A2 Level Physics

Chapter 13 – Nuclear Physics

13.1.2 Radioactivity

Worked Examples

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Nuclear Radiation

Exam Style Question 1

(a) Complete the table below for the three types of ionising radiation.

radiation	nature	range in air	penetration ability
α			0.2 mm of paper
β	electron		
γ		several km	

(b) Describe briefly, with the aid of a sketch, an absorption experiment to distinguish between the three radiations listed above.

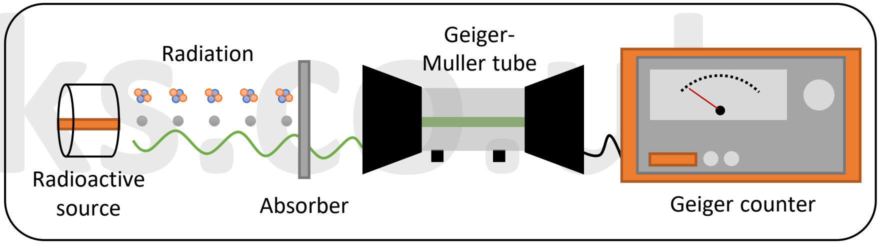
Nuclear Radiation

Exam Style Question 1

(a)Complete the table below for the three types of ionising radiation.

radiation	nature	range in air	penetration ability
α	He nucleus	A few cm/ 3 to 10 cm	0.2 mm of paper
β	electron	About 1 m	1 to 10 mm Al
γ	High energy E-M radiation	several km	Several metres of concrete

(b) Describe briefly, with the aid of a sketch, an absorption experiment to distinguish between the three radiations listed above.



When using a G-M tube to measure radiation from a source, it's important to account for background radiation. Take multiple measurements of background radiation and calculate the average count rate. Then, measure the count rate with the source and with different materials between the source and G-M tube, such as paper and aluminium. Subtract the background radiation count rate from each measurement to get the corrected count rate. Depending on the material used and the decrease in count rate, you can determine the type of radiation emitted by the source.

Nuclear Radiation

Exam Style Question 2

The radioactive nucleus of plutonium $\left({}^{238}_{94}Pu\right)$ decays by emitting an alpha particle $\left({}^{4}_{2}He\right)$ of kinetic energy $5.6 MeV$ with a half-life of $88\ years$. The plutonium nucleus decays into an isotope of uranium.

(a) State the number of neutrons in the uranium isotope.

(b) The mass of an alpha particle is $6.65 \times 10^{-27}\ kg$.

(i) Show that the kinetic energy of the alpha particle is about $9 \times 10^{-13}\ J$.

(ii) Calculate the speed of the alpha particle.

(c) In a space probe, a source containing plutonium-238 nuclei is used to generate $62\ W$ for the onboard electronics.

(i) Use your answer to $(b)(i)$ to show that the initial activity of the sample of plutonium-238 is about $7 \times 10^{13}\ Bq$.

(ii) Calculate the decay constant of the plutonium-238 nucleus.
$1\ year = 3.16 \times 10^{7}\ s$

(iii) The molar mass of plutonium-238 is $0.24\ kg$. Calculate

(1) the number of plutonium-238 nuclei in the source

(2) the mass of plutonium in the source.

Nuclear Radiation

Exam Style Question 2

(a) State the number of neutrons in the uranium isotope.

$$ {}^{238}_{94}Pu \rightarrow {}^{234}_{92}U + {}^{4}_{2}He + (Energy) $$

Therefore:

$$ no.neutrons = 234 - 92 = 142 $$

(b) The mass of an alpha particle is $6.65 \times 10^{-27}\ kg$.

(i) Show that the kinetic energy of the alpha particle is about $9 \times 10^{-13}\ J$.

$$ KE = 5.6\ MeV $$

So convert MeV to Joules:

$$ KE = 5.6\ MeV = 5.6 \times 10^{6} \times 1.6 \times 10^{-19}\ J $$
$$ KE = 8.96 \times 10^{-13}\ J\ (2\ d.p.) $$

(ii) Calculate the speed of the alpha particle.

