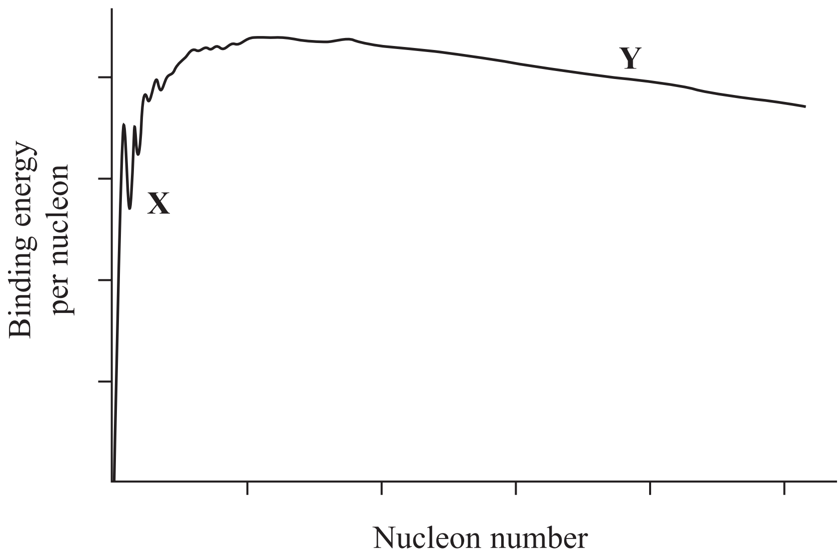
Answer ALL questions.

All multiple choice questions must be answered with a cross ☒ in the box for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Which row of the table shows a base quantity and its base SI unit?

(Total for Question 1 = 1 mark)

2 The diagram shows binding energy per nucleon against nucleon number for atomic nuclei.



Which line of the table correctly identifies the process that would increase stability for nuclei in the positions indicated by X and Y?

	X	Y
☐ **A**	nuclear fission	nuclear fission
☐ **B**	nuclear fission	nuclear fusion
☐ **C**	nuclear fusion	nuclear fission
☐ **D**	nuclear fusion	nuclear fusion

(Total for Question 2 = 1 mark)

10 A detector is placed 30 cm from a gamma source, the count rate is 64 counts per minute.

The detector is then placed 60 cm from the source. The background rate is presumed to be a constant 24 counts per minute.

Which of the following gives the expected counts per minute?

☒ **A** 16

☒ **B** 32

☒ **C** 34

☒ **D** 44

(Total for Question 10 = 1 mark)

16 Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

(a) The rock sample contains uranium. The radioactive decay of uranium allows it to be used to determine the time since the rock was formed on the Earth.

(i) The uranium isotope $^{238}_{92}U$ becomes the lead isotope $^{206}_{82}Pb$ through a series of radioactive decays.

Calculate the number of α particles and the number of β particles emitted for one nucleus of $^{238}_{92}U$ to decay to become a nucleus of $^{206}_{82}Pb$.

(2)

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Number of α particles = ...

Number of β particles = ...

(ii) The half-life of ${}^{238}_{92}U$ is 4.47×10^9 years.

The half-lives of the other stages in the decay to ${}^{206}_{82}Pb$ are relatively so short that they can be ignored.

There was no lead in the rock when it formed, so all the ${}^{206}_{82}Pb$ in the sample is a product of ${}^{238}_{92}U$ decay. In the sample, for every 103 uranium nuclei present at the start, 50 are now lead nuclei.

Show that the age of the sample is about 4×10^9 years.

(3)

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(b) The gravitational potential between the Earth and the Moon due to the combined effect of their gravitational fields increases to a maximum value of $-1.28\,\mathrm{MJ\,kg^{-1}}$ at a point between them.

Calculate the minimum speed at which a rock would have to leave the Earth in order to reach the Moon.

In your calculation, you may assume the rock has zero kinetic energy when it has maximum potential energy.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6370 km

(4)

Minimum speed = ...

(c) Four billion years ago, the Moon had a different orbital period, because it was closer to the Earth than it is today.

Calculate the period of the Moon's orbit four billion years ago, when the radius of its orbit was 1.34×10^{8} m.

mass of Earth = 5.97×10^{24} kg

(3)

Period = ...

(Total for Question 16 = 12 marks)

18 At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

(a) In a fusion experiment at CCFE, ions of two isotopes of hydrogen fuse to produce helium ions and fast-moving neutrons.

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n}$$

Show that a single fusion reaction releases about 3×10^{-12} J of energy.

mass of $^{2}_{1}\text{H}$ = 2.013553 u

mass of $^{3}_{1}\text{H}$ = 3.015501 u

mass of $^{4}_{2}\text{He}$ = 4.001506 u

mass of $^{1}_{0}\text{n}$ = 1.008665 u

(4)

(b) Fusion occurs naturally in the core of stars.

Explain why very high densities of matter and very high temperatures are needed to bring about and maintain nuclear fusion in stars.

(2)

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(c) In a plasma experiment 5.0 mg of deuterium, an isotope of hydrogen, occupies a volume of 98 m^3. The temperature of deuterium is raised to 1.3×10^8 K. In this experiment, the deuterium behaves as an ideal gas.

(i) Calculate the pressure due to the deuterium ions.

mass of deuterium ion = 3.3×10^{-27} kg

(3)

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Pressure = ...

(ii) Calculate the root mean square speed of the deuterium ions at this temperature.

(2)

Root mean square speed = ...

