

Q1.

- (a) One purpose of the coolant in a thermal nuclear reactor is to maintain a safe working temperature within the core.

State the other purpose.

(1)

- (b) State **two** properties that engineers consider when choosing a liquid to use as a coolant in a thermal nuclear reactor.

1

2

(2)

- (c) Explain how the power output of a thermal nuclear reactor is decreased.

(2)

(Total 5 marks)

Q2.

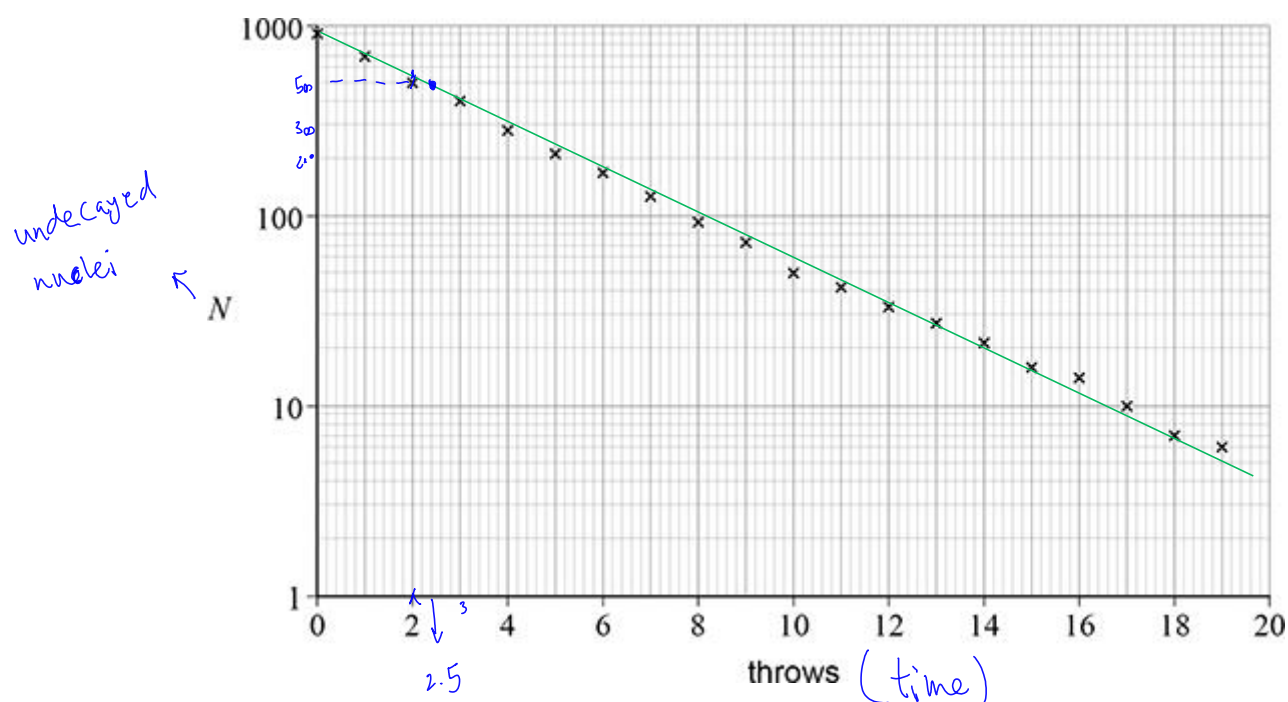
A team of students uses 900 dice, each with n sides, to model the decay of a radioactive material. Each die represents a single undecayed nucleus. A throw of the dice represents a constant time interval.

When the dice are thrown, those that show a 1 represent decayed nuclei and are removed.

The students count the number N of 'undecayed' dice that remain.

The procedure is repeated using the undecayed dice.

The figure below shows the students' data.



- (a) Explain why N has been plotted on a logarithmic scale in above figure.

(1)

Decay constant: probability of decay of a nucleus per unit time.

- (b) In this experiment, a decay constant λ can be defined that models the radioactive decay constant.

Determine λ .

Go on to use your value for λ to show that $n = 4$ for the dice used in this experiment.

$$A = \lambda N$$

$$\lambda = \frac{\ln 2}{T_{1/2}} = 0.277 \text{ throws}^{-1} \approx 0.28$$

2.5

$$n = \frac{1}{\lambda} = \frac{1}{0.28} = 3.57 \approx 3.6 \approx 4$$

number of undecayed nuclei

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

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

$\lambda =$ _____ throw⁻¹

(5)

- (c) A typical radioactive source used in schools has an activity of 100 kBq.
A radioactive source used in a hospital has an activity of 370 GBq.

