Physics Department

Nuclear Physics Questions

Nuclear Physics Questions

RADIOACTIVITY AND THE NUCLEUS

1. Define i) atomic number ii) mass number for an atom.
   In what ways are isotopes of an element i) similar ii) different?

2. The nuclear radiation from a source is investigated by a student using a counter which can detect alpha , beta and gamma radiation. The student first notes the count rate when the source in not present.
   a) What is the counter detecting and why does the student do this?
   b) When the counter is placed close to the source a high count rate is observed. When a piece of paper is placed between the source and counter there is very little change in count rate. Explain what deduction can be made about the radiation emitted by the source.
   c) It is found that the count rate is reduced to half its original value when a thin sheet of low density material is placed between the source and counter. Name the radiation being heavily absorbed by the thin metal sheet and explain another way of checking that the source emits that radiation.

3. Of the three types of radiation alpha, beta and gamma emitted by a radioactive source, which
   i) travels at greatest speed in air
   ii) consists of helium nuclei
   iii) forms thick straight tracks in cloud chamber?

4. The following count rates were noted when a G M tube attached to a scaler was placed at various distances from a source in air

Distance / mm	5	10	15	20	25	30	35	40
Count rate / min	500	330	230	150	100	20	2	2

   a) What is the approximate range of the particles?
   b) Name the most probable type of radiation and give a necessary property of the detector.
   c) Explain why the count rate becomes constant but never drops to zero.

5. A beta source is placed 0.2m from the window of a GM tube which is attached to a counter. Aluminium plates of various standard thicknesses are placed between the source and the detector and the count rate measured. The background count was 23 counts per minute.

Count rate/min	974	933	644	478	435	340
Thickness /mm	0.65	1.50	3.80	6.50	8.30	10.80

   a) Why should the distance be kept constant at 0.2 m ?
   b) Plot a graph and estimate the count rate when there is no plate between the source and detector.
   c) If a permissible count rate of 30 per minute is allowed, what thickness of aluminium shield should be used to enclose the source?
   d) If the source and detector were placed in an evacuated chamber, would there be any noticeable difference in the results?

6. A beam of mono-energetic gamma rays is partially absorbed by a sheet of lead and passes into a GM tube connected to a scaler. The table shows the corrected count rate which is observed for different thicknesses of lead absorber.

Thickness / mg cm^{-2}	0	5	10	15	20	25	30
Corrected count rate /s	870	650	490	370	280	210	160

Determine the thickness of absorber which is required to reduce the intensity to one half.

7. A counter registers the count rate for a gamma source in air.

Count rate / min	1620	420	120	84
Distance/ m	0.5	1.0	2.0	2.5

Background count = 20 counts per minute

a) Plot a graph of corrected count rate against distance.
b) Plot a graph which shows gamma ray absorption obeys an inverse square law.
c) At what distance will the counter register 200 counts per minute?

8. Radioactive substances X and Y contain originally the same number of particles. X has a half life of 10 min and Y of 5 min. What is the ratio of their rates of disintegration a) initially b) after 10 min c) after 20 min?

9. The half life of ${}^{246}_{90}Cf$ is 1.5 days. If a freshly prepared sample contains 10^{10} atoms, how many remain undecayed at the end of 15 days?

10. The half life of X is 4 hours. After 16 hours what percentage of X remains?

11. A gas emitting alpha particles is placed in an ionisation chamber and gives a reading of 860 μA soon after the gas is introduced and 180μA after a further 2 min 45 sec. What is its estimated half life?

12. A pure sample of ${}^{14}_{6}C$ emits 3.2×10^5 beta particles each second. After what time will the rate of emission fall to below 1.0×10^4 /s? (Half life of ${}^{14}_{6}C$ = 5500 years)

13. Living organisms absorb radioactive carbon ${}^{14}_{6}C$ and there is no further uptake after death. Due to the presence of this isotope, which has a half life of 5500 years, samples of bones from an archaeological site were found to have an average activity of 26 units. Recent skeletons gave an activity of 32.6 units. Estimate the age of the specimen of bones.

14. If ${}^{238}_{92}U$ emits 8 alpha and 6 beta particles in the course of its decay series what will be the atomic number and mass number of the final isotope produced?

15. If ${}^{214}_{83}Ra$ eventually becomes ${}^{206}_{82}Pb$. How many Alpha and beta particles are produced in the process?

1 Cobalt-60 has a half-life of 5.3 year. When fresh, a particular source has 5.0×10^{20} atoms of cobalt-60. It is useful until the activity has fallen below 1.5×10^{12} Bq.

(a) What is meant by an activity of 1 Bq?

(b) Draw a graph showing the number of radioactive atoms over a period of three half lives.

