AQA A-LEVEL PHYSICS · 7408

PHYSICS



EXAM QUESTION PACK

3.8.1.4 NUCLEAR INSTABILITY

SCORE	PERCENTAGE
/55	%

STEMUP

These questions belong to AQA, not to us.

The examination questions, mark schemes and examiner reports in this pack were written and published by AQA. They are past assessment materials, reproduced here so that students can revise from them.

What we do not own

STEMUP is not affiliated with AQA and does not own, and makes no claim to own, any of the question, mark scheme or examiner report material in this pack. AQA has not endorsed, approved or been involved in the production of it. AQA and the qualification titles used here belong to their respective owners and appear for identification only.

Where to find the originals

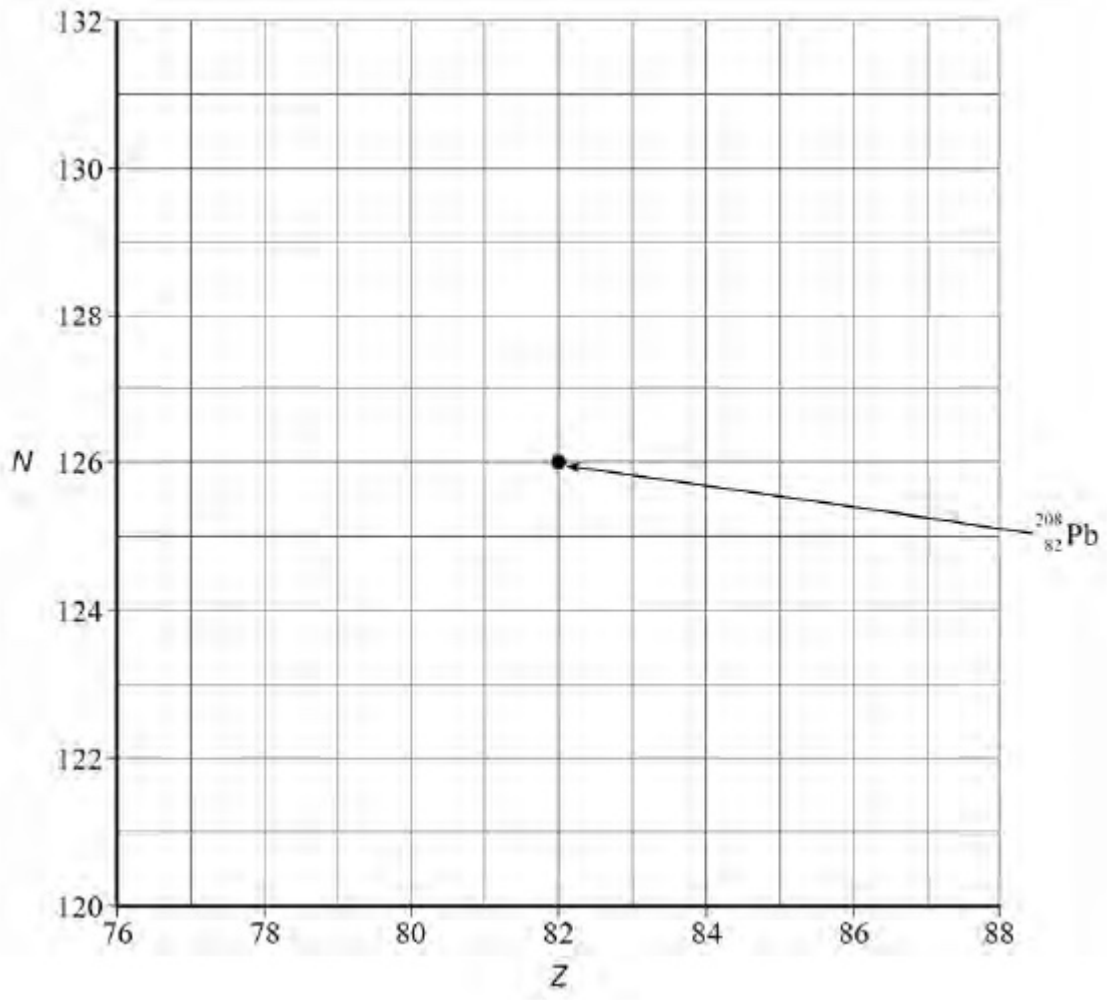
AQA publishes its past papers, mark schemes and examiner reports free of charge. Always check the current specification at aqa.org.uk before you revise, because content and wording can change between series.

