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.

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(1)

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

1 ___

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2 ___

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(2)

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

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(2)

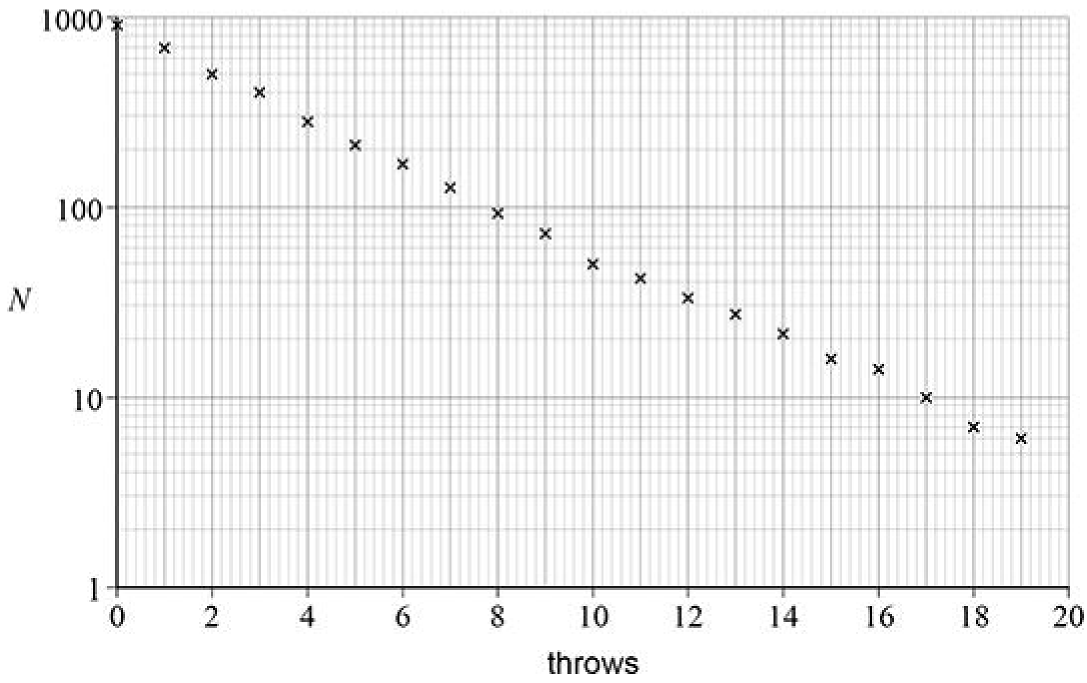
(Total 5 marks)

Q2.

A team of students uses 900 dice, each with n sides, to model the decay of a radioactive material. Each dice 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.

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(1)

(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.

λ = ____________________ $throw^{-1}$

(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.

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(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.

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(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.

1 ____

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2 ____

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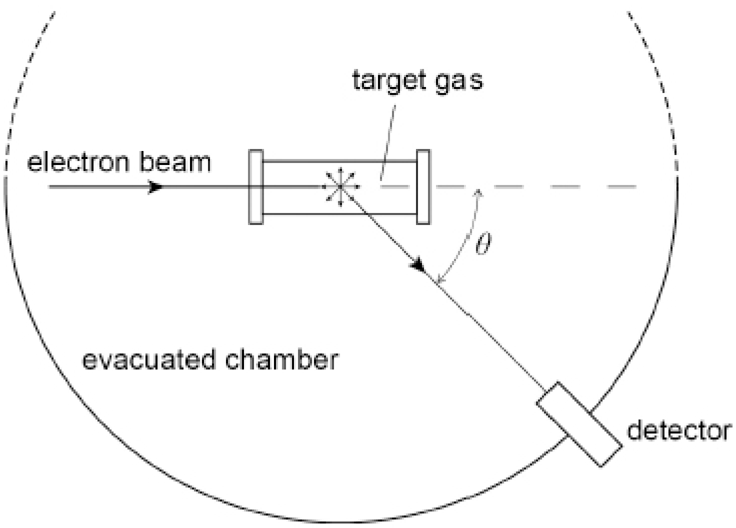
(2)

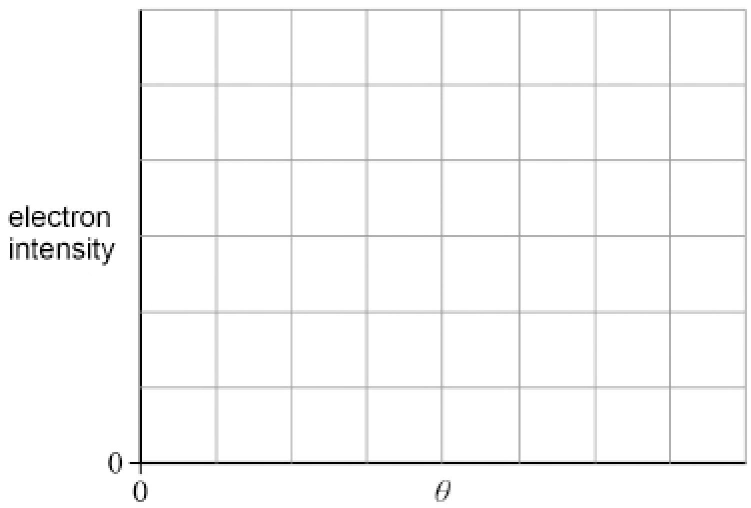
(b) **Figure 1** shows a beam of electrons, each with the same high energy, incident on a target gas.
The electrons are diffracted by the nuclei in the gas.
The intensities of these diffracted electrons are measured at various angles θ.
The data are used to determine the nuclear radius R of the atoms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