(c) Determine the decay constant of cobalt-60.

(d) After what time will it be necessary to replace the source?

2 Radiocarbon dating is possible because of the presence of radioactive carbon-14 ($^{14}_{6}C$) caused by the collision of neutrons with nitrogen-14 ($^{14}_{7}N$) in the upper atmosphere. The equation for the reaction is:

$$^{14}_{7}N + ^{1}_{0}n = ^{14}_{6}C + X$$

The half-life of carbon-14 is 5.7×10^{3} years.

(a) (i) What are the proton and nucleon numbers of the particle shown as X in the above equation.

(ii) Identify the particle X.

(b) The mass of carbon-14 produced by this reaction in one year is 7.5 kg. 14 g of carbon-14 contains 6.0×10^{23} atoms.

(i) Find the number of carbon-14 atoms produced each year.

(ii) Calculate the decay constant of carbon-14 in year^{-1}.

(iii) Assuming that the number of carbon-14 atoms in the Earth and its atmosphere remains constant, then the number that decay each year is the same as the answer to **(i)**. Use this fact and your answer to **(ii)** to calculate the number of carbon-14 atoms in the Earth and its atmosphere.

(c) A sample of wood (containing carbon-14) from a tree that has recently been chopped down has an activity of 0.80 Bq. A sample of a similar size from an ancient boat had an activity of 0.30 Bq.

(i) Draw a graph to show how the activity of carbon-14 in the sample having an initial activity of 0.80 Bq will vary over a period of three half-lives.

(ii) Use the graph to estimate the age of the boat.

(iii) Explain why an activity of 0.80 Bq would be hard to measure in the school laboratory.

1 Calculate the mass changes and energy released for the following fission.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{148}_{57}La + ^{85}_{35}Br + 3^{1}_{0}n$$

2 (a) Deduce how many neutrons will be released in the fission below.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + x^{1}_{0}n$$

(b) Calculate the mass change and energy released for the fission.

Mass of neutron = 1.009 u

mass of $^{235}_{92}U$ = 235.124 u

mass of $^{148}_{57}La$ = 147.961 u

mass of $^{85}_{35}Br$ = 84.938 u

mass of $^{141}_{56}Ba$ = 140.914 u

1 Check whether the following fusion reactions are possible. If they are, determine the energy yield per reaction in MeV:

(a) $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He$

(b) $^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2^{1}_{1}H$

(c) $^{7}_{3}Li + ^{2}_{1}H \rightarrow ^{9}_{4}Be$.

Use the following masses:

$^{2}_{1}H$ = 2.0141 u

$^{1}_{1}H$ = 1.0079 u

$^{4}_{2}He$ = 4.0026 u

$^{3}_{2}He$ = 3.0160 u

$^{7}_{3}Li$ = 7.0160 u

$^{9}_{4}Be$ = 9.0122 u.

2 Calculate the energy release for the complete fusion of one mole of $^{2}_{1}H$ in the reaction below.

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

(The Avagadro number is $6.0 \times 10^{23}\ \text{mol}^{-1}$.)

3 Explain, in terms of the binding energy curve, why the fusion of iron nuclei could not be the basis for energy production.

4 Investigate and report on the common fusion reactions that occur in the Sun.

1 (a) Uranium-238 decays by alpha emission to thorium-234. The table shows the masses of the nuclei of uranium-238 ($^{238}_{92}U$), thorium-234 and an alpha particle (helium-4).

Table 5.9

Element	Nuclear mass/u
Uranium-238	238.0002
Thorium-234	233.9941
Helium-4, alpha particle	4.0015

(i) How many neutrons are there in a uranium-238 nucleus?

(ii) How many protons are there in a nucleus of thorium?

(b) (i) Determine the mass change in kg when a nucleus of uranium-238 decays by alpha emission to thorium-234.

(ii) Determine the increase in kinetic energy of the system when a nucleus of uranium-238 decays by alpha emission to thorium-234.

2 (a) Calculate the mass change in kg when a tritium ($^{3}_{1}H$) nucleus is formed from its constituent parts.

Mass of

tritium nucleus = 3.016050 u

Mass of proton = 1.007277 u

Mass of neutron = 1.008665 u

Atomic mass unit, u = 1.660566×10^{-27} kg

Speed of light = $3.0 \times 10^{8}\ \text{m s}^{-1}$

(b) Calculate the binding energy, in J, of the tritium nucleus.

16. Write down nuclear equations for the following radioactive disintegrations:

i) Uranium $^{238}_{92}U$ decays by alpha emission to an isotope of thorium (Th).

ii) Lead $^{210}_{82}$ Pb decays by beta emission to an isotope of Bismuth (Bi).

iii) Gold $^{203}_{80}$Au decays by beta emission to an isotope of mercury (Hg).

iv) Radon $^{222}_{86}$Rn decays by alpha emission to an isotope of Polonium (Po).