State **one** safety measure when using a radioactive source in a school laboratory.

Go on to discuss how this safety measure needs to be adapted for safe use of the hospital radioactive source.

(2)

- (d) X-rays are a form of ionising radiation.

A person has check-ups with a dentist every six months.
The dentist only takes X-ray images when the person has reported a problem.

Suggest why.

(2)

(Total 10 marks)

Q3.

- (a) Nuclear radii can be estimated using either alpha particles or high-energy electrons.

State **two** advantages of using high-energy electrons rather than alpha particles for this estimate.

$$\lambda = \frac{h}{mv}$$

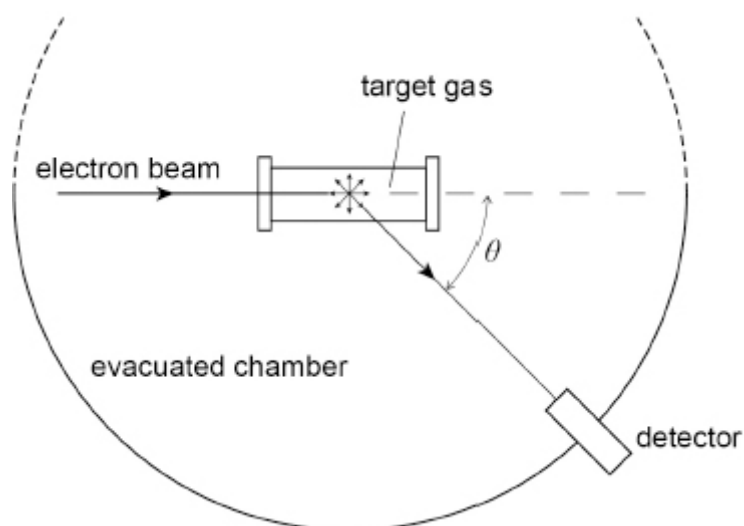
1 _____

2 _____

(2)

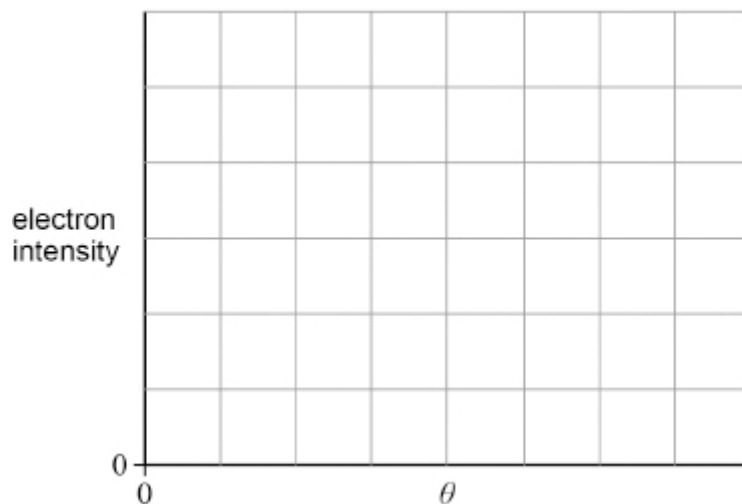
- (b) **Figure 1** shows a beam of electrons, each with the same high energy, incident on a target gas. The electrons are diffracted by the nuclei in the gas. The intensities of these diffracted electrons are measured at various angles θ . The data are used to determine the nuclear radius R of the atoms in the gas.

Figure 1



Sketch on **Figure 2** a graph showing how the electron intensity varies with θ .

Figure 2



(2)

- (c) The radius R of a nucleus is related to its nucleon number by $R = R_0 A^{\frac{1}{3}}$.

Show that this equation is consistent with the idea that all nuclei have the same density.

(2)

- (d) The equation $R = R_0 A^{\frac{1}{3}}$ is derived from experimental data.

Suggest **one** reason why the constant density of nuclear material derived from this equation is only approximate.

(1)

- (e) The measured radius R of $^{35}_{17}\text{Cl}$ is $4.02 \times 10^{-15} \text{ m}$.

Calculate an estimate of

- the constant R_0
- the density of nuclear material.

$R_0 =$ _____ m density = _____ kg m^{-3}

(3)

(Total 10 marks)

Q4.

- (a) Carbon is used as the moderator in some thermal nuclear reactors.

Identify **one** other material commonly used as a moderator.

(1)

- (b) State **two** benefits of slowing down the neutrons released during fission.