If you hold the rights to any material in this pack and would like it amended or removed, contact admin@stemup.co.uk and we will act on it.

Q1.

A nucleus of polonium Po may decay to the stable isotope of lead $^{208}_{82}Pb$ through a chain of emissions following the sequence α β^- β^- α.

The graph shows the position of the isotope $^{208}_{82}Pb$ on a grid of neutron number *N* against proton number *Z*.



(a) Draw **four** arrows on the graph to show the sequence of changes to *N* and *Z* that occur as the polonium nucleus is transformed into $^{208}_{82}Pb$.

(2)

(b) A nucleus of the stable isotope $^{208}_{82}Pb$ has more neutrons than protons.

Explain why there is this imbalance between proton and neutron numbers by referring to the forces that operate within the nucleus. Your explanation should include the range of the forces and which particles are affected by the forces.

_____

_____

STEMUP.CO.UK

(4)

(c) Many, but not all, isotopes of lead are stable. For example, $^{208}_{82}Pb$ decays by electron capture to become an isotope of thallium, Tl.

Write the equation to represent this decay, including the isotope of thallium produced.

(1)

(d) The thallium nucleus is formed in an excited state. Electromagnetic radiation is emitted from the thallium atom following its formation.

Explain the origin and location of **two** sources of this radiation.

Source 1 _____

Source 2 _____

STEMUP.CO.UK

(2)

(e) Other nuclides also emit electromagnetic radiation.

Explain why the metastable form of the isotope of technetium $^{99}_{43}Tc$ is a radioactive source suitable for use in medical diagnosis.

(2)

(Total 11 marks)

Q2.

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} ⬭

(Total 1 mark)

Q3.

Which of the following substances can be used as a moderator in a nuclear reactor?

A Boron ⬭

B Concrete ⬭

STEMUP.CO.UK

C Uranium-238 ⬭

D Water ⬭

(Total 1 mark)

Q4.

(a) Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}Co$.

nuclear mass of $^{59}_{27}Co$ = 58.93320 u

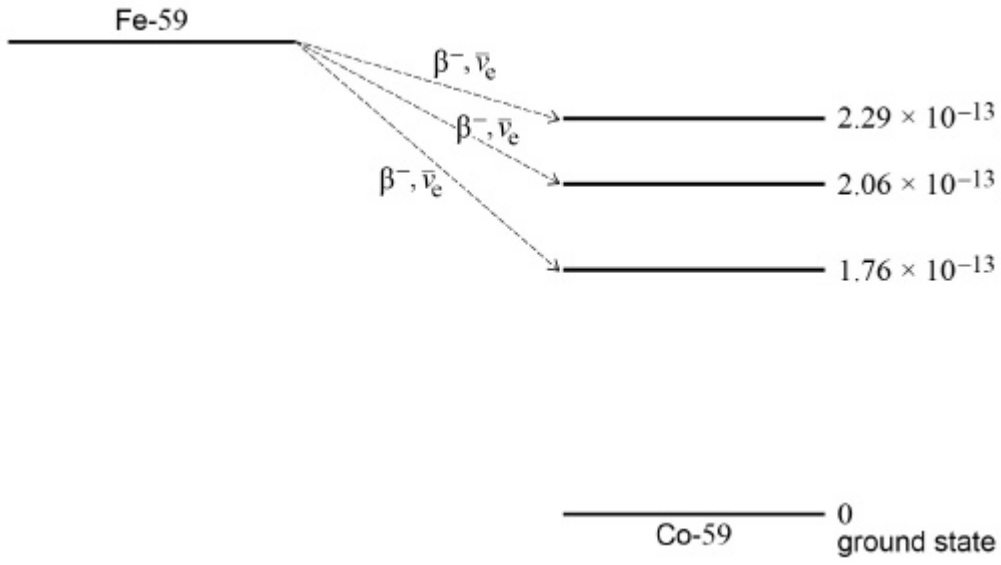
binding energy = _____ MeV

(3)

(b) A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown below. The energies of the excited states are shown relative to the ground state.



