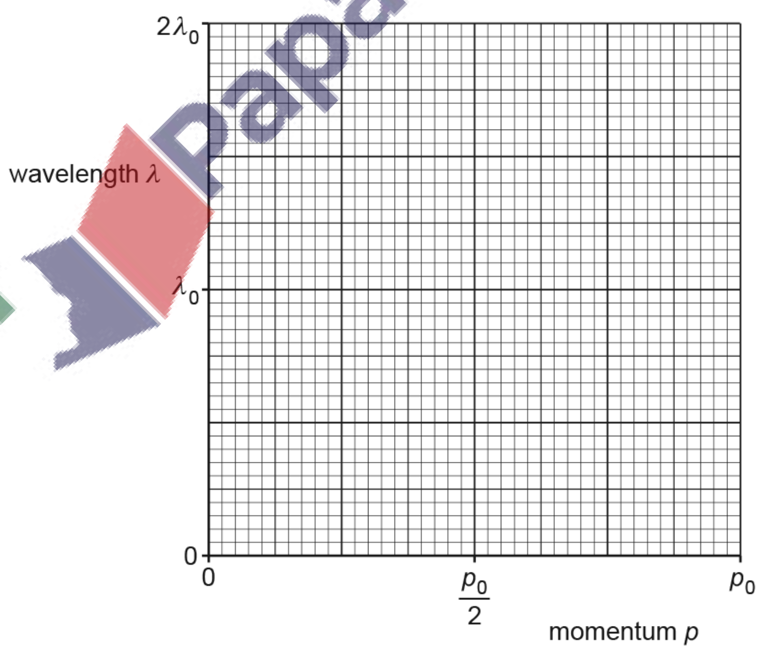

Fig. 6.2

[2]

(c) A radioactive isotope decays with a half-life of 15 s to form a stable product.

A fresh sample of the radioactive isotope at time $t = 0$ contains N_0 nuclei and no nuclei of the stable product.

On Fig. 6.3, sketch the variation with t of the number n of nuclei of the stable product for time $t = 0$ to time $t = 45$ s.

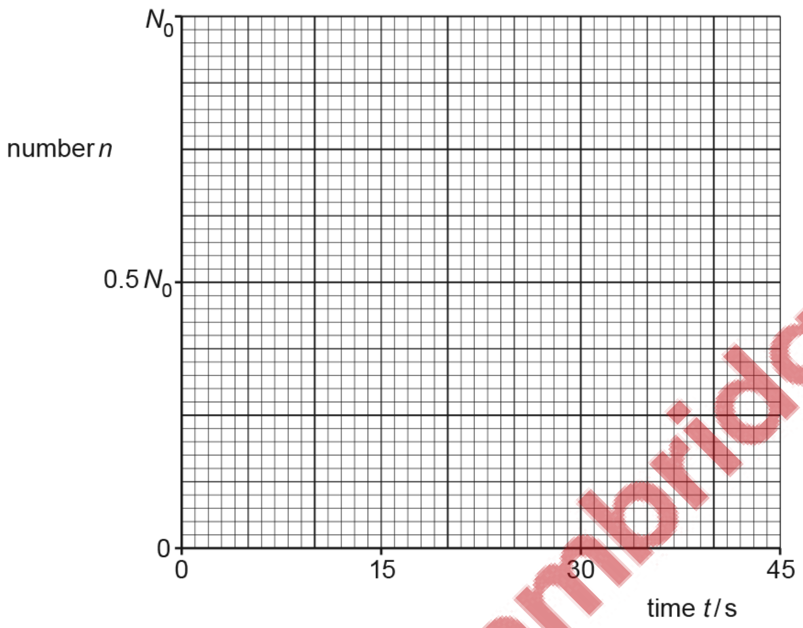

Fig. 6.3

[3]

[Total: 8]

417. 9702_w21_qp_41 Q: 12

(a) Define radioactive *decay constant*.

....

....

.... [2]

(b) A sample of radioactive iodine-131 ($^{131}_{53}\mathrm{I}$) of mass 5.87×10^{-10} kg has an activity of 2.92×10^{9} Bq.

Determine the decay constant of iodine-131.

decay constant = ... s^{-1} [3]

(c) Suggest **two** reasons why a detector placed near to the sample in **(b)** would record a count rate much less than 2.92×10^{9} counts per second.

1. ....

....

2. ....

....

[2]

[Total: 7]

418. 9702_w21_qp_42 Q: 12

(a) Radioactive decay is both random and spontaneous.

State what is meant by:

(i) *random*

....

.... [1]

(ii) *spontaneous*.

....

.... [1]

(b) A sample of radioactive material contains atoms of an unstable nuclide X. The activity of the sample due to the atoms of X is A. The variation with time t of ln A is shown in Fig. 12.1.

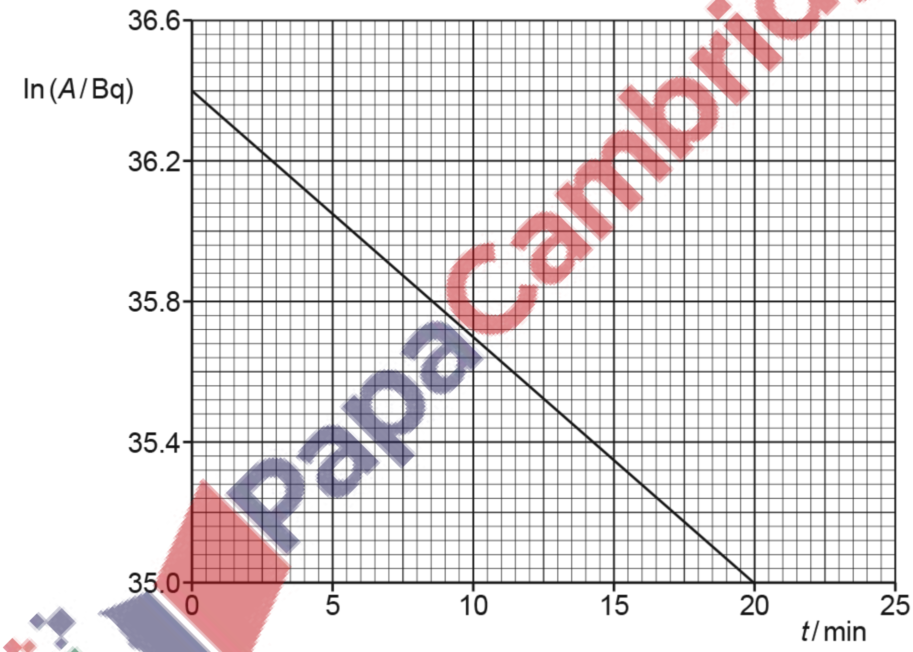

Fig. 12.1

(i) Use Fig. 12.1 to determine the half-life, in minutes, of nuclide X.

half-life = ... min [3]

(ii) At time $t = 0$, the mass of the atoms of X in the sample is 5.66×10^{-7} kg.