Use $KE = \frac{1}{2}mv^2$ and rearrange for v:

$$ v = \sqrt{\frac{KE}{\frac{1}{2}m}} = \sqrt{\frac{8.96 \times 10^{-13}\ J}{\left(\frac{1}{2}\right)(6.65 \times 10^{-27}\ kg)}} $$
$$ v = 1.6 \times 10^{7}\ m\ s^{-1}\ (2\ s.f.) $$

(c) In a space probe, a source containing plutonium-238 nuclei is used to generate $62\ W$ for the onboard electronics.

(i) Use your answer to $(b)(i)$ to show that the initial activity of the sample of plutonium-238 is about $7 \times 10^{13}\ Bq$.

$$ activity = \frac{62\ W}{8.96 \times 10^{-13}\ J} $$
$$ activity = 6.92 \times 10^{13}\ Bq\ (2\ d.p.) $$

Nuclear Radiation

Exam Style Question 2

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$1\ year\ =\ 3.16\ \times\ 10^{7}\ s$

(iii) The molar mass of plutonium-238 is $0.24\ kg$. Calculate

(1) the number of plutonium-238 nuclei in the source

(2) the mass of plutonium in the source.

Nuclear Radiation

Exam Style Question 2

(ii) Calculate the decay constant of the plutonium-238 nucleus.
$1\ year\ =\ 3.16\ \times\ 10^{7}\ s$

Use $T_{\frac{1}{2}} = \frac{In(2)}{\lambda}$ and rearrange for λ

$$\lambda = \frac{In(2)}{T_{\frac{1}{2}}} = \frac{In(2)}{88\ years \times 365\ days \times 24\ hours \times 60mins \times 60\ secs}$$

$$\lambda = 2.5 \times 10^{-10}\ s^{-1}\ (2\ s.f.)$$

(iii) The molar mass of plutonium-238 is $\mathbf{0.24\ kg}$. Calculate

(1) the number of plutonium-238 nuclei in the source

Use $A = \lambda N$ and rearrange for N

$$N = \frac{A}{\lambda}$$

$$N = \frac{6.92 \times 10^{13}\ Bq}{2.49 \ldots \times 10^{-10}\ s^{-1}}$$

$$N = 2.78 \times 10^{23}\ (2\ d.p.)$$

(2) the mass of plutonium in the source.

Use $N = \frac{mN_A}{M_A}$ and rearrange for m

$$m = \frac{N\ M_A}{N_A}$$

$$m = \frac{(2.78 \times 10^{23})(0.24\ kg)}{(6.02 \times 10^{23}\ mol^{-1})}$$

$$m = 0.11\ kg\ (2\ s.f.)$$

Nuclear Radiation

Exam Style Question 3

(a) A sample of a radioactive isotope contains 4.5×10^{23} active undecayed nuclei. The half-life of the isotope is $12\ hours$. Calculate

(i) the initial activity of the sample

(ii) the number of active nuclei of the isotope remaining after 36 hours.

(iii) the number of active nuclei of the isotope remaining after 50 hours.

(b) Explain why the activity of a radioactive material is a major factor when considering the safety precautions in the disposal of nuclear waste.

Nuclear Radiation

Exam Style Question 3

(a) Calculate

(i) the initial activity of the sample.

Use $A = \lambda N_0$

But we have the half life therefore use $T_{\frac{1}{2}} = \frac{In(2)}{\lambda}$ so $\lambda = \frac{In(2)}{T_{\frac{1}{2}}}$

$$A = \left(\frac{In(2)}{(12\ hours \times 60\ mins \times 60\ secs)}\right)(4.5 \times 10^{23})$$
$$A = 7.22 \times 10^{18}\ s^{-1}\ (2\ d.p.)$$

(ii) the number of active nuclei of the isotope remaining after 36 hours.

The half life is 12 hours therefore to get to 36 hours we have 3 half lives so divide the original number of undecayed nuclei by two, three times, i.e.:

$$1 \ldots \frac{4.5 \times 10^{23}}{2} = 2.25 \times 10^{23}$$
$$2 \ldots \frac{2.25 \times 10^{23}}{2} = 1.125 \times 10^{23}$$
$$3 \ldots \frac{1.125 \times 10^{23}}{2} = 5.625 \times 10^{22}$$

Therefore the number of active nuclei of the isotope remaining after 36 hours is 5.6×10^{22}.