1 _____

2 _____

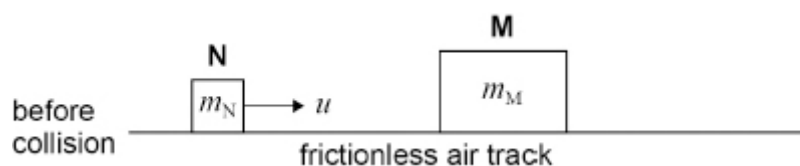
(2)

- (c) The collision of a neutron with the nucleus of a moderator atom is modelled using two gliders on a horizontal frictionless air track.

In **Figures 1** and **2** the glider **N** of mass m_N represents the neutron and the glider **M** of mass m_M represents the moderator nucleus.

Figure 1 shows glider **N** travelling with initial speed u towards the stationary glider **M**.

Figure 1



The gliders collide. **N** rebounds with speed v as shown in **Figure 2**.

Figure 2

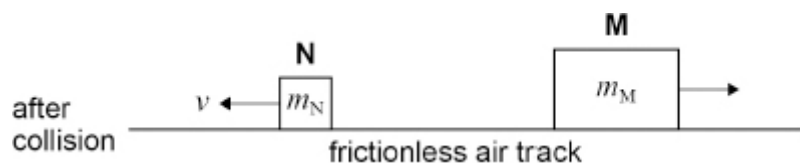
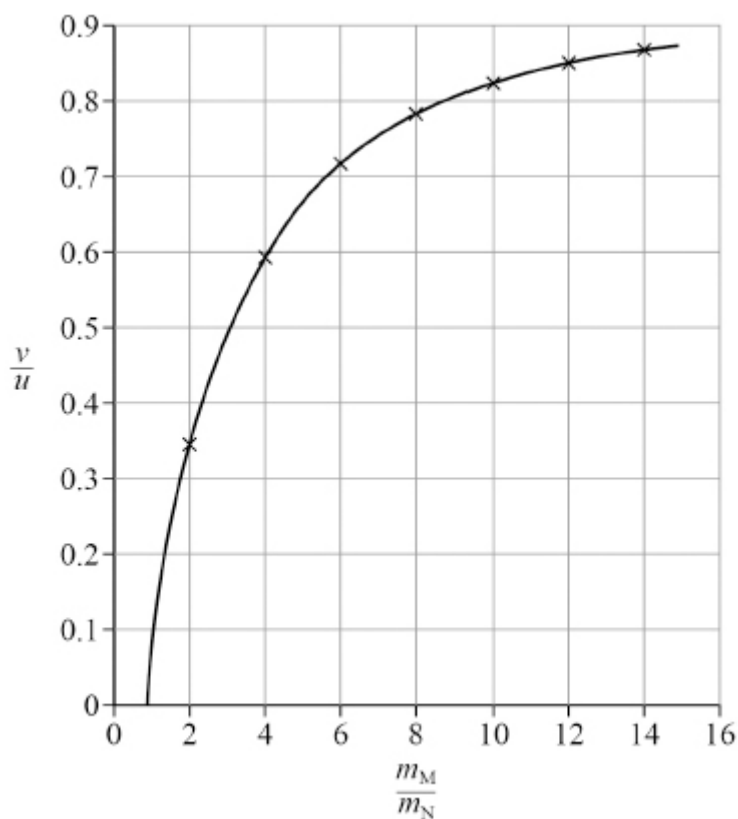


Figure 3 shows the variation of the ratio $\frac{v}{u}$ with the ratio $\frac{m_M}{m_N}$.

Figure 3



Show that when $\frac{m_M}{m_N}$ is 12, **N** loses about 30% of its initial kinetic energy in the collision.

(2)

- (d) In a reactor, the speed of a fast-moving neutron is reduced by a series of γ random collisions with carbon-12 nuclei.

The final kinetic energy E_f of the neutron is

$$E_f = E_0 e^{-by}$$

where E_0 is the initial kinetic energy of the neutron and $b = 0.73$

A thermal neutron has kinetic energy equivalent to that of the average particle of an ideal gas with a temperature of 350 K.

One neutron has an initial kinetic energy of 1.0 MeV.

Calculate the minimum value of y required so that this neutron becomes a thermal neutron.

$$y = \underline{\hspace{2cm}} \quad (3)$$

- (e) Explain, with reference to **Figure 3**, why elements with a small nucleon number are preferred as moderator materials.

(2)

(Total 10 marks)

Q5.

Fission and fusion are two processes that can result in the transfer of binding energy from nuclei.

- (a) State what is meant by the binding energy of a nucleus.