Determine the nucleon number of X.

nucleon number = ... [3]

[Total: 8]

419. 9702_w21_qp_43 Q: 12

(a) Define radioactive *decay constant*.

....

....

.... [2]

(b) A sample of radioactive iodine-131 ($^{131}_{53}\mathrm{I}$) of mass 5.87×10^{-10} kg has an activity of 2.92×10^{9} Bq.

Determine the decay constant of iodine-131.

decay constant = ... s^{-1} [3]

(c) Suggest **two** reasons why a detector placed near to the sample in **(b)** would record a count rate much less than 2.92×10^{9} counts per second.

1. ....

....

2. ....

....

[2]

[Total: 7]

420. 9702_m20_qp_42 Q: 12

(a) Explain what is meant by the *binding energy* of a nucleus.

....

....

.... [2]

(b) The following nuclear reaction takes place:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{55}Cs + ^{90}_{x}Rb + y^{1}_{0}n$$

(i) Determine the values of x and y.

x = ...

y = ...
[1]

(ii) State the name of this type of nuclear reaction.

.... [1]

(iii) Compare the binding energy per nucleon of uranium-235 with the binding energy per nucleon of caesium-144.

....

.... [1]

(c) Yttrium-90 decays into zirconium-90, a stable isotope.

A sample initially consists of pure yttrium-90.

Calculate the time, in days, when the ratio of the number of yttrium-90 nuclei to the number of zirconium-90 nuclei would be 2.0.

The half-life of yttrium-90 is 2.7 days.

time = ... days [3]

[Total: 8]

421. 9702_s20_qp_41 Q: 12

(a) The decay of a sample of a radioactive isotope is said to be random and spontaneous.

Explain what is meant by the decay being:

(i) *random*

....

.... [1]

(ii) *spontaneous*.

....

.... [1]

(b) A radioactive isotope X has a half-life of 1.4 hours.

Initially, a pure sample of this isotope X has an activity of 3.6×10^5 Bq.

Determine the activity of the isotope X in the sample after a time of 2.0 hours.

activity = ... Bq [3]

(c) The variation with time t of the actual activity A of the sample in **(b)** is shown in Fig. 12.1.

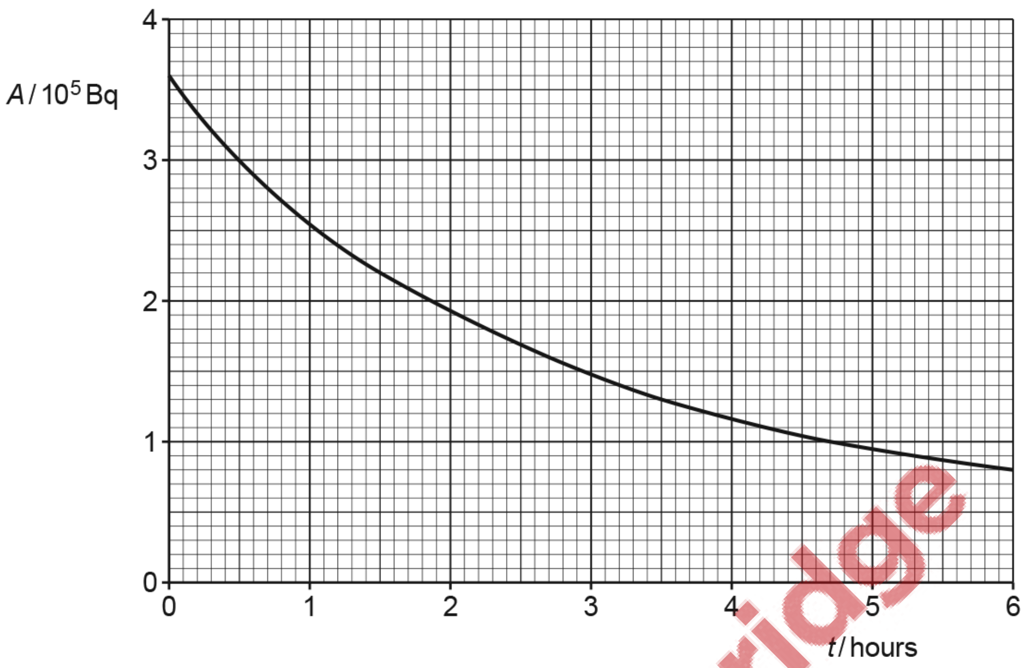

Fig. 12.1

(i) The initial activity of isotope X in the sample is 3.6×10^5 Bq.

Use information from **(b)** to sketch, on the axes of Fig. 12.1, the variation with time t of the activity of a pure sample of isotope X. [1]

(ii) Suggest an explanation for any difference between the actual activity of the sample shown in Fig. 12.1 and the curve you have drawn for the activity of isotope X.

....

....

.... [2]

[Total: 8]

422. 9702_s20_qp_43 Q: 12

(a) The decay of a sample of a radioactive isotope is said to be random and spontaneous.

Explain what is meant by the decay being:

(i) *random*

....

.... [1]

(ii) *spontaneous*.

....

.... [1]

(b) A radioactive isotope X has a half-life of 1.4 hours.

Initially, a pure sample of this isotope X has an activity of 3.6×10^5 Bq.

Determine the activity of the isotope X in the sample after a time of 2.0 hours.

activity = ... Bq [3]

(c) The variation with time t of the actual activity A of the sample in **(b)** is shown in Fig. 12.1.