(iii) the number of active nuclei of the isotope remaining after 50 hours.

Use $N = N_0 e^{-\lambda t}$

Remember to use $\lambda = \frac{In(2)}{T_{\frac{1}{2}}} = \frac{In(2)}{12\ hours}$

$$N = (4.5 \times 10^{23}) e^{-\left(\frac{In(2)}{12\ hours}\right)(50\ hours)}$$
$$N = 2.5 \times 10^{22}$$

Nuclear Radiation

Exam Style Question 3

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(iii) the number of active nuclei of the isotope remaining after 50 hours.

(b) Explain why the activity of a radioactive material is a major factor when considering the safety precautions in the disposal of nuclear waste.

Nuclear Radiation

Exam Style Question 3

(b) Explain why the activity of a radioactive material is a major factor when considering the safety precautions in the disposal of nuclear waste.

Material with a long half life activity will last for a long period hence you need a long term disposal.

OR

Material with a short half life have initial high activity hence precautions needed for initial period of disposal.

Nuclear Radiation

Exam Style Question 4

(a) (i) What is meant by the random nature of radioactive decay?

(ii) Explain what is meant by each of the following.

- isotopes
- radioactive half-life
- radioactive decay constant

(b) The radioactive isotope of iodine ^{131}I has a half-life of $8.04\ days$. Calculate

(i) the decay constant of ^{131}I,

(ii) the number of atoms of ^{131}I necessary to produce a sample with an activity of $5.0\ \times\ 10^4$ disintegrations s^{-1} (Bq),

(iii) the time taken, in hours, for the activity of the same sample of ^{131}I to fall from $5.4\ \times\ 10^4$ disintegrations s^{-1} to $5.0\ \times\ 10^4$ disintegrations s^{-1} .

Nuclear Radiation

Exam Style Question 4

(a)(i) What is meant by the random nature of radioactive decay?
It is not possible to predict when a nucleus will decay. The decay of an atom is a chance event that cannot be accurately predicted.

(ii) Explain what is meant by each of the following.

- Isotopes: are atoms of the same element having the same proton number but a different nucleon number.

-radioactive half-life: The mean time taken for half of the nuclei originally present to decay.

- radioactive decay constant: λ is the probability of decay of a nucleus per unit time. $\frac{dN}{dt} = -\lambda N$.

(b) The radioactive isotope of iodine ^{131}I has a half-life of $8.04\ days$. Calculate

(i) the decay constant of ^{131}I,

Use $\lambda = \frac{In(2)}{T_{1/2}}$

$$\lambda = \frac{In(2)}{8.04\ days \times 24\ hours \times 3400\ seconds}$$

$$\lambda = 9.978279617 \times 10^{-7} \approx 1.0 \times 10^{-6}\ s^{-1}\ (1\ s.f.)$$

(ii) the number of atoms of ^{131}I necessary to produce a sample with an activity of $5.0\ \times\ 10^4$ disintegrations s^{-1} (Bq),

Use $A = \lambda N$ and rearrange for N:

$$N = \frac{A}{\lambda} = \frac{5.0 \times 10^4\ s^{-1}}{1.0 \times 10^{-6}\ s^{-1}}$$

$$N = 5.0 \times 10^{10}$$

Nuclear Radiation

Exam Style Question 4

(a) (i) What is meant by the random nature of radioactive decay?

(ii) Explain what is meant by each of the following.

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- radioactive half-life
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(b) The radioactive isotope of iodine ^{131}I has a half-life of 8.04 $days$. Calculate

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(ii) the number of atoms of ^{131}I necessary to produce a sample with an activity of 5.0×10^4 disintegrations s^{-1} (Bq),

(iii) the time taken, in hours, for the activity of the same sample of ^{131}I to fall from 5.4×10^4 disintegrations s^{-1} to 5.0×10^4 disintegrations s^{-1} .

Nuclear Radiation

Exam Style Question 4

(iii) the time taken, in hours, for the activity of the same sample of ^{131}I to fall from 5.4×10^4 disintegrations s^{-1} to 5.0×10^4 disintegrations s^{-1} .