(2)

- (b) Calculate, in MeV, the binding energy for a nucleus of iron $^{56}_{26}\text{Fe}$.

mass of $^{56}_{26}\text{Fe}$ nucleus = 9.288×10^{-26} kg

$$m_p = 1.673 \times 10^{-27} \text{ kg}$$

$$m_n = 1.675 \times 10^{-27} \text{ kg}$$

individual mass of nucleons: $26 \times 1.673 \times 10^{-27} + 30 \times 1.675 \times 10^{-27} = 9.3748 \times 10^{-26} \text{ kg}$

$$\Delta m = (9.3748 - 9.288) \times 10^{-26} = 8.68 \times 10^{-28} \text{ kg}$$

* $1 \text{ u} = 931.5 \text{ MeV} = 1.661 \times 10^{-27} \text{ kg}$ binding energy = _____ MeV

(3)

$$\frac{8.68 \times 10^{-28}}{1.661 \times 10^{-27}} = 0.52257 \text{ u} \rightarrow 0.52257 \times 931.5 = 486.8 \text{ MeV}$$

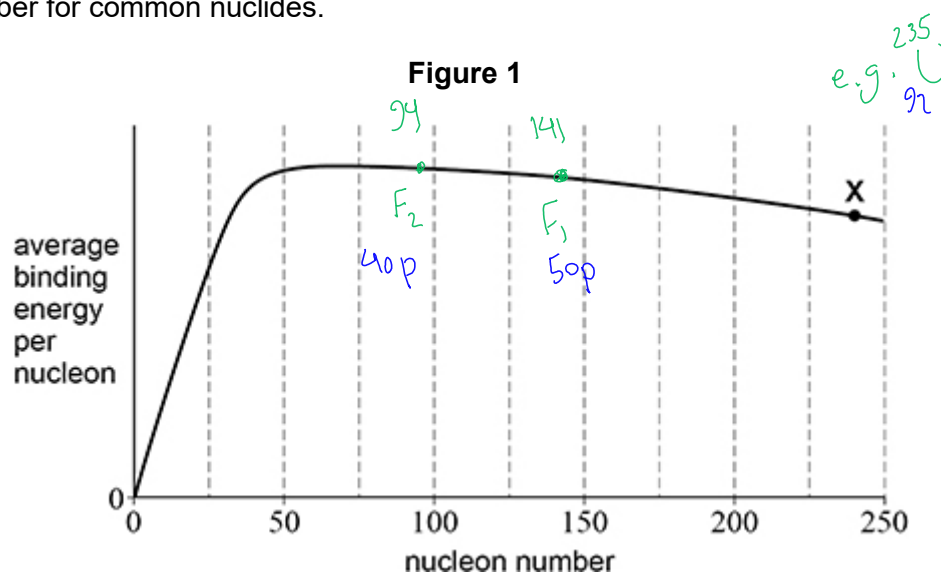
or

$$E = mc^2 = 8.68 \times 10^{-28} \times (3 \times 10^8)^2 = 7.812 \times 10^{-11} \text{ J}$$

$$\frac{7.812 \times 10^{-11}}{1.6 \times 10^{-13} \times 10^6} = 488.25 \text{ MeV}$$

↓
Mega

Figure 1 shows a graph of average binding energy per nucleon against nucleon number for common nuclides.

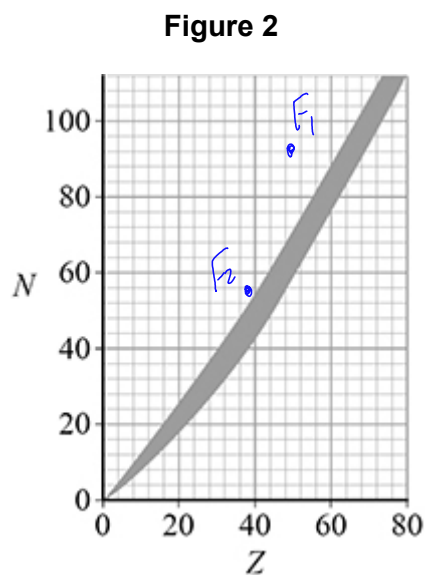


- (c) The nuclide labelled **X** in **Figure 1** undergoes fission.

Annotate **Figure 1** with **F₁** and **F₂** to show **one** possible pair of nuclides resulting from the fission of **X**.

(2)

- (d) **Figure 2** shows a graph of N against Z for stable nuclides.



Deduce the likely initial mode of decay of F_1 and F_2 .
Refer to **Figure 2** in your answer.

(3)

(Total 10 marks)