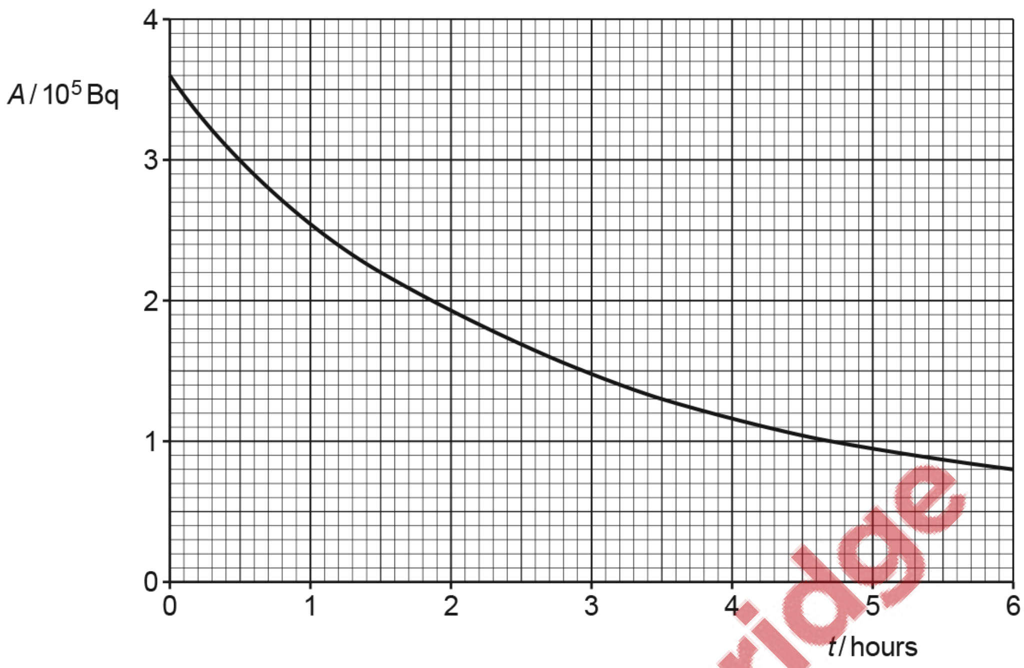

Fig. 12.1

(i) The initial activity of isotope X in the sample is 3.6×10^5 Bq.

Use information from **(b)** to sketch, on the axes of Fig. 12.1, the variation with time t of the activity of a pure sample of isotope X. [1]

(ii) Suggest an explanation for any difference between the actual activity of the sample shown in Fig. 12.1 and the curve you have drawn for the activity of isotope X.

....

....

.... [2]

[Total: 8]

423. 9702_s19_qp_41 Q: 12

(a) A sample of a radioactive isotope contains N nuclei of the isotope at time T.
At time $(T + \Delta T)$, the sample contains $(N - \Delta N)$ nuclei of the isotope. The time interval ΔT is short.

Use the symbols N, ΔN, T and ΔT to give expressions for:

(i) the average activity of the sample during the time ΔT

.... [1]

(ii) the probability of decay of a nucleus in the time ΔT

.... [1]

(iii) the decay constant λ of the isotope.

.... [1]

(b) The isotope polonium-208 ($^{208}_{84}$Po) is radioactive and decays to form lead-204 ($^{204}_{82}$Pb).
The nuclear equation for this decay is

$$^{208}_{84}\text{Po} \longrightarrow {}^{204}_{82}\text{Pb} + {}^{4}_{2}\text{He}.$$

Data for nuclear masses are given in Fig. 12.1.

	mass / u
$^{4}_{2}$He	4.002 603
$^{204}_{82}$Pb	203.973 043
$^{208}_{84}$Po	207.981 245

Fig. 12.1

(i) Determine, for the decay of one nucleus of polonium-208:

1. the change, in u, of the mass

mass change = ... u [1]

2. the total energy, in pJ, released.

energy = ... pJ [3]

(ii) The polonium-208 nucleus is initially stationary. The initial kinetic energy of the $^{4}_{2}$He nucleus (α-particle) is found to be less than the energy calculated in **(i) part 2**.

Suggest **two** possible reasons for this difference.

1. ....

....

2. ....

....
[2]

[Total: 9]

424. 9702_s19_qp_42 Q: 12

(a) State what is meant by the *binding energy* of a nucleus.

....

....

....[2]

(b) Some masses are shown in Fig. 12.1.

	mass / u
proton ($^1_1$p)	1.007
neutron ($^1_0$n)	1.009
lanthanum-141 ($^{141}_{57}$La) nucleus	140.911

Fig. 12.1

Calculate the binding energy of a nucleus of lanthanum-141.

binding energy = ... J [4]

(c) The nuclide lanthanum-141 ($^{141}_{57}$La) has a half-life of 3.9 hours.

Initially, a radioactive source contains only lanthanum-141. The initial activity of the source is A_0.

(i) Calculate the time for the activity of the lanthanum-141 to be reduced to $0.40A_0$.

time = ... hours [3]

(ii) Suggest why the total activity of the radioactive source measured at the time calculated in **(i)** may be greater than $0.40A_0$.

....

....[1]

[Total: 10]

425. 9702_s19_qp_43 Q: 12

(a) A sample of a radioactive isotope contains N nuclei of the isotope at time T.
At time $(T + \Delta T)$, the sample contains $(N - \Delta N)$ nuclei of the isotope. The time interval ΔT is short.

Use the symbols N, ΔN, T and ΔT to give expressions for:

(i) the average activity of the sample during the time ΔT

.... [1]

(ii) the probability of decay of a nucleus in the time ΔT

.... [1]

(iii) the decay constant λ of the isotope.

.... [1]

(b) The isotope polonium-208 ($^{208}_{84}Po$) is radioactive and decays to form lead-204 ($^{204}_{82}Pb$).
The nuclear equation for this decay is

$$^{208}_{84}Po \longrightarrow ^{204}_{82}Pb + ^{4}_{2}He.$$

Data for nuclear masses are given in Fig. 12.1.

	mass / u
$^{4}_{2}He$	4.002 603
$^{204}_{82}Pb$	203.973 043
$^{208}_{84}Po$	207.981 245

Fig. 12.1

(i) Determine, for the decay of one nucleus of polonium-208:

1. the change, in u, of the mass

mass change = ... u [1]

2. the total energy, in pJ, released.

energy = ... pJ [3]

(ii) The polonium-208 nucleus is initially stationary. The initial kinetic energy of the $^{4}_{2}$He nucleus (α-particle) is found to be less than the energy calculated in **(i) part 2**.

Suggest **two** possible reasons for this difference.

1. ....

....

2. ....

....
[2]

[Total: 9]

426. 9702_w19_qp_42 Q: 12

Radon-222 ($^{222}_{86}$Ra) is a radioactive gas that decays randomly with a decay constant of 7.55×10^{-3} hour^{-1}.

(a) State what is meant by:

(i) *random* decay

....

.... [1]

(ii) *decay constant*.

....

....

.... [2]

(b) The activity of radon gas in a sample of 4.80×10^{-3} m^3 of air taken from a building is 0.600 Bq.

There are 2.52×10^{25} air molecules in a volume of 1.00 m^3 of air.

Calculate, for 1.00 m^3 of the air, the ratio

$$\frac{\text{number of air molecules}}{\text{number of radon atoms}}.$$

ratio = ... [5]

[Total: 8]

427. 9702_m18_qp_42 Q: 13

(a) **(i)** Define radioactive *decay constant*.