Use $N = N_0 e^{-\lambda t}$ and rearrange for t

$$5.0 \times 10^4 = (5.4 \times 10^4)e^{-(1.0\times10^{-6})t}$$

$$\frac{5.0 \times 10^4}{5.4 \times 10^4} = e^{-(1.0\times10^{-6})t}$$

$$In\left(\frac{5.0 \times 10^4}{5.4 \times 10^4}\right) = -(1.0 \times 10^{-6})t$$

$$-0.0769610\ldots = -(1.0 \times 10^{-6})t$$

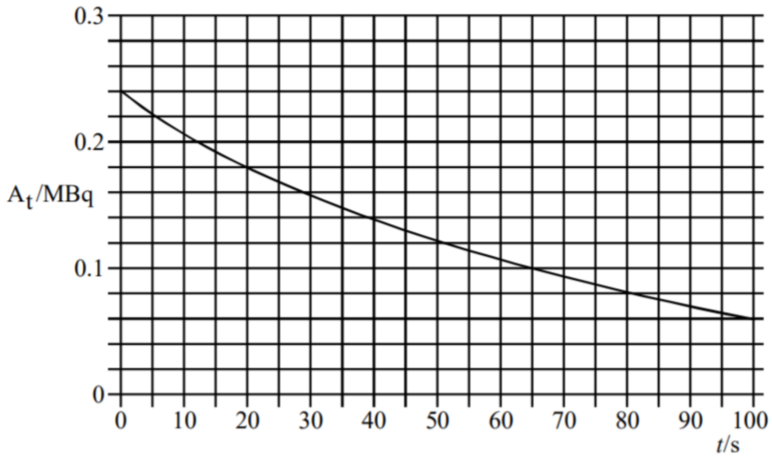
$$t = \frac{-0.0769610\ldots}{-1.0 \times 10^{-6}} = 76961.04\ldots seconds$$

$$t = \frac{76961.04\ldots seconds}{3600\ seconds} = 21.4\ hours\ (3\ s.f.)$$

Nuclear Radiation

Exam Style Question 5

A radioactive nuclide decays by emitting α particles. The graph shows how the rate of decay A of the source changes with time t.



(a) Determine

(i) the half-life of the nuclide,

(ii) the decay constant,

(iii) the initial number of undecayed nuclei present at time $t = 0$.

(b) Each decay releases $1.0 \times 10^{-12}\ J$. For the time interval between $t = 30s$ and $t = 80s$, calculate

(i) the number of nuclei which decay,

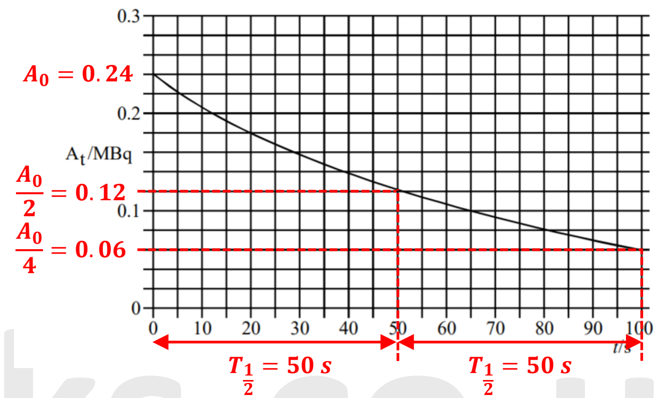
(ii) the energy released.

Nuclear Radiation

Exam Style Question 5

(a)Determine

(i) the half-life of the nuclide,



The half life of the nuclide is 50 s.

(ii) the decay constant,

Use $\lambda = \frac{In(2)}{T_{1/2}}$

$$\lambda = \frac{In(2)}{50\ s} = 0.01386\ldots = 0.014\ s^{-1}\ (2\ s.f.)$$

(iii) the initial number of undecayed nuclei present at time $t = 0$.