17. In the nuclear reactor the following reaction takes place

$$^{235}_{92}U \quad + \quad ^{1}_{0}n \quad = \; ^{236}_{92}U$$

The U formed is unstable and disintegrates, with the release of 2 or 3 neutrons and a considerable amount of energy.

a) What do the numbers 236 and 92 represent?

b) Use the information given above to explain what is meant by a chain reaction.

c) What are moderators? Why are they necessary in a nuclear reactor?

d) What is the source of energy in the above reaction?

e) How is the heat removed from the core of the reactor and how is this heat used to generate electricity?

18. a) What is nuclear fusion?

b) Which fusion reaction is most likely to be used in a nuclear fusion reactor?

c) Why is it proving difficult to achieve these nuclear reactions?

19. a) What is an alpha particle?

b) What is its charge?

c) what is its relative mass?

d) The model of atomic structure known as the nuclear atom was developed as a result of alpha particle scattering experiments.

i) State what was observed when a very thin metal foil was bombarded with alpha particles.

ii) Explain how these observations suggest that the positive charge and mass of an atom is concentrated in a very small nucleus occupying a tiny fraction of the total volume of an atom.

20. a) What is meant by i) radioactive half life ii) decay constant? State the relationship between these two quantities.

b) A pure radioactive sample contains initially 2.0×10^{21} atoms, the half life being 25 years. If, on the decay of each atom , 4.7 MeV of energy is produced, calculate

i) the total energy, in J, produced in a period of 30 years,

ii) the initial rate of production of energy. (1 MeV = 1.6×10^{13} J)

c) A quantity of highly active waste consists of two radioactive isotopes, A and B, in roughly equal proportions. A emits beta particles and gamma rays, the half life being 20 days; B emits alpha particles; the half life being 20 years. Outline the physical problems of storing the waste for a long period of time and discuss briefly the effects this might have on the surrounding environment.

Fisson Questions

1. In a reactor a nucleus of the uranium isotope ${}^{235}_{92}U$ undergoes fission whe it absorbs a neutron ${}^{1}_{0}n$. One possible pair of products is ${}^{90}_{36}K$ and ${}^{143}_{56}Ba$.

   a) i) Write an equation for this reaction showing all the particles produced.
   ii) Explain with the aid of a diagram, how a chain reaction is produced.

   b) Fission occurs with neutrons of kinteic energy 0.025eV.
   i) Express 0.025eV in joules.
   ii) Determine the speed of the 0.025eV neutrons.

2. Nuclear fission in the uranium isotopes U – 238 and U – 235 is caused by neutron bombardment.

   a) i) State the principal features of nuclear fission.

   ii) State one similarity and one difference between the nuclei of U – 238 and U – 235.

   b) A free neutron decays by β-emission. Write a nuclear equation for this reaction.

   c) Free neutrons have a half life of 12 minutes. Determine their decay constant in s^{-1}.

3. Deuterium $({}^{2}_{1}H)$ and tritium $({}^{3}_{1}H)$ nuclei will fuse together, as illustrated in the equation below:

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{A}_{Z}X + neutron $$

   a) State the nucleon number and the proton number fot the product of the reaction which has been written as X in the equation.

   Nucleaon number ……………………..

   Proton number ………………………….

   b) The masses of the particles involved in the reaction are:

Mass of ${}^{2}_{1}H$	= 3.34250 x 10^{-27} kg
Mass of ${}^{3}_{1}H$	= 5.00573 x 10^{-27} kg
Mass of ${}^{A}_{Z}X$	= 6.62609 x 10^{-27} kg
Mass of neutron	= 1.67438 x 10^{-27} kg

   i) Explain why energy is released during this reaction.
   ii) Calculate the amount of energy released when a deuterium nucleus fuses with a tritium nucleus.

Q1. A nuclide of manganese $\left({}^{52}_{25}Mn\right)$ undergoes beta$^+$ decay to form a nuclide of chromium (Cr).

(a) Complete the equation for this decay process.

$$ {}^{52}_{25}Mn \rightarrow {}^{.....}_{24}Cr + {}^{........}_{........}\beta^{+} + {}^{........}_{........} $$

(2)

(b) State the name of the exchange particle involved in this beta$^+$ decay.

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(1)
(Total 3 marks)

Q2. (a) An unstable nucleus, ${}^{A}_{Z}X$, can decay by emitting a β⁻ particle.

(i) What part of the atom is the same as a β⁻ particle?

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(1)

(ii) State the changes, if any, in *A* and *Z* when X decays.

change in *A* ....

change in *Z* ....

