1 (a) Suggest, with a reason, which type of radiation is likely to be the most appropriate for the sterilisation of metallic surgical instruments.

γ α & β will only do 1 side, γ will do both

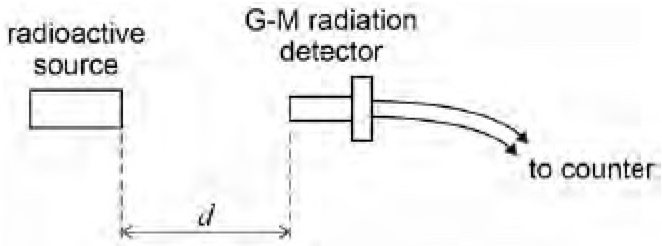
(1)

(b) Explain why the public need not worry that irradiated surgical instruments become radioactive once sterilised.

To become radioactive nucleus must be effected. γ's effect the electrons

(1)

(c) A student detects the counts from a radioactive source using a G-M radiation detector as shown in the diagram.



The student measures the count rate for three different distances d. The table shows the count rate, in counts per minute, corrected for background for each of these distances.

***d*/m**	**Corrected count rate / counts per minute**	$r^2 \times d$		
0.20	9013	360		
0.50	1395	348		
1.00	242	242		

Explain, with the aid of suitable calculations, why the data in the table are **not** consistent with an inverse-square law. You may use the blank columns for your working.

count $\propto \frac{1}{r^2}$ $\therefore$ $r^2 \times$ count = constant (or should do)

it is constant so data not consistent

(2)

(d) State **two** possible reasons why the results do **not** follow the expected inverse-square law.

Reason 1 radiation is a random process

Reason 2 source is not a point source

(2)

(Total 6 marks)

2 During a single fission event of uranium-235 in a nuclear reactor the total mass lost is 0.23 u. The reactor is 25% efficient.

How many events per second are required to generate 900 MW of power?

A 1.1 × 10^{14} ○

B 6.6 × 10^{18} ○

[✓ **C**] 1.1 × 10^{20} ○

D 4.4 × 10^{20} ○

1 u = 1.661×10^{-27} kg

$\therefore$ mass loss = 3.82×10^{-28} kg

$E = mc^2 = 3.44 \times 10^{-11}$ J

only 25% efficient so useful energy =

$\frac{3.44 \times 10^{-11}}{4} = 8\ 6 \times 10^{-12}$ J

$\frac{900 \times 10^6}{8.6 \times 10^{-12}} = 1.04 \times 10^{20}$ so C

(Total 1 mark)

3 An ancient sealed flask contains a liquid, assumed to be water. An archaeologist asks a scientist to determine the volume of liquid in the flask without opening the flask. The scientist decides to use a radioactive isotope of sodium ($^{24}_{11}\mathrm{Na}$) that decays with a half-life of 14.8 h.

(a) She first mixes a compound that contains 3.0 × 10^{-10} g of sodium-24 with 1500 cm^3 of water. She then injects 15 cm^3 of the solution into the flask through the seal.
Show that initially about 7.5 × 10^{10} atoms of sodium-24 are injected into the flask.

$24g = 6.02\times10^{23}$ so we have $\frac{3\times10^{-10}}{24}\times6.02\times10^{23}$

$= 7.5\times10^{12}$

so 7.5×10^{12} in 1500 from which 15 is taken. ie $1/100$ so $\underline{7.5\times10^{10}}$

(1)

(b) Show that the initial activity of the solution that is injected into the flask is about 1 × 10^6 Bq.

Activity $A = \lambda N$

$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}} = \frac{\ln 2}{14.8\times60\times60}$

$= \underline{1.3\times10^{-5}}$

$\therefore A = 1.3\times10^{-3}\times7.5\times10^{10}$

$976\times10^5 = 1.0\times10^6$

activity = _______________Bq

(3)

(c) She waits for 3.5 h to allow the injected solution to mix thoroughly with the liquid in the flask. She then extracts 15 cm^3 of the liquid from the flask and measures its activity which is found to be 3600 Bq.

Calculate the total activity of the sodium-24 in the flask after 3.5 h and hence determine the volume of liquid in the flask.