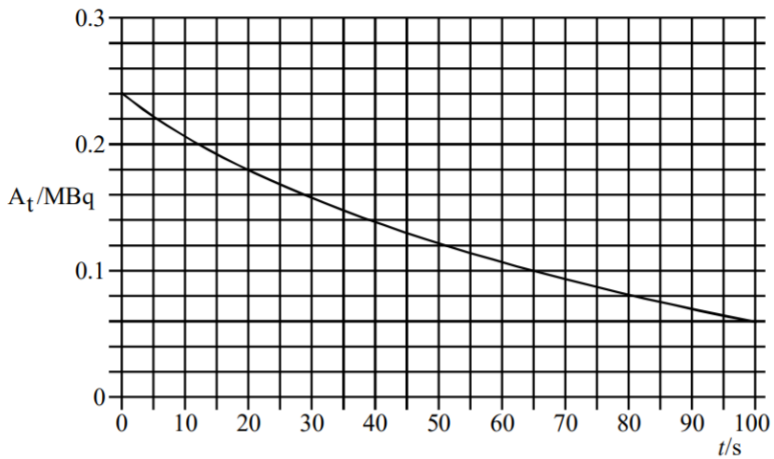
Use $A = \lambda N$ and rearrange for N

$$N = \frac{A}{\lambda} = \frac{0.24 \times 10^6\ Bq}{0.01386\ldots s^{-1}}$$

$$N = 1.7 \times 10^7\ (2\ s.f.)$$

Exam Style Question 5

A radioactive nuclide decays by emitting α particles. The graph shows how the rate of decay A of the source changes with time t.



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(i) the number of nuclei which decay,

(ii) the energy released.

Nuclear Radiation

Exam Style Question 5

(b) Each decay releases $1.0 \times 10^{-12}\ J$. For the time interval between $t = 30s$ and $t = 80s$, calculate

(i) the number of nuclei which decay,

Use $N = N_0 e^{-\lambda t}$

At $t = 30s$: $N_{30} = (1.7 \times 10^7)e^{-(0.01386\ldots)(30)} = 1.12 \times 10^7$

At $t = 80\ s$: $N_{80} = (1.7 \times 10^7)e^{-(0.01386\ldots)(80)} = 5.6 \times 10^6$

Number decayed $= 1.12 \times 10^7 - 5.6 \times 10^6 = 5.6 \times 10^6$

(ii) the energy released.

Energy released = $5.6 \times 10^6 \times 1.0 \times 10^{-12} = 5.6 \times 10^{-6}\ J$

Nuclear Radiation

Exam Style Question 6

(a) A radioactive source gives an initial count rate of $110\ counts\ per\ second$. After $10\ minutes$ the count rate is $84\ counts\ per\ second$.

$background\ radiation\ =\ 3\ counts\ per\ second$

(i) Give three origins of the radiation that contributes to this background radiation.

(ii) Calculate the decay constant of the radioactive source in s^{-1}.

(iii) Calculate the number of radioactive nuclei in the initial sample assuming that the detector counts all the radiation emitted from the source.

(b) Discuss the dangers of exposing the human body to a source of α radiation. In particular compare the dangers when the α source is held outside, but in contact with the body, with those when the source is placed inside the body.

Nuclear Radiation

Exam Style Question 6

(a) (i) Give three origins of the radiation that contributes to this background radiation.

- Cosmic rays
- Ground, rocks and buildings
- Air
- Nuclear weapons testing/nuclear accidents
- Nuclear power
- Discharge/waste from nuclear power
- Medical waste

(a) (ii) Calculate the decay constant of the radioactive source in s^{-1}.

Use $C = C_0 e^{-\lambda t}$ and rearrange for λ

$$(84 - 3) = (110 - 3)e^{-\lambda(10mins \times 60\ seconds)}$$

$$\frac{81}{107} = e^{-\lambda(600\ seconds)}$$

$$In\left(\frac{81}{107}\right) = -\lambda(600\ seconds)$$

$$\lambda = \frac{In\left(\frac{81}{107}\right)}{-600}$$

$$\lambda = 4.63966 \ldots \times 10^{-4} = 4.64 \times 10^{-4}\ s^{-1}\ (2\ d.p.)$$

(a) (iii) Calculate the number of radioactive nuclei in the initial sample assuming that the detector counts all the radiation emitted from the source.