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

STEMUP.CO.UK

maximum kinetic energy = _____ MeV

(2)

(c) Following the production of excited states of $^{59}_{27}Co$, γ-radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

maximum number = _____

(1)

(d) Calculate the longest wavelength of the emitted γ-radiation.

Longest wavelength = _____ m

(3)

(Total 9 marks)

Q5.

A pure sample of nuclide **X** containing N nuclei has an activity A.
The half-life of **X** is 6000 years.

A pure sample of nuclide **Y** containing $3N$ nuclei has an activity $6A$.

What is the half-life of nuclide **Y**?

A 1000 years ⬭

B 3000 years ⬭

C 12 000 years ⬭

D 18 000 years ⬭

(Total 1 mark)

Q6.

Cobalt-60 has a half-life of 5.27 years.

What is the total activity of 1.0 g of cobalt-60?

A 4.2×10^{13} Bq ⬭

B 2.2×10^{14} Bq ⬭

STEMUP.CO.UK

C 2.5×10^{15} Bq ⬭

D 1.3×10^{21} Bq ⬭

(Total 1 mark)

Q7.

$^{232}_{90}Th$ is an unstable nuclide in a radioactive decay series. It decays by emitting an α particle. The next two nuclides in the series emit β^- particles.

What nuclide is formed after these three decays have taken place?

A $^{230}_{90}Th$ ⬭

B $^{228}_{92}U$ ⬭

C $^{228}_{88}Ra$ ⬭

D $^{228}_{90}Th$ ⬭

(Total 1 mark)

Q11.

(a) State the condition for momentum to be conserved in a system.

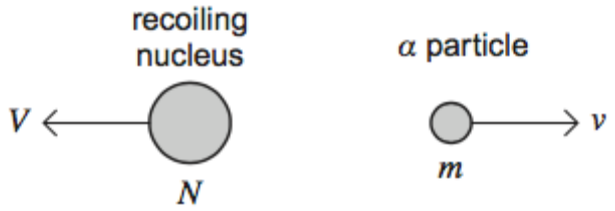
_____

_____

_____

(1)

(b) When a stationary unstable nucleus emits an α particle with velocity v the resulting nucleus recoils with velocity V, as shown in the diagram.



The mass of the α particle is m and the mass of the recoiling nucleus is N.

(i) Show how the principle of conservation of momentum may be used to derive an expression for V in terms of N, m and v.

(2)

STEMUP.CO.UK

(ii) Assume that all of the energy released in the emission process is transferred as kinetic energy to the α particle and the recoiling nucleus. The total energy released is E.
Use your result from part **(b)(i)** to show that the kinetic energy of the α particle is given by

$$E_\alpha = \left(\frac{N}{N+m}\right)E$$

(4)

(c) (i) The isotope of radon $^{220}_{86}\mathrm{Rn}$ decays by emitting an α particle.

State the nucleon number of the recoiling nucleus.

nucleon number = _____

(1)

(ii) The total energy released when a nucleus of $^{220}_{86}\mathrm{Rn}$ decays is 1.02×10^{-12} J.

Calculate the magnitude of the momentum of the α particle.
State an appropriate unit for your answer.

Mass of a nucleon = 1.66×10^{-27} kg

momentum = _____ unit _____

(4)

(d) Explain why the expressions in parts **(b)(i)** and **(b)(ii)** could **not** be applied when an unstable nucleus decays by emitting a β^- particle.

_____

_____

_____

_____

STEMUP.CO.UK

(1)

(Total 13 marks)

Q12.

(a) Which ionizing radiation produces the greatest number of ion pairs per mm in air? Tick (✓) the correct answer.

α particles	
β particles	
γ rays	
X−rays	

(1)

(b) (i) Complete the table showing the typical maximum range in air for α and β particles.

Type of radiation	Typical range in air / m
α	
β	

(2)

(ii) γ rays have a range of at least 1 km in air.

However, a γ ray detector placed 0.5 m from a γ ray source detects a noticeably smaller count-rate as it is moved a few centimetres further away from the source.

Explain this observation.

_____

_____

_____

(1)

(c) Following an accident, a room is contaminated with dust containing americium which is an α−emitter.

Explain the most hazardous aspect of the presence of this dust to an unprotected human entering the room.

_____

_____

STEMUP.CO.UK

_____

_____

(2)

(Total 6 marks)

Q13.