....

....

....[2]

(ii) Show that the decay constant λ is related to the half-life $t_{\frac{1}{2}}$ of a radioactive isotope by the expression

$$\lambda t_{\frac{1}{2}} = \ln 2$$

[2]

(b) A small volume of solution containing the radioactive isotope sodium-24 ($^{24}_{11}Na$) has an initial activity of 3.8×10^4 Bq. Sodium-24, of half-life 15 hours, decays to form a stable daughter isotope.

All of the solution is poured into a container of water. After 36 hours, a sample of water of volume $5.0\,cm^3$, taken from the container, is found to have an activity of 1.2 Bq.

Assuming that the solution of the radioactive isotope is distributed uniformly throughout the container of water, calculate the volume of water in the container.

volume = ... cm^3 [4]

[Total: 8]

428. 9702_s18_qp_41 Q: 13

(a) State what is meant by *radioactive decay*.

....

....

....

....[2]

(b) The variation with time t of the number N of technetium-101 nuclei in a sample of radioactive material is shown in Fig. 13.1.

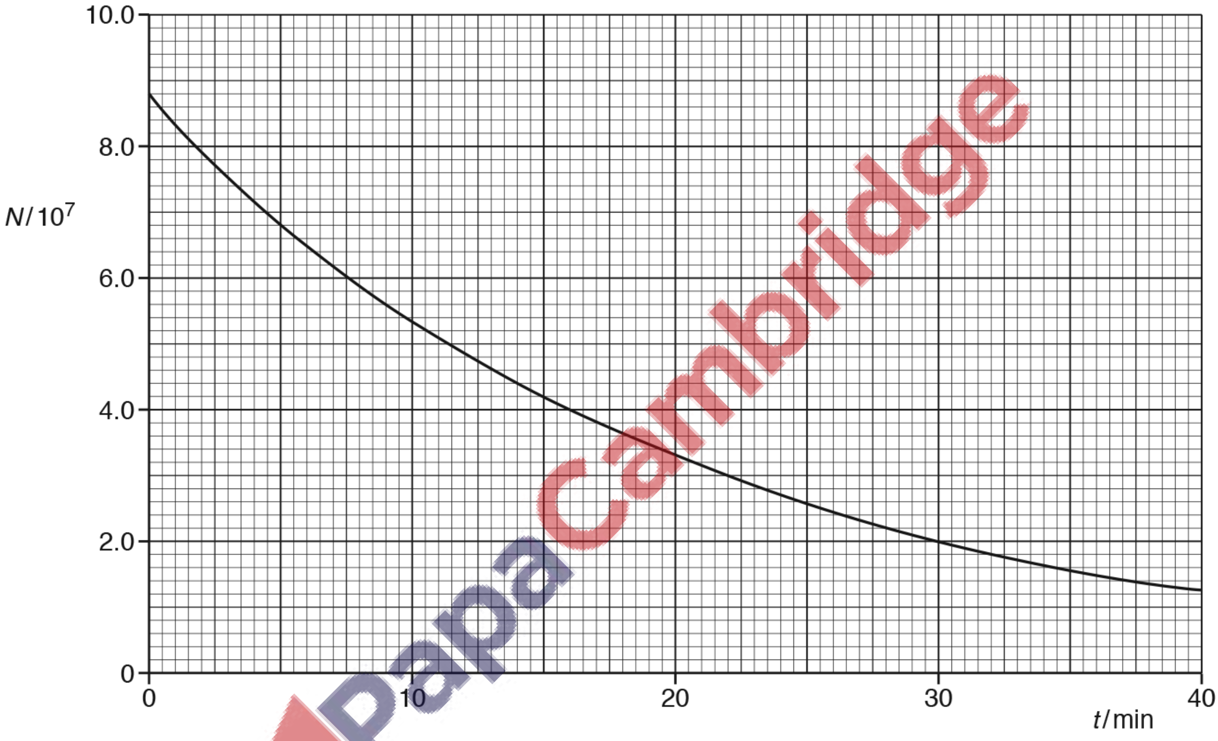

Fig. 13.1

(i) Use Fig. 13.1 to determine the activity, in Bq, of the sample of technetium-101 at time t = 14.0 minutes. Show your working.

activity = ... Bq [4]

(ii) Without calculating the half-life of technetium-101, use your answer in **(i)** to determine the decay constant λ of technetium-101.

λ = ... s^{-1} [2]

[Total: 8]

429. 9702_s18_qp_42 Q: 12

(a) State what is meant by *radioactive decay*.

....

....

....

....[2]

(b) An unstable nuclide P has decay constant λ_P and decays to form a nuclide D.
This nuclide D is unstable and decays with decay constant λ_D to form a stable nuclide S. The decay chain is illustrated in Fig. 12.1.

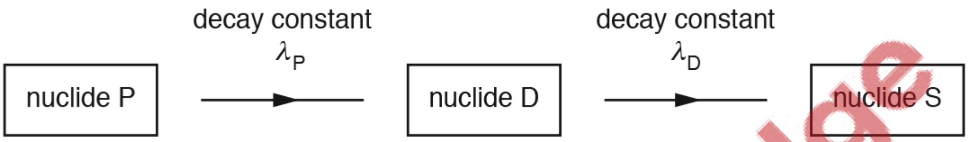

Fig. 12.1

The symbols P, D and S are not the nuclide symbols.

Initially, a radioactive sample contains only nuclide P.

The variation with time *t* of the number of nuclei of each of the three nuclides in the sample is shown in Fig. 12.2.