Use $\frac{dN}{dt} = -\lambda N$ and rearrange for N

Remember the initial count rate is $110\ counts\ per\ second$ therefore $\frac{dN}{dt} = 110 - 3 = 107$

$$N = \frac{107}{4.639 \ldots \times 10^{-4}\ s^{-1}} = 2.31 \times 10^{5}\ (2\ d.p)$$

Nuclear Radiation

Exam Style Question 6

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Nuclear Radiation

Exam Style Question 6

(b) Discuss the dangers of exposing the human body to a source of α radiation. In particular compare the dangers when the α source is held outside, but in contact with the body, with those when the source is placed inside the body.

α radiation is highly ionising, hence causes cancer, damage to cells/DNA or even kill cells.
Outside the body, α radiation causes less damage because the α radiation is absorbed by dead skin and so some α's are directed away from the body.
Inside the body the alpha radiation causes more damage because all alphas are absorbed by living tissue and alpha radiation can reach vital organs causing damage.

Nuclear Radiation

Exam Style Question 7

(a) Describe what is meant by the spontaneous and random nature of radioactive decay of unstable nuclei.

(b) Define the decay constant.

(c) Explain the technique of radioactive carbon-dating.

(d) The activity of a sample of living wood was measured over a period of time and averaged to give $0.249\ Bq$. The same mass of a sample of dead wood was measured in the same way and the activity was $0.194\ Bq$. The half-life of carbon-14 is $5570\ years$.

(i) Calculate

(1) the decay constant in y^{-1} for the carbon-14 isotope

(2) the age of the sample of dead wood in years.

(ii) Suggest why the activity was measured over a long time period and then averaged

(iii) Explain why the method of carbon-dating is not appropriate for samples that are greater than 10^5 years old.

Nuclear Radiation

Exam Style Question 7

(a)Describe what is meant by the spontaneous and random nature of radioactive decay of unstable nuclei.

Spontaneous: the decay cannot be induced and occurs without external influence.

Random: Cannot predict when the nucleus will decay.

(b) Define the decay constant.

The probability of decay of a nucleus per unit time.

(c) Explain the technique of radioactive carbon-dating.

Living plants absorb carbon-14.

Once dead, the plant does not take any more carbon-14.

Therefore, the activity of carbon-14 in the plant starts to fall, with a half-life of around 5730 years.

You can then test to find the current amount of carbon-14 in them, and date them.

$x = x_0 e^{-\lambda t}$ is used with the data above to estimate the age.

(d) (i) Calculate:

(1) the decay constant in y^{-1} for the carbon-14 isotope.

Use $\lambda = \frac{In\ (2)}{T_{1/2}}$

$$\lambda = \frac{In(2)}{5570}$$

$$\lambda = decay\ constant = 1.24 \times 10^{-4}\ y^{-1}$$

(2) the age of the sample of dead wood in years.

Use $A = A_0 e^{-\lambda t}$ and rearrange for t

$$0.194 = 0.249 e^{-(1.24\times10^{-4})t}$$

$$\frac{0.194}{0.249} = e^{-(1.24\times10^{-4})t}$$

$$In\left(\frac{0.194}{0.249}\right) = -(1.24 \times 10^{-4})t$$

$$-0.24959\ldots = -(1.24 \times 10^{-4})t$$

$$t = \frac{-0.24959\ldots}{-1.24 \times 10^{-4}} = 2012.86\ldots = 2.0 \times 10^3\ years\ (1\ s.f.)$$

Exam Style Question 7

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(c) Explain the technique of radioactive carbon-dating.

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(ii) Suggest why the activity was measured over a long time period and then averaged

(iii) Explain why the method of carbon-dating is not appropriate for samples that are greater than 10^5 years old.

Nuclear Radiation

Exam Style Question 7

(ii) Suggest why the activity was measured over a long time period and then averaged.

The activity Is very small and the decay is random.

(iii) Explain why the method of carbon-dating is not appropriate for samples that are greater than 10^5 years old.

Activity is so low that it cannot be differentiated from the background.

Please see '13.1.1 Radioactivity notes' pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.