$A = A_0 e^{-\lambda t}$

$A = 1\times10^6\times e^{-(1.3\times10^{-5}\times3.5\times60^2)}$

$\Rightarrow A = 1\times10^6\times0.85$

$= \underline{85\times10^5}$ ← total activity in flask

$\therefore$ $15cm^3$ has 3600

so vol of flask $= \frac{8.5\times10^5}{3600}\times15 = 236\times15$

$= 3500$ (2sf)

cm^3

(3)

(d) The archaeologist obtained an estimate of the volume knowing that similar empty flasks have an average mass of 1.5 kg and that mass of the flask and liquid was 5.2 kg. Compare the estimate that the archaeologist could obtain from these masses with the volume calculated in part 4.3 and account for any difference.

similar = 5·2 − 1·5 = 3700 cm^3
so sample is a bit smaller.
we assumed contents was water – probably not. Also perhaps the
mass of our flask is a bit higher

(2)

(Total 9 marks)

4 The Rutherford scattering experiment led to

A the discovery of the electron. ○

B the quark model of hadrons. ○

[✓ **C**] the discovery of the nucleus. ○

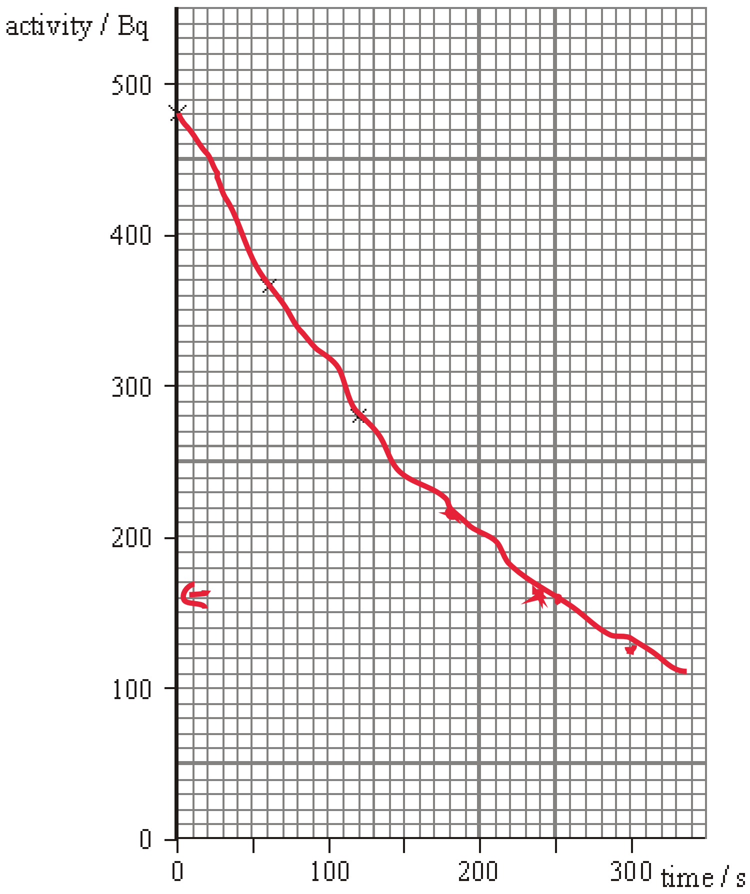
D evidence for wave-particle duality. ○

(Total 1 mark)

5 The table below gives the values for the activity of a radioactive isotope over a period of a few minutes.

time/s	0	60	120	180	240	300
activity/Bq	480	366	280	214	163	124

(a) Complete the graph below by plotting the remaining points and drawing an appropriate curve.



but repeat, take average!

(3)

(b) Use the graph to determine the half-life of the isotope.

half-life 160 s

(3)

(c) Initially there were 1.1 × 10^5 atoms of the isotope present. Calculate the decay probability of the isotope.

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} \Rightarrow \lambda = \frac{\ln 2}{160}$

decay probability 4×10^{-3}

(2)

(Total 8 marks)

6 A Geiger counter is placed near a radioactive source and different materials are placed between the source and the Geiger counter.

The results of the tests are shown in the table.