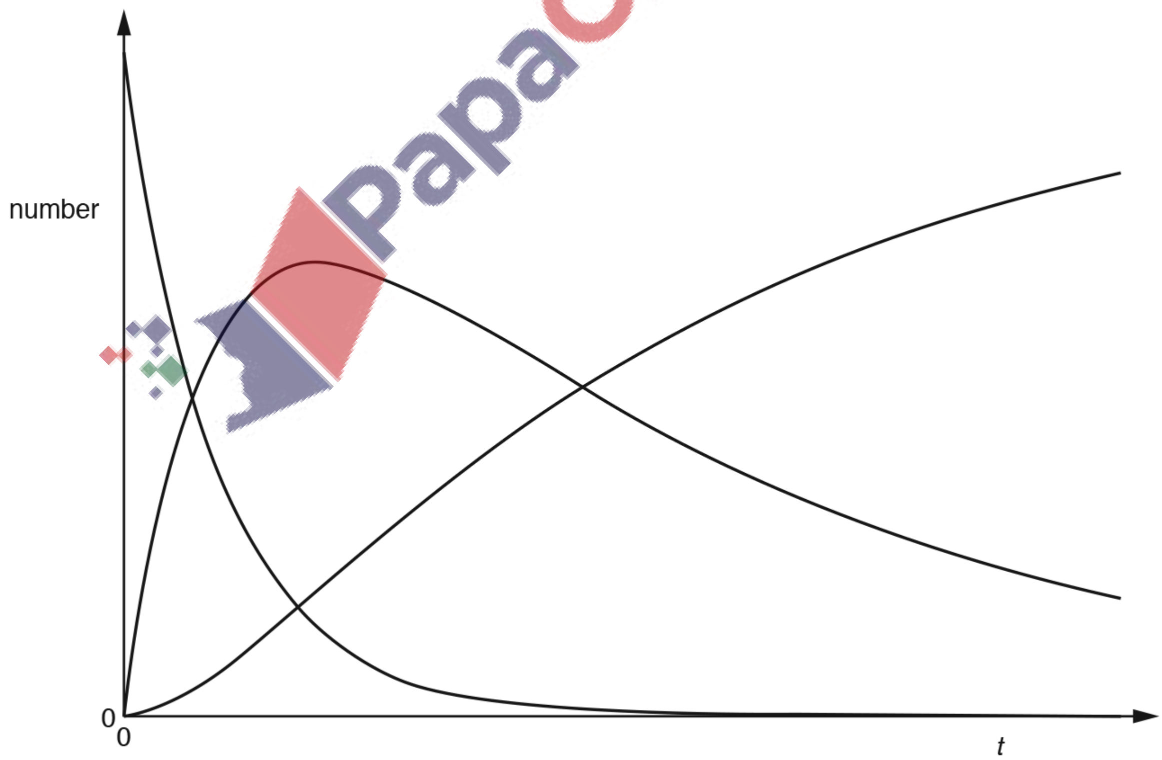

Fig. 12.2

(i) On Fig. 12.2, use the symbols P, D and S to identify the curve for each of the three nuclides. [2]

(ii) The half-life of nuclide P is 60.0 minutes.

Calculate the decay constant λ_P, in s^{-1}, of this nuclide.

λ_P = ... s^{-1} [2]

(c) In the decay chain shown in Fig. 12.1, λ_P is approximately equal to $5\lambda_D$.

The decay chain of a different nuclide E is illustrated in Fig. 12.3.

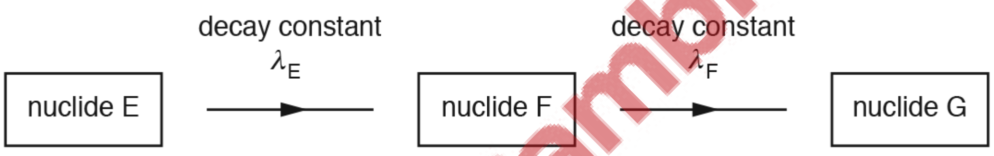

Fig. 12.3

The decay constant λ_F of nuclide F is very much larger than the decay constant λ_E of nuclide E.

By reference to the half-life of nuclide F, explain why the number of nuclei of nuclide F in the sample is always small.

....

....

....[2]

[Total: 8]

430. 9702_s18_qp_43 Q: 13

(a) State what is meant by *radioactive decay*.

....

....

....

....[2]

(b) The variation with time t of the number N of technetium-101 nuclei in a sample of radioactive material is shown in Fig. 13.1.

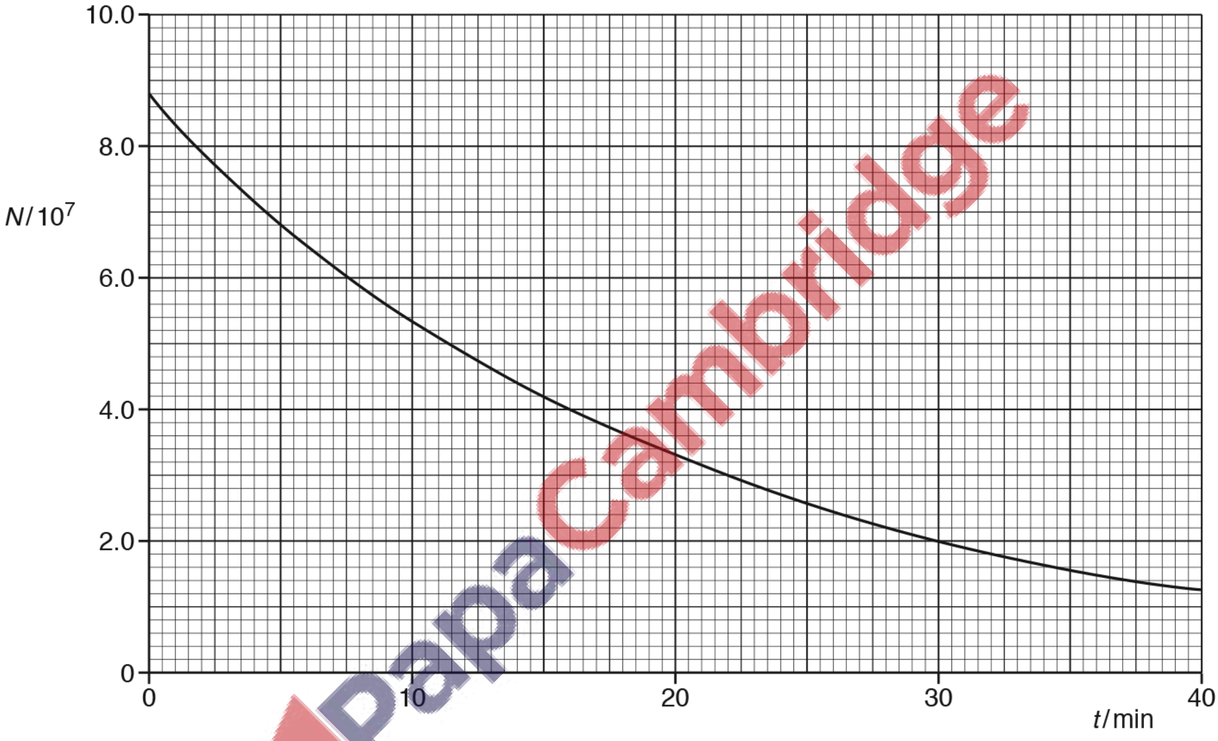

Fig. 13.1

(i) Use Fig. 13.1 to determine the activity, in Bq, of the sample of technetium-101 at time t = 14.0 minutes. Show your working.

activity = ... Bq [4]

(ii) Without calculating the half-life of technetium-101, use your answer in **(i)** to determine the decay constant λ of technetium-101.