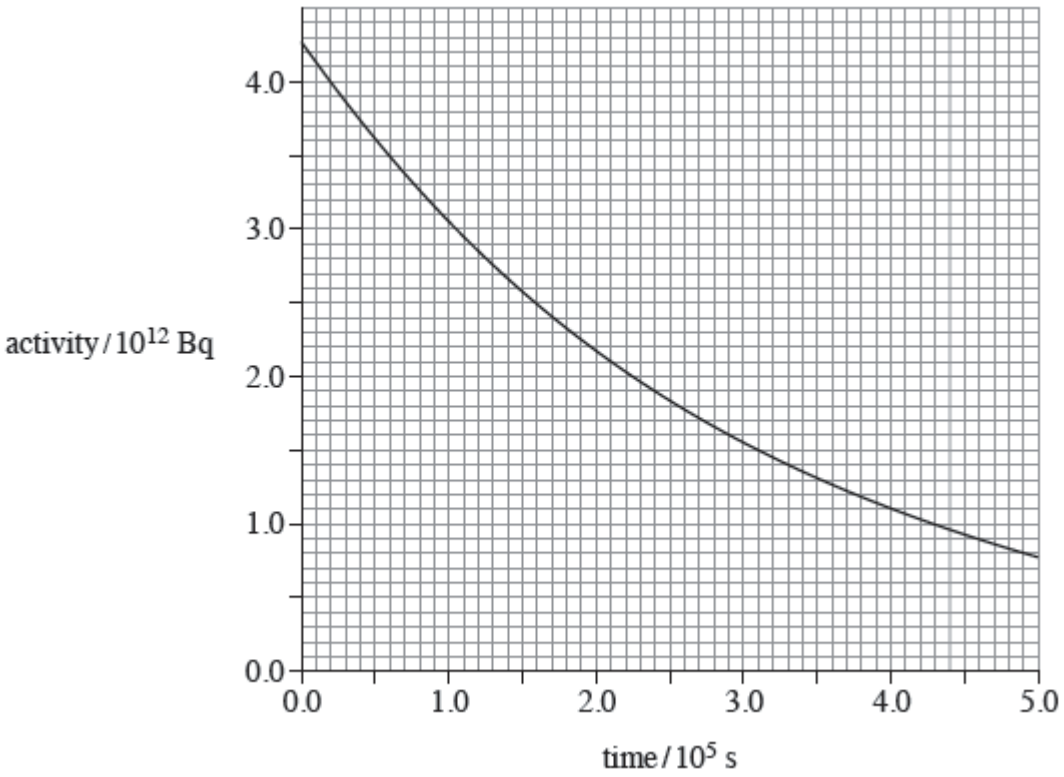
A rod made from uranium−238 ($^{238}_{92}\mathrm{U}$) is placed in the core of a nuclear reactor where it absorbs free neutrons.
When a nucleus of uranium−238 absorbs a neutron it becomes unstable and decays to neptunium−239 ($^{239}_{93}\mathrm{Np}$), which in turn decays to plutonium−239 ($^{293}_{94}\mathrm{Pu}$).

(a) Write down the nuclear equation that represents the decay of neptunium−239 into plutonium−239.

(2)

(b) A sample of the rod is removed from the core and its radiation is monitored from time t = 0 s.
The variation of the activity with time is shown in the graph.

STEMUP.CO.UK



(i) Show that the decay constant of the sample is about 3.4×10^{-6} s^{-1}.

(2)

(ii) Assume that the activity shown in the graph comes only from the decay of neptunium.

Estimate the number of neptunium nuclei present in the sample at time $t = 5.0 \times 10^5$ s.

STEMUP.CO.UK

number of nuclei _____

(1)

(c) (i) A chain reaction is maintained in the core of a thermal nuclear reactor that is operating normally.

Explain what is meant by a chain reaction, naming the materials and particles involved.

_____

_____

_____

_____

(2)

(ii) Explain the purpose of a moderator in a thermal nuclear reactor.

_____

_____

_____

_____

_____

_____

(2)

(iii) Substantial shielding around the core protects nearby workers from the most hazardous radiations. Radiation from the core includes α and β particles, γ rays, X−rays, neutrons and neutrinos.

Explain why the shielding becomes radioactive.

_____

_____

_____

_____

(2)

(Total 11 marks)

STEMUP.CO.UK