(2)

(b) In the process of β⁻ decay an *anti-neutrino* is also released.

(i) Give an equation for this decay.

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(1)

(ii) State and explain which conservation law may be used to show that it is an *anti-neutrino* rather than a *neutrino* that is released.

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(2)

(iii) What must be done to validate the predictions of an unconfirmed scientific theory?

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(2)
(Total 8 marks)

Q3.(a) The unstable uranium nucleus $^{236}_{92}U$ is produced in a nuclear reactor.

(i) Complete the equation which shows the formation of $^{236}_{92}U$.

$$+ \qquad \rightarrow \ ^{236}_{92}U$$

(ii) $^{236}_{92}U$ can decay by nuclear fission in many different ways. Complete the equation which shows one possible decay channel.

$$^{236}_{92}U \rightarrow \ ^{145}_{56}Ba \ + \qquad + \ 4^{1}_{0}n$$

(2)

(b) Calculate the energy released, in MeV, in the fission reaction.

atomic mass of $^{145}_{56}Ba$ = 144.92694 u

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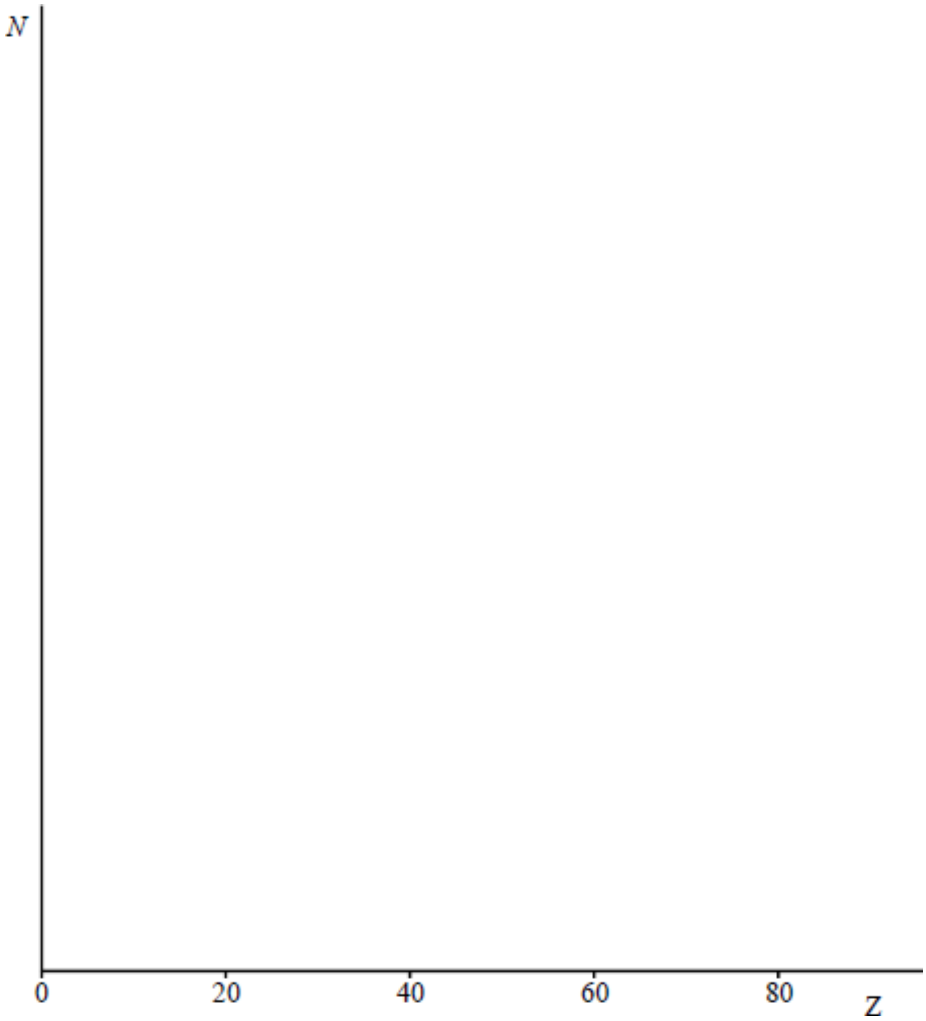
(3)
(Total 5 marks)

Q4.(a) Sketch a graph to show how the number of neutrons, N, varies with the number of protons, Z, for stable nuclei over the range Z = 0 to Z = 80. Draw a scale on the N axis.



(2)

(b) On the same graph, enclosing each region by a line, indicate the region in which nuclides are likely to decay, by

(i) α emission, labelling the region A,

(ii) β^- emission, labelling the region B,

(iii) β^+ emission, labelling the region C.