Material	**Count rate of Geiger counter / s^{-1}**
None	1000
Paper	1000
Aluminium foil	250
Thick steel	50

What is the radiation emitted by the source?

no α

some β

some γ

A α only ○

B α and γ ○

C α and β ○

[✓ **D** β and γ] ○

(Total 1 mark)

7 A nucleus of plutonium ($^{240}_{94}\mathrm{Pu}$) decays to form uranium (U) and an alpha-particle (α).

(a) Complete the equation that describes this decay:

$$^{240}_{94}\mathrm{Pu} \rightarrow {}^{236}_{92}U \quad {}^{4}_{2}\alpha$$

(2)

(b) (i) Show that about 1 pJ of energy is released when one nucleus decays.

mass of plutonium nucleus = 3.98626×10^{-25} kg
mass of uranium nucleus = 3.91970×10^{-25} kg
mass of alpha particle = 6.64251×10^{-27} kg
speed of electromagnetic radiation = 2.99792×10^{8} m s^{-1}

$$\Delta m = \left[6\ 64251 \times 10^{-27} + 3.91970 \times 10^{-25}\right] - 3.98626 \times 10^{-25}$$

$$1.349 \times 10^{-29}\ \mathrm{kg}$$

$$\therefore\ E = \Delta m c^2 = 1.2 \times 10^{-12}\ \mathrm{J} \approx 1\ \mathrm{pJ}$$

(3)

(ii) The plutonium isotope has a half-life of 2.1 × 10^{11} s. Show that the decay constant of the plutonium is about 3 × 10^{-12} s^{-1}.

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{2.1 \times 10^{11}} = 3.3 \times 10^{-12} /s$$

$$\approx \underline{3 \times 10^{-12}}$$

(2)

(iii) A radioactive source in a school laboratory contains 3.2 × 10^{21} atoms of plutonium. Calculate the energy that will be released in one second by the decay of the plutonium described in part (b)(i).

$$\text{Activity} = \lambda N = 3.3 \times 10^{-12} \times 3.2 \times 10^{21} = 9.6 \times 10^{9}$$

$$= 1.06 \times 10^{10}$$

$$\therefore\ \text{energy} = 1.06 \times 10^{10} \times 1.2\,\mathrm{pJ} = \underline{12.7 \times 10^{-3}\ \mathrm{J}}$$

(3)

=

(iv) Comment on whether the energy release due to the plutonium decay is likely to change by more than 5% during 100 years. Support your answer with a calculation.

$T_{\frac{1}{2}} = 2.1 \times 10^{11}$ s

100 yrs = $100 \times 365 \times 24 \times 60^2$

$= 3.15 \times 10^9$ s

This is 1/100 of a half life so little change

or

$A = A_0 e^{-\lambda t}$

$= 1.06 \times 10^{10} e^{-(3.3 \times 10^{-12} \times 3.15 \times 10^9)}$

$A = 1.049 \times 10^{10} = 1.05 \times 10^{10}$

which is 1 part in 106

(4)

(Total 14 marks)

Mark schemes

1 (a) γ radiation because it is very / the most penetrating

OR

γ radiation because it is penetrating enough to irradiate all sides of the instruments

OR

γ radiation is penetrating so instruments can be sterilised without removing the packaging

✓ OWTTE

The quoted radiation must be gamma only and not a mixture

It is not sufficient to just state 'gamma'. The mark is based on the reason for the choice

1

(b) To become radioactive the nucleus has to be affected which (ionising) radiation does not do

OR

(Ionising) radiation only affects the outer electrons and not the nucleus

OR

The energy of the radiation is insufficient to induce radioactivity. (For this mark high energy is not the same as highly ionizing)

OR

(Ionising) radiation does not affect the nucleus ✓ owtte

1

(c) (Conclusion using the inverse square law $I = k/d^2$)

Make the point that $I \times d^2$ should be constant if the inverse square law is operating ✓ owtte

Show calculations using data from 3 rows

The column may be completed in the following ways ✓

Corrected count rate count s^{-1}	$I \times d^2$ Using I as count rate		$I \times d^2$ Using I ∞ count in 1.0 minute
150	6.00	Or	361
23.3	5.83		349
4.03	4.03		242

Accept 2 sig figs and 1 sig fig in the case of the 4 and 6 in the second column shown here.