λ = ... s^{-1} [2]

[Total: 8]

431. 9702_w18_qp_41 Q: 12

(a) State what is meant by *radioactive decay*.

....

....

....

....[3]

(b) The variation with time t of the number N of undecayed nuclei in a sample of a radioactive isotope is shown in Fig. 12.1.

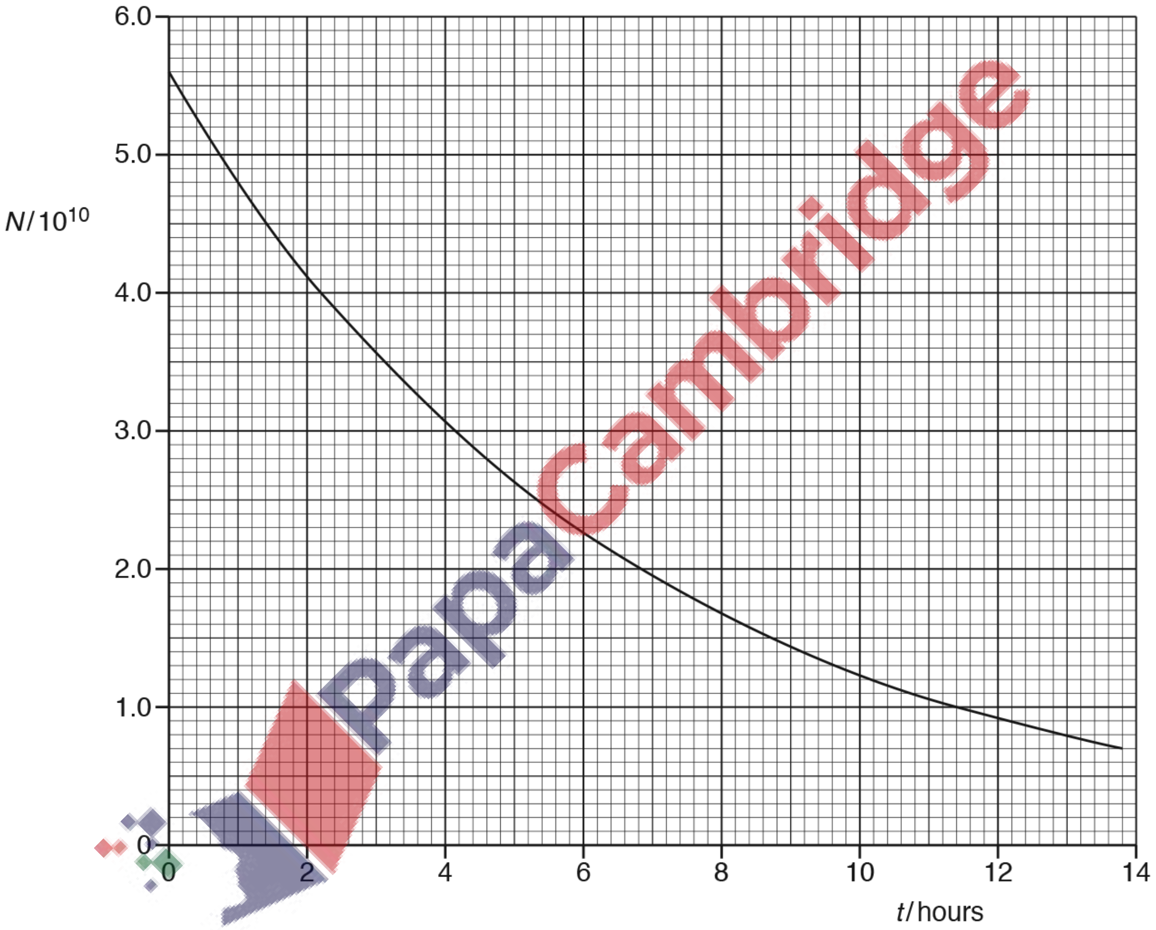

Fig. 12.1

(i) Use the gradient of the line in Fig. 12.1 to determine the activity, in Bq, of the sample at time $t = 4.0$ hours. Show your working.

activity = ... Bq [3]

(ii) Use your answer in **(i)** to show that the decay constant λ of the isotope is approximately $4 \times 10^{-5}\,s^{-1}$.

[2]

(c) A sample of a different radioactive isotope has an initial activity of 4.6×10^3 Bq. The sample must be stored safely until its activity is reduced to 1.0×10^3 Bq.

The decay constant of the isotope is $5.5 \times 10^{-7}\,s^{-1}$. The decay products are not radioactive.

Calculate the minimum time, in days, for which the sample must be stored.

time = ... days [3]

[Total: 11]

432. 9702_w18_qp_43 Q: 12

(a) State what is meant by *radioactive decay*.

....

....

....

....[3]

(b) The variation with time t of the number N of undecayed nuclei in a sample of a radioactive isotope is shown in Fig. 12.1.