(iii) The temperature of the plasma is monitored using the Doppler effect. Light from a laser is directed into the plasma and the wavelength of the light reflected is measured.

The Doppler shift observed when light is reflected by a deuterium ion is twice the Doppler shift that would be observed for a source of light moving at the same speed as the deuterium ion.

Calculate the maximum wavelength of light that would be detected after reflection from a deuterium ion moving at $1.5 \times 10^6\,\mathrm{m\,s^{-1}}$.

wavelength of laser light = 1064 nm

(3)

Maximum wavelength detected = ...

(Total for Question 18 = 14 marks)

TOTAL FOR PAPER = 90 MARKS

20 The photograph shows a vase made of uranium glass. Uranium glass is radioactive.

Uranium glass usually contains a maximum of 2% uranium. Uranium glass made in the early part of the 20th century can contain up to 25% uranium.

A student carried out an investigation to determine the percentage of uranium in the glass.

The student measured the count rate by placing a Geiger Muller (GM) tube against the vase at a single position. This value was used to calculate the decay rate for the whole vase.

(a) (i) Show that the decay constant for uranium is about $5 \times 10^{-18}\,\text{s}^{-1}$

half-life of uranium = $1.41 \times 10^{17}\,\text{s}$

(2)

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(ii) Calculate the percentage of uranium, by mass, in the glass.

area of GM tube window = $6.36 \times 10^{-5}\,\text{m}^2$
surface area of vase = $0.0177\,\text{m}^2$
background count rate = 525 counts in 10 minutes
count rate when GM tube next to vase = 3623 counts in 5 minutes
mass of vase = 149 g
mass of uranium atom = 238 u

(6)

Percentage of uranium = ...

(iii) The uranium decays by emitting alpha particles.

Criticise the method used to determine the percentage of uranium in the vase.

(2)

(b) A uranium nucleus decays to thorium by emission of an alpha particle.

It can be assumed that all the energy of the decay is transferred to kinetic energy of the alpha particle.

Calculate the speed of the emitted alpha particle.

mass of uranium nucleus = 238.0003 u
mass of thorium nucleus = 233.9942 u
mass of alpha particle = 4.0015 u

(5)

Speed of alpha particle = ...

(Total for Question 20 = 15 marks)

TOTAL FOR PAPER = 90 MARKS

6 In a particular radioactive decay, there is a mass decrease equivalent to 0.05 u.

Which of the following expressions gives the energy released in MeV?

☒ **A** $\dfrac{0.05 \times 1.66 \times 10^{-27} \times \left(3 \times 10^{8}\right)^{2}}{1.6 \times 10^{-19}}$

☒ **B** $\dfrac{0.05 \times 1.67 \times 10^{-27} \times \left(3 \times 10^{8}\right)^{2}}{1.6 \times 10^{-19}}$

☒ **C** $\dfrac{0.05 \times 1.66 \times 10^{-27} \times \left(3 \times 10^{8}\right)^{2}}{1.6 \times 10^{-13}}$

☒ **D** $\dfrac{0.05 \times 1.67 \times 10^{-27} \times \left(3 \times 10^{8}\right)^{2}}{1.6 \times 10^{-13}}$

(Total for Question 6 = 1 mark)

(Total for Question 9 = 1 mark)

10 A student used a Geiger-Müller (GM) tube to determine a value for the background count. He recorded the count for 2 minutes, every 15 minutes, as shown in the table.

Time / min	**Count for 2 min**
0	34
15	39
30	28

The counts are not the same.

Which of the following is the reason for this?

☒ **A** The background count rate is random.

☒ **B** The counter is incorrectly calibrated.

☒ **C** The temperature has not stayed constant.

☒ **D** There is a systematic error in the measurement.

(Total for Question 10 = 1 mark)

13 Actinium-225 and bismuth-210 are radioactive isotopes. A sample of each isotope is prepared so that each sample has the same number of nuclei initially.

Explain why the activity of each sample would be the same after 10 days.

half-life of actinium-225 = 10 days
half-life of bismuth-210 = 5 days

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(Total for Question 13 = 4 marks)

21 A hundred years ago, a method to determine the age of certain rocks was developed. An unstable isotope of rubidium is present in some rocks when they form. Over time the rubidium decays to a stable isotope of strontium.

(a) Rubidium decays to strontium via β^- decay. Complete the nuclear equation representing the decay.

$$^{\dots\dots}_{37}\text{Rb} \rightarrow \, ^{87}_{\dots\dots}\text{Sr} + \, ^{\dots\dots}_{\dots\dots}\beta^- + \bar{\nu}_e$$

(2)

(b) A sample of Moon rock from the Apollo 11 mission was analysed to determine the age of the rock. When the sample was analysed the number of rubidium atoms was N_R and the number of strontium atoms was N_S.

As strontium atoms have all been produced from the decay of rubidium, the original number of rubidium atoms in the sample was $(N_R + N_S)$.

From the analysis of the sample, it was determined that $\dfrac{N_S}{N_R} = 0.0532$

Deduce whether this ratio is consistent with the Earth and the Moon forming at the same time.

age of Earth = 4.5×10^9 years
half-life of rubidium isotope = 4.88×10^{10} years

(5)

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P 6 9 4 4 2 A 0 2 4 3 2

(c) Give a reason why the half-life of the rubidium isotope is hard to determine.

(1)

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(d) Recent investigations suggest that the half-life of the rubidium isotope may be larger than the traditionally accepted value.

Explain how this would affect the ages obtained by this dating method.

(2)

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(Total for Question 21 = 10 marks)

TOTAL FOR PAPER = 90 MARKS