(3)

(c) Complete the table.

mode of decay	change in proton number Z	change in neutron number N
α emission	−2	
β^- emission		
β^+ emission		
e capture		
p emission		0
n emission	0	

(3)
(Total 8 marks)

Q5. Natural uranium consists of 99.3% $^{238}_{92}U$ and 0.7% $^{235}_{92}U$. In many nuclear reactors, the fuel consists of enriched uranium enclosed in sealed metal containers.

(a) (i) Explain what is meant by *enriched uranium*.

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(ii) Why is enriched uranium rather than natural uranium used in many nuclear reactors?

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(2)

(b) (i) By considering the neutrons involved in the fission process, explain how the rate of production of heat in a nuclear reactor is controlled.

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(ii) Explain why all the fuel in a nuclear reactor is **not** placed in a single fuel rod.

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(5)
(Total 7 marks)

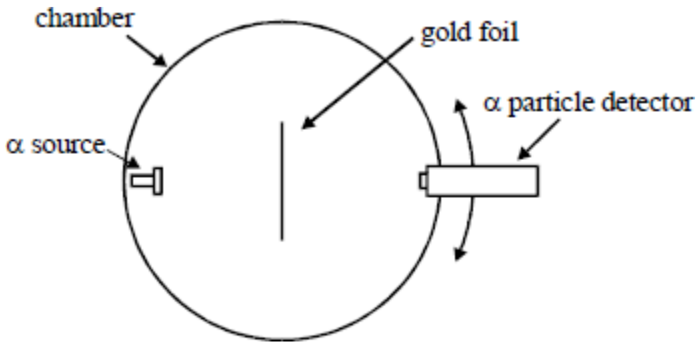
Nuclear Comprehension Question

In an early model, the atom was imagined as a sphere of positive charge with negatively charged electrons dotted around inside, rather like plums in a pudding. An experiment was carried out in 1905 to support this 'plum pudding' model of the atom but the results were unexpected.

Rutherford designed an experiment to test the plum pudding model. It was carried out by his assistants Geiger and Marsden. A beam of alpha particles was aimed at very thin gold foil and their passage through the foil detected. The scientists expected the alpha particles to pass straight through the foil but something else also happened.

Some of the alpha particles emerged from the foil at different angles and some even came straight back. The scientists realised that the positively charged alpha particles were being repelled and deflected by a tiny concentration of positive charge in the atom. As a result of this experiment, the plum pudding model was replaced by the nuclear model of the atom.

Q. The diagram below shows the apparatus used to investigate Rutherford scattering, in which α particles are fired at a gold foil.



(a) Why is it essential for there to be a vacuum in the chamber?

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(2)

(b) What observations made with this apparatus support each of the following conclusions? No explanation is required.

(i) The nuclear radius of gold is much smaller than its atomic radius.

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(ii) Most of the mass of an atom of gold is contained in its nucleus.

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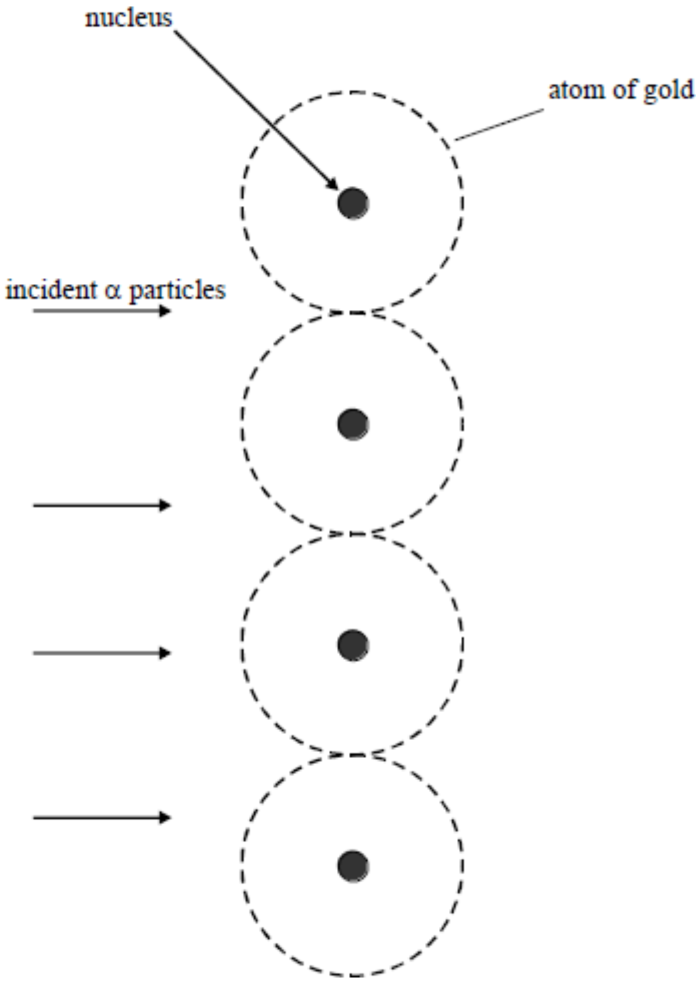
(3)

(c) The drawing below shows α particles incident on a layer of atoms in a gold foil.