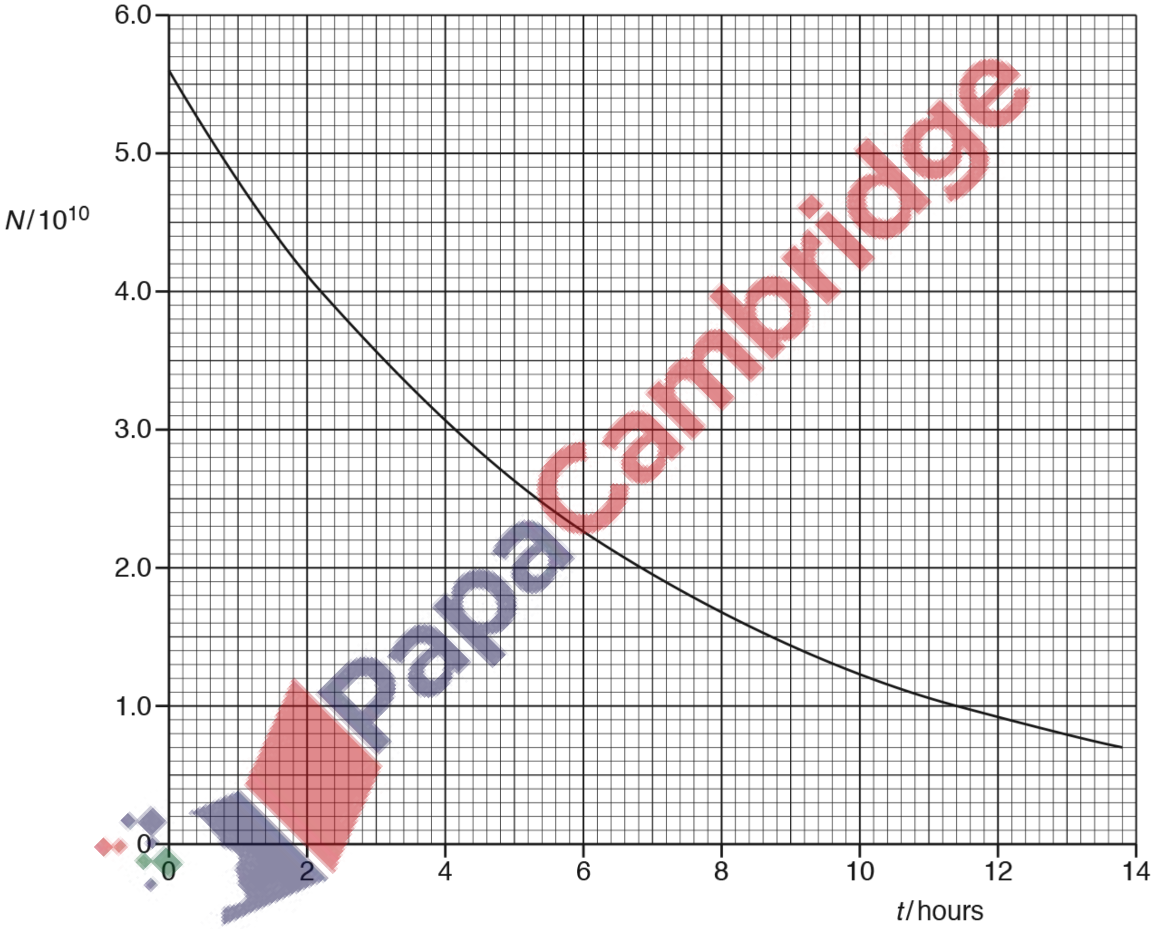

Fig. 12.1

(i) Use the gradient of the line in Fig. 12.1 to determine the activity, in Bq, of the sample at time $t = 4.0$ hours. Show your working.

activity = ... Bq [3]

(ii) Use your answer in **(i)** to show that the decay constant λ of the isotope is approximately $4 \times 10^{-5}\,s^{-1}$.

[2]

(c) A sample of a different radioactive isotope has an initial activity of 4.6×10^{3} Bq. The sample must be stored safely until its activity is reduced to 1.0×10^{3} Bq.

The decay constant of the isotope is $5.5 \times 10^{-7}\,s^{-1}$. The decay products are not radioactive.

Calculate the minimum time, in days, for which the sample must be stored.

time = ... days [3]

[Total: 11]

433. 9702_w17_qp_41 Q: 12

(a) A radiation detector is placed close to a radioactive source. The detector does not surround the source.
Radiation is emitted in all directions and, as a result, the activity of the source and the measured count rate are different.

Suggest two other reasons why the activity and the measured count rate may be different.

1. ....

....

2. ....

.... [2]

(b) The variation with time *t* of the measured count rate in **(a)** is shown in Fig. 12.1.

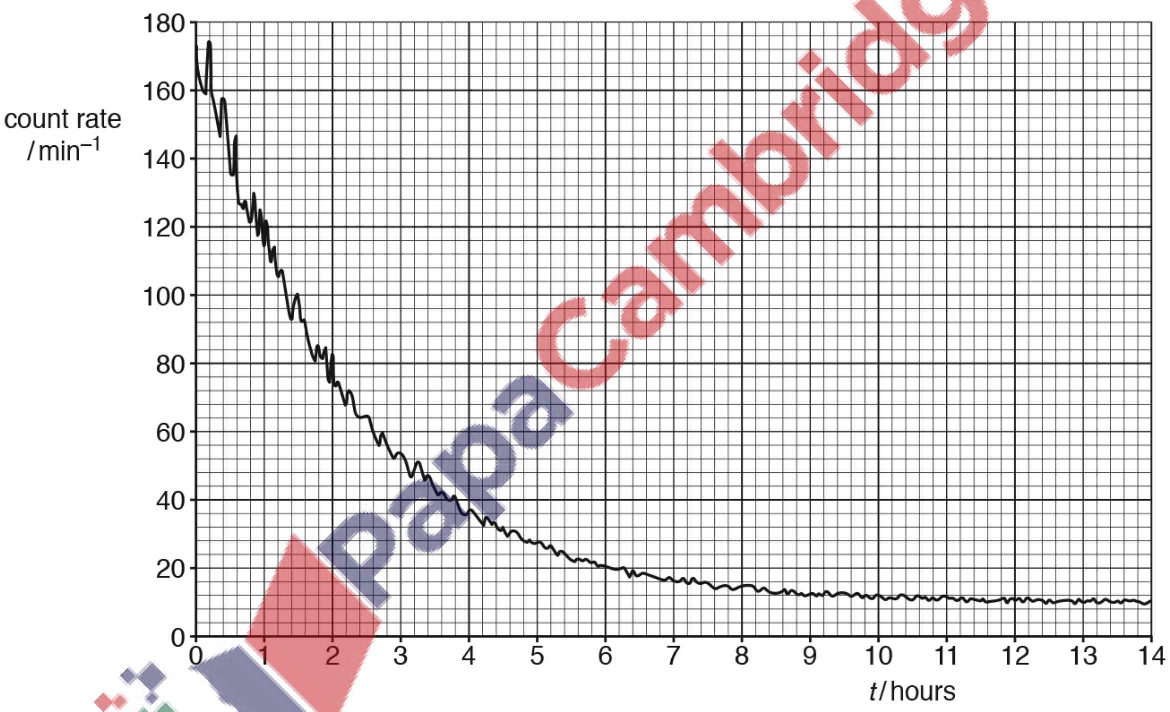

Fig. 12.1

(i) State the feature of Fig. 12.1 that indicates the random nature of radioactive decay.

....

.... [1]

(ii) Use Fig. 12.1 to determine the half-life of the radioactive isotope in the source.

half-life = ... hours [4]

(c) The readings in **(b)** were obtained at room temperature.
A second sample of this isotope is heated to a temperature of 500 °C.
The initial count rate at time $t = 0$ is the same as that in **(b)**.
The variation with time t of the measured count rate from the heated source is determined.

State, with a reason, the difference, if any, in

1. the half-life,

....

....

....

2. the measured count rate for any specific time.

....

....

....

[3]

[Total: 10]

434. 9702_w17_qp_42 Q: 12

The isotope iodine-131 ($^{131}_{53}I$) is radioactive with a decay constant of 8.6×10^{-2} day^{-1}.
β^- particles are emitted with a maximum energy of 0.61 MeV.