The mark is mainly based on the technique used.

The written answer must be enough to indicate a conclusion.

This mark can be gained even if there is a slip in the table.

The conclusion mark can be gained even if the second mark is lost because only two data points are taken.

Look out for different approaches. E.g. use the CCR at one distance to predict the CCR at other distances if the inverse function is followed. E.g. CCR might be in order 9013,1440 and 360.

2

(d) **Mark given for any of these ideas (max 2)**

The random nature of the radiation count (although small in this case)

Dead-time in the G-M detector

d is not the real distance between source and detector **OR** source is not a point source

The source may not be a pure gamma emitter

(Gamma and beta is acceptable but not gamma and alpha together)

A reference to short half-life provided that an explanation of how this has an effect on separate measurements eg activity changes during the measurements

Assumes no absorption between source and detector(although small in this case)
✓✓

No credit for unexplained bland statements such as 'because of systematic errors' ***OR*** *'more data needs to be taken to be certain' etc.*

Note: reference to background count does not gain a mark because the corrected count-rate is supplied in the question.

2

[6]

2 **C**

[1]

3 (a) $(3.0 \times 10^{-10}/24) \times 6.02 \times 10^{23}$ seen✓

(7.52×10^{10})

1

(b) Decay constant = (0.69 / 14.8 h^{-1}) or 1.3 × 10^{-5} s^{-1}✓

A = 1.30 × 10^{-5} × 7.5 × 10^{10} ✓

9.75 × 10^{5} Bq ✓

Allow 2 or 3 sf

Allow use of A = λN with an incorrectly calculated decay constant

3

(c) Activity 3.5 h later should be A = 9.8 × 10^{5} $e^{-0.0466 \times 3.5}$ ✓

8.33 × 10^{5} Bq✓

Volume of liquid = (8.33 × 10^{5} / 3600) × 15 = 3470 cm^{3}✓

3

(d) Estimate gives 3700 compared with 3500✓

Flask has more mass than average / liquid is not water✓

2

[9]

4 **C**

[1]

5 (a) all plots correct to ½ small square
deduct 1 mark for one incorrect, 2 marks for 2+ incorrect

B2

line appropriate

B1

3

(b) one correct determination from correct numbers

B1

154 ± 10 s

B1

two correct determinations and average

B1

3

(c) (use of $A = \lambda N$) $480 = \lambda \times 1.1 \times 10^{-5}$

[allow $\lambda = \ln 2/t_{½}$]

C1

4.4×10^{-3} s^{-1} [4.36]

A1

2

[8]

6 **D**

[1]

7 (a) 236/92/U

B1

4/2/α [4/2/He]

B1

(b) (i) Equation correct **or** Evaluates mass difference

B1

$(1.349 \times 10^{-29}$ kg)
Uses $E = mc^2$

B1

to yield energy (1.21 pJ)

B1

(ii) uses $t_{½} = [\log_e 2/\lambda] = 0.69/2.1 \times 10^{11}$

M1

to yield $\lambda = 3.29 \times 10^{-12}\ s^{-1}$

C1

(iii) uses $A = \lambda N$ $[= 1.05 \times 10^{10}]$ **or** $N_1 = N_0e^{-\lambda t}$

C1

uses $A \times 1.21 \times 10^{-12}$ **or** $(N_0 - N_1) \times 1.21 \times 10^{-12}$

C1

= 12.7 mJ

A1

(iv) $A = A_0 e^{-\lambda t}$

C1

$0.95 = e^{-3.29 \times 10{-}12\, t}$ [or log expression]

C1

$t = 1.56 \times 10^{10}$ s = 495 years

C1

correct deduction from candidate answer

B1

or

100 y = 3.19×10^9 s

C1

$A = A_0 e^{-\lambda t} = 1.056 \times 10^{10}\ e^{-0.0104}$ [ecf from first mark]

C1

$A = 1.046 \times 10^{10}$ [ecf from first mark]

C1

Change is 1 part in 105 OWTTE so no significant change

B1

or

Half life calc/fractional change/2^n/99% left so no sig change

or

further alternative

[14]