On this figure draw the complete path followed by **each** of the α particles shown.



(3)
(Total 8 marks)

Q1. (a) $^{212}_{83}$Bi can decay into $^{208}_{82}$Pb by a β- followed by an α decay, or by an α followed by a β- decay. One or more of the following elements is involved in these decays:

$_{80}$Hg , $_{81}$Tl , $_{84}$Po , $_{85}$At .

Write out decay equations showing each stage in both of these decays.

First decay path	**Second decay path**

(6)

(b) (i) Describe how you would perform an experiment that demonstrates that gamma radiation obeys an inverse square law.

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(ii) Explain why gamma radiation obeys an inverse square law but alpha and beta radiation do not.

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(9)
(Total 15 marks)

Q2. (a) (i) Explain why, despite the electrostatic repulsion between protons, the nuclei of most atoms of low nucleon number are stable.

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(ii) Suggest why stable nuclei of higher nucleon number have greater numbers of neutrons than protons.

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(iii) All nuclei have approximately the same density. State and explain what this suggests about the nature of the strong nuclear force.

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(6)

(b) (i) Compare the electrostatic repulsion and the gravitational attraction between a pair of protons the centres of which are separated by 1.2×10^{-15} m.

proton charge	=	1.6×10^{-19} C
proton mass	=	1.7×10^{-27} kg
gravitational constant	=	6.7×10^{-11} N m^{2} kg^{-2}
permittivity of free space	=	8.9×10^{-12} F m^{-1}

(ii) Comment on the relative roles of gravitational attraction and electrostatic repulsion in nuclear structure.

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(5)
(Total 11 marks)

A2-2012 Q1

When a satellite is launched to a distant planet, a radioisotope thermoelectric generator (RTG) is used to provide electrical power for the satellite. This consists of a decaying radioactive source producing heat which can then be converted to electrical power. NASA is allowed to launch with a maximum 25 kg mass of plutonium dioxide (PuO_2) on a single satellite, but it never uses the maximum.

a) Pu-238 itself alpha decays and NASA quotes the *specific activity* of the radioactive PuO_2 as 17 Cu/g, where 1 curie (Cu) is 3.7×10^{10} decays per second. Calculate the number of alphas released per second from 1 g of PuO_2.

b) If the plutonium emits 5.5 MeV alphas, how many watts of power per gram are released by the radioactive source? This quantity is known as the *power density*.

c) At launch, 4.5 kW of heat power are required from the source. What mass of radioactive PuO_2 is required?

d) If the conversion efficiency from thermal to electrical energy is 7%, what electrical power will this supply initially?

e) Why are solar panels not used for satellites travelling to distant planets?

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

(6 marks)

Radioactivity.

Pg 3 1, same p's different n's, 3, γ, α, α.

Pg 4

8, =1:2, 1:1, 2:1

9, 9.76×10^6

10, $\frac{1}{16}$ or 6.25 %

11, 1 min 12 sec

12, 27,500 yrs

13, 1800 yrs

14, 82, 206

15, 3β, 2α

Pg 6

16, $^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}\alpha$

$^{210}_{82}Pb \rightarrow ^{210}_{83}Bi + ^{0}_{-1}\beta$

$^{203}_{80}Au \rightarrow ^{203}_{81}Hg + ^{0}_{-1}\beta$

$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}\alpha$

18, $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He$ time at high enough temp.

19, He nuclei, 2 e charges, 4 a.m.u.

20, $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$, 8.5×10^8 J, 1.29W

1 (a) See Module 2
(c) 0.13 $year^{-1}$ or $4.1 \times 10^{-9}\ S^{-1}$
(d) 2.5 year

2 (a) (i) Proton number is 1; nucleon number is 1
(ii) Proton
(b) (i) 3.2×10^{26}
(ii) $1.2 \times 10^{-4}\ year^{-1}$
(iii) 2.6×10^{30}
(c) (ii) 8000 year

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1 0.207 u; 193 MeV

2 (a) 3 (b) 0.266 u; 247 MeV

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1 (a) Yes: 24 MeV (b) Yes: 13 MeV
(c) Yes: 17 MeV

2 1.1×10^{12} J

3 See page 119

4 Arguments related to low count rate in comparison to background.

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1 (a) (i) 146 (ii) 90
(b) (i) 7.6×10^{-30} kg (ii) 6.9×10^{-13} J

2 (a) 1.42×10^{-29} kg (b) 1.28×10^{-12} J

Page 18

1

	ΔU/kJ	Q/kJ	W/kJ
A	200	100	100
B	0	50	−50
C	−50	−300	250
D	120	520	−400

2 (a) C (b) B and D
(c) A, B and D

1 160 J. Work is done by the gas.