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(1)

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

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(1)

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

1 ____

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2 ____

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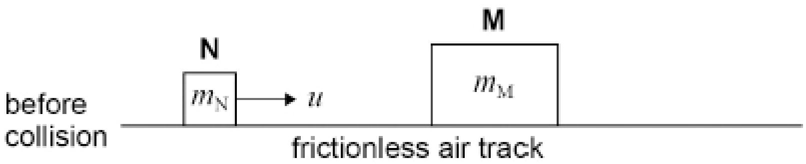
(2)

(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

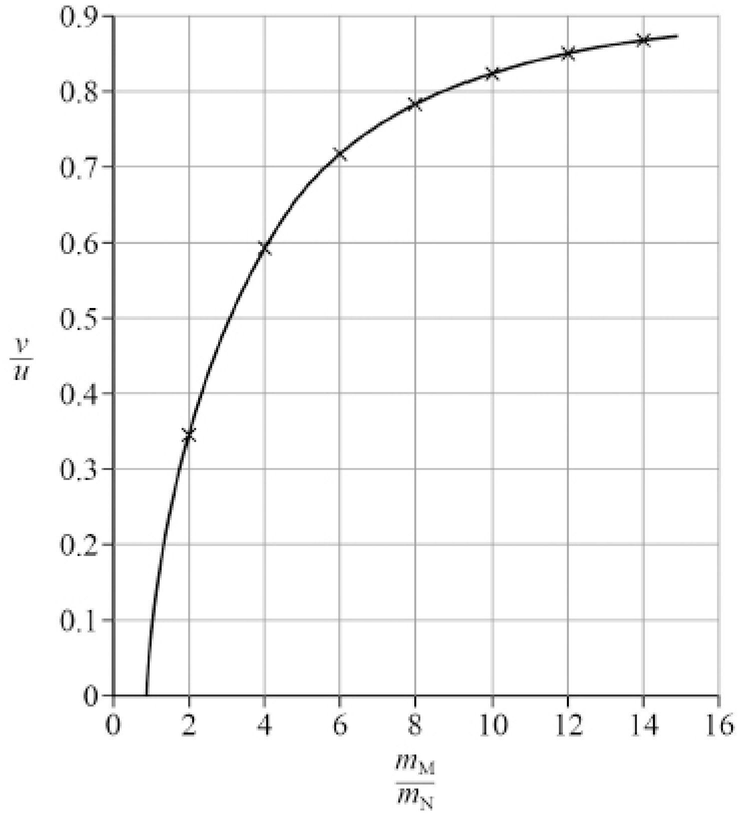


The gliders collide. **N** rebounds with speed v as shown in **Figure 2**.

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 y 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 = ______________________

(3)

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

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(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.

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(2)

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

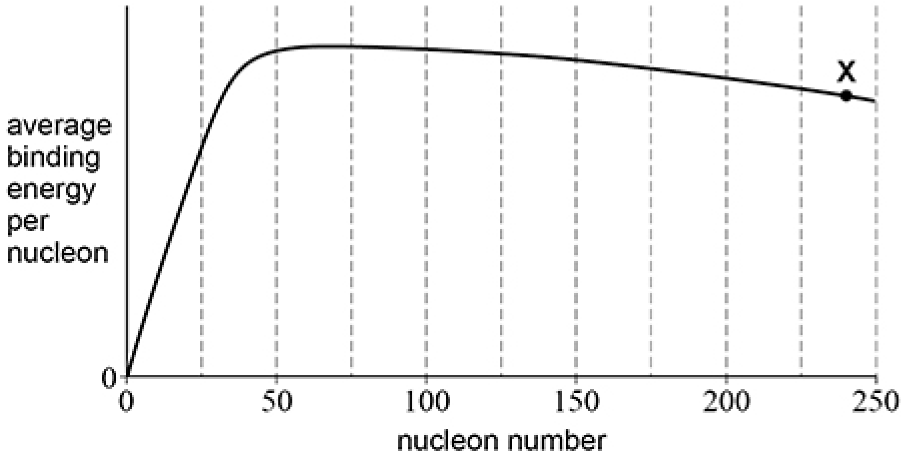
mass of $^{56}_{26}Fe$ nucleus = 9.288×10^{-26} kg

binding energy = ____________________ MeV

(3)

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

Figure 1



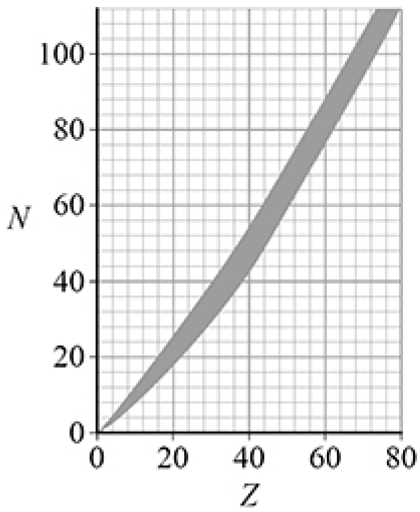
(c) The nuclide labelled **X** in **Figure 1** undergoes fission.

Annotate **Figure 1** with $\mathbf{F_1}$ and $\mathbf{F_2}$ 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.

Figure 2



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

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(3)
(Total 10 marks)