(a) State what is meant by

(i) *radioactive*,

....

....

.... [2]

(ii) *decay constant*.

....

....

.... [2]

(b) Explain why the emitted β^- particles have a range of energies.

....

....

.... [2]

(c) A sample of blood contains 1.2×10^{-9} g of iodine-131.

Determine, for this sample of blood,

(i) the activity of the iodine-131,

activity = ... Bq [3]

(ii) the time for the activity of the iodine-131 to be reduced to 1/50 of the activity calculated in **(i)**.

time = ... days [2]

[Total: 11]

435. 9702_w17_qp_43 Q: 12

(a) A radiation detector is placed close to a radioactive source. The detector does not surround the source.
Radiation is emitted in all directions and, as a result, the activity of the source and the measured count rate are different.

Suggest two other reasons why the activity and the measured count rate may be different.

1. ....

....

2. ....

.... [2]

(b) The variation with time t of the measured count rate in **(a)** is shown in Fig. 12.1.

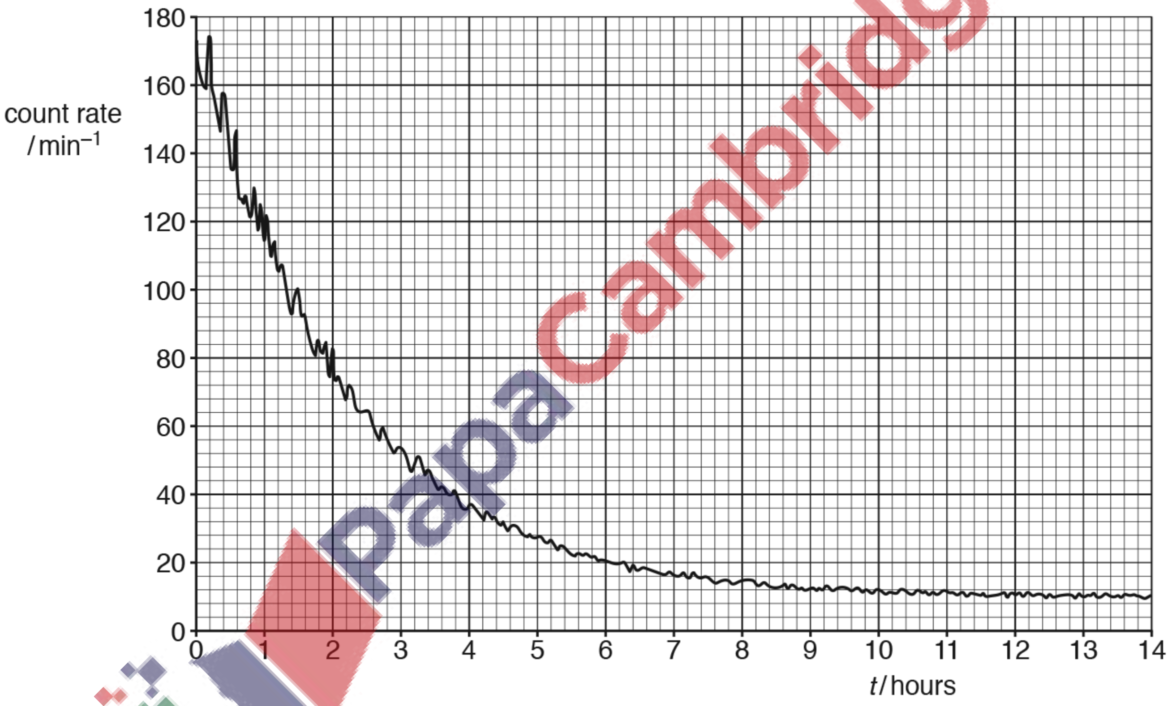

Fig. 12.1

(i) State the feature of Fig. 12.1 that indicates the random nature of radioactive decay.

....

.... [1]

(ii) Use Fig. 12.1 to determine the half-life of the radioactive isotope in the source.

half-life = ... hours [4]

(c) The readings in **(b)** were obtained at room temperature.
A second sample of this isotope is heated to a temperature of 500 °C.
The initial count rate at time $t = 0$ is the same as that in **(b)**.
The variation with time t of the measured count rate from the heated source is determined.

State, with a reason, the difference, if any, in

1. the half-life,

....

....

....

2. the measured count rate for any specific time.

....

....

....

[3]

[Total: 10]

436. 9702_m16_qp_42 Q: 13

Beryllium-7 ($^{7}_{4}Be$) is produced in the upper atmosphere and then sinks down onto the Earth's surface. Nuclei of beryllium-7 decay with a half-life of 53.3 days to form stable nuclei.

The activity of a sample of beryllium-7 on a tree leaf is 39 mBq.

(a) Show that the decay constant of beryllium-7 is $1.5 \times 10^{-7}\,s^{-1}$.

[1]

(b) Determine the mass of the beryllium-7 on the leaf.

mass = ... kg [3]

(c) The leaf is covered so that no further beryllium-7 is added to the existing sample from the atmosphere.

Calculate the time that must elapse before the activity of the sample is reduced to 2.0 mBq.

time = ... s [2]

[Total: 6]

437. 9702_w16_qp_41 Q: 12

Radon-222 ($^{222}_{86}Rn$) is a radioactive element found in atmospheric air.
The decay constant of radon-222 is $2.1 \times 10^{-6}\,s^{-1}$.

(a) **(i)** Define radioactive *half-life*.

....

....

.... [2]

(ii) Show that the half-life $t_{\frac{1}{2}}$ is related to the decay constant λ by the expression

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

[2]

(b) Radon-222 is considered to be an unacceptable health hazard when the activity of radon-222 is greater than 200 Bq in 1.0 m^3 of air.

Calculate the minimum mass of radon-222 in 1.0 m^3 of air above which the health hazard becomes unacceptable.

mass = ... kg [4]

[Total: 8]

438. 9702_w16_qp_43 Q: 12

Radon-222 ($^{222}_{86}$Rn) is a radioactive element found in atmospheric air.
The decay constant of radon-222 is $2.1 \times 10^{-6}\,s^{-1}$.

(a) **(i)** Define radioactive *half-life*.

....

....

.... [2]

(ii) Show that the half-life $t_{\frac{1}{2}}$ is related to the decay constant λ by the expression

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

[2]

(b) Radon-222 is considered to be an unacceptable health hazard when the activity of radon-222 is greater than 200 Bq in $1.0\,m^3$ of air.

Calculate the minimum mass of radon-222 in $1.0\,m^3$ of air above which the health hazard becomes unacceptable.

mass = ... kg [4]

[Total: 8]