2 (a) 30 J of work done on the gas.
(b) 30 J of work done by the gas.
(c) 25 J of work done by the gas.
(d) 0 No change in volume so gas neither does work nor has work done on it.

3 (a) 10.5 J (b) energy input
(c) refrigerator

Page 12

1 3.1×10^{-24} Ns

2 3.9×10^{24}

3 3.4×10^{25}

4 (a) (i) 6.2×10^{-21} J (ii) 2.1×10^{-20} J
(b) (i) 480 m s^{-1} (ii) 890 m s^{-1}

5 250 m s^{-1}

6 (a) 2.2×10^5 K
(b) Molecules have a range of speeds at a given temperature. Some molecules will have this speed at lower temperatures.

7 (a) B
(b) 18.1 K (32.9 K − 14.8 K)

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1 (a) 143 kJ (b) 3.45 MJ
(c) 165 W

2 (a) 1650 s
(b) Some energy from the ring is used directly to heat the air in the room. When the pan is above room temperature it will transfer energy to heat the surroundings.

3 350 m s^{-1}

4 0.052 kg

5 6.1 kW

6 (a) 7.8 K
(b) Energy lost to air as it falls: energy shared with the ground on landing.

7 5500 s (approximately 90 minutes)

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1 17 000 J

2 380 000 J

3 2800 J kg^{-1} K^{-1}

4 250 s

① $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{36}Kr + ^{143}_{56}Ba + 3 \times ^{1}_{0}n$

4×10^{-21} J, 2.2×10^{3} $m s^{-1}$

② $^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}\beta + \bar{\nu}_e$ $\lambda = 9.63 \times 10^{-4}$ s^{-1}

③ $A = 4$, $Z = 2$ before 8.348×10^{-27} kg energy =
after 8.300×10^{-27} kg 4.3×10^{-12} J

Basic Exam Question Answers

A1. (a) correct numbers for beta+ (0, (+)1) and chromium (52) B1

(electron) neutrino with correct numbers (0,0) B1 **2**

(b) W+/W/(intermediate vector) boson (not Z boson) B1 **1**

[3]

A2. (a) (i) an electron **(1)** **1**

(ii) change in *A* = 0 **(1)**

change in *Z* = +1 **(1)** **2**

(b) (i) $^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}e + \overline{\nu_e}$ **(1)**

or $n \rightarrow p + e^- + \overline{\nu_e}$

or $d \rightarrow u + e^- + \overline{\nu_e}$ **1**

(ii) lepton number must be conserved **(1)**

lepton number before decay equals zero

hence after decay lepton number of electrons cancels with lepton number of anti-neutrino **or** zero on both sides **(1)**

2

(iii) hypothesis needs to be tested by experiment **(1)**

experiment must be repeatable **(1)**

or hypothesis rejected

2

[8]

A3.(a) (i) ${}^{1}_{0}n + {}^{235}_{92}U > {}^{236}_{92}U$ **(1)**

(ii) ${}^{235}_{92}U \rightarrow {}^{145}_{56}Ba + {}^{87}_{36}Kr + 4{}^{1}_{0}n$ **(1)**

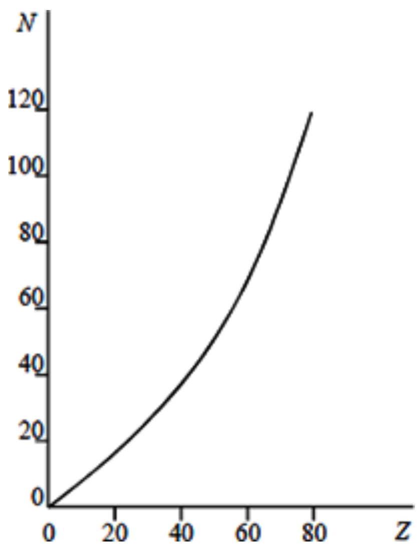
(2)

(b) ($\Delta m = m_u - m$Ba $- m$Kr $- 4m_n$, electron masses balance)
Δm = 236.04573 – 144.92694 – 86.91340 – 4 × 1.00867 **(1)**
= 0.17071 u **(1)**
Q (= 0.17071 × 931.3 MeV) = 159(MeV) **(1)**

(3)

[5]

A4.(a)



straight line between (Z = 0, N = 0) to (Z = 20, N = 20) **(1)**
curving upwards to Z = 80; N = 110 – 130 **(1)**

(2)

(b) (i) A = any region below the line of stability but $N > 80$ and $Z > 60$

(ii) B = any region above and close to the line of stability **(1)**

(iii) C = any region below and close to the line of stability **(1)**

(3)

(c)

mode of decay	change in proton number, Z	change in neutron number, N
α emission	–2	–2
β^- emission	+1	–1
β^+ emission	–1	+1
e capture	–1	+1
p emission	–1	0
n emission	0	–1

(1)(1) (1) – lose one mark for each row in error

(3)

[8]

M5.(a) (i) proportion of U-235 is greater than in natural uranium **(1)**

(ii) induced fission more probable with U-235 than with U-238 **(1)**

2

(b) (i) for steady rate of fission, one neutron per fission required to go on to produce further fission **(1)**
each fission produces two or three neutrons on average **(1)**
some neutrons escape [or some absorbed by U-238 without fission] **(1)**
control rods absorb sufficient neutrons (to maintain steady rate of fission) **(1)**

(ii) neutrons need to pass through a moderator **(1)**
to slow them (in order to cause further fissions or prevent U-238 absorbing them) **(1)**
neutrons that leave the fuel rod (and pass through the moderator) are unlikely to re-enter the same fuel rod **(1)**
makes it easier to replace the fuel in stages **(1)**

max 5

[7]

Nuclear Comprehension Answers

A (a) to prevent the α particles being absorbed or scattered **(1)**
by air molecules **(1)**

(2)

(b) (i) little or no deflection **(1)**
by a majority of α particles **(1)**

(ii) some α particles suffer large deflection
[or backscattering occurs] **(1)**

(3)

(c) **first** path continues undeflected **(1)**
third path shows backscattering (inside the dotted circle) **(1)**
second path undeflected or deflected downwards and
fourth path undeflected or deflected upwards **(1)**

(3)

[8]

Extended Writing Answers

A1. (a) number correct for alpha **(1)**

number correct for beta **(1)**

alpha decay first goes via Tl **(1)**

numbers correct for Tl (208, 81) **(1)**

beta decay first goes via Po **(1)**

numbers correct for Po (212, 84) **(1)**

6

(b) (i) use of GM tube + counter/rate-meter **(1)**
measurement of count rate **(1)**
at range of distances + suitable ruler or tape measure **(1)**
specifies suitable range **(1)**
determines background & corrects **(1)**
safety precaution given **(1)**
graph of count rate or corrected count rate against $1/d^2$ **(1)**

max 6

(ii) gamma not absorbed **(1)**
spreads uniformly from a point
source/spherically symmetrically **(1)**
area over which it spreads is proportional
to radius squared **(1)**
alpha and beta are absorbed in addition to spreading out **(1)**

max 3

[15]

A2. (a) (i) strong nuclear force acts on all nucleons/both forces act on
protons/mention of gluons as force carrier B1

strong nuclear force > electrostatic repulsion

B1

(ii) neutrons spread the protons out/neutrons reduce electrostatic repulsion

B1

(iii) strong nuclear force has short range

M1

if snf fell off more gradually bigger nuclei would have lower densities/…more rapidly still higher densities

A1

strong nuclear force acts on all nucleons

M1

attractive nature of snf means all nucleons in contact/close packed

A1

strong nuclear force becomes repulsive at very small separations

M1

prevents nuclei from becoming denser

A1

needs minimum of two M1s to score all three here

max 6

(b) (i) $F_E \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ or $F_E \propto k\frac{Q_1 Q_2}{r^2}$ with *k* defined

C1

1.59×10^{2} N

A1

$F_G = G\frac{m_1 m_2}{r^2}$

C1

1.3×10^{-34} N

A1

(ii) can ignore gravitation when considering nuclear forces **or** gravitational force is much weaker than electrostatic force **not** e.c.f.

B1

5

[11]

Question 1

(a) $17 \times 3.7 \times 10^{10} = 6.3 \times 10^{11}$ decays per second ✓ [1]

(b) $6.3 \times 10^{11} \times 5.5 \times 10^{6} \times 1.6 \times 10^{-19} = 0.55$ W per g ✓✓
Mark lost for incorrect order of magnitude [2]

(c) Mass required = 4,500 ÷ 0.55 = 8,100 g = 8.1 kg ✓ [1]

(d) 4,500 W x 0.07 = 315 W ✓ [1]

(e) Satellites far from the sun receive too little power / area of panels would need to be too great / intensity of solar radiation is too low owtte* ✓ [1]

[Q1: 6 marks]