Answer **all** the questions

1 A stationary uranium-238 nucleus $\left({}^{238}_{92}\text{U}\right)$ decays into a nucleus of thorium-234 by emitting an alpha-particle.

(a) The chemical symbol for thorium is Th. Write a nuclear equation for this decay.

[2]

(b) The mass of the uranium nucleus is 4.0×10^{-25} kg. After the decay the thorium nucleus has a speed of 2.4×10^{5} m s^{-1}.

Calculate the kinetic energy, in MeV, of the alpha-particle.

kinetic energy = ... MeV **[4]**

(c) The uranium-238 $\left({}^{238}_{92}\text{U}\right)$ nucleus starts the decay chain which ends with a nucleus of lead-206 $\left({}^{206}_{82}\text{Pb}\right)$.

Show that 14 particles are emitted during this decay chain. Explain your reasoning.

[3]

2 $^{60}_{27}\text{Co}$ is produced by irradiating the stable isotope $^{59}_{27}\text{Co}$ with neutrons.

Each nucleus of $^{60}_{27}\text{Co}$ then decays into a nucleus of nickel (Ni) by the emission of a low energy beta-minus particle, one other particle and two gamma photons.

(a) Complete the nuclear equations for these two processes.

$$^{59}_{27}\text{Co} + ^{\cdots\cdots}_{\cdots\cdots}\text{n} \longrightarrow ^{60}_{27}\text{Co} \longrightarrow ^{\cdots\cdots}_{\cdots\cdots}\text{Ni} + ^{\cdots\cdots}_{\cdots\cdots}\text{e} + \cdots\cdots\cdots + 2\gamma$$

[3]

(b) Students want to carry out an investigation into gamma photon absorption using a source of $^{60}_{27}\text{Co}$.

They add sheets of lead between the source **S** and a radiation detector **T**, to give a total thickness *d* of lead. **S** and **T** remain in fixed positions, as shown in Fig. 2.1.

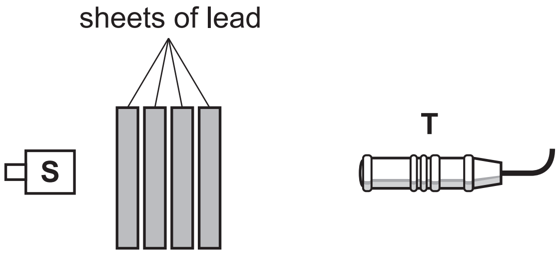

Fig. 2.1

(i) The $^{60}_{27}\text{Co}$ source emits beta radiation as well as gamma radiation.

Explain why this would not affect the experiment.

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.... **[1]**

Question 2 continues on page 6

(ii) The students record the number N of gamma photons detected by **T** in 10 minutes for each different thickness d of lead. The background count is negligible.

The results are shown in a table. The table includes values of ln N, including the absolute uncertainties.

N	***d* / mm**	**ln *N***
4300 ± 440	0	8.37 ± 0.10
2500 ± 250	10	7.82 ± 0.10
1400 ± 150	20	7.24 ± 0.11
800 ± 90	30	6.68 ± 0.11
500 ± 60	40	6.21 ± 0.12
300 ± 40	50	

N and d are related by the equation $N = N_0 e^{-\mu d}$ where N_0 and μ are constants.

1. The students decide to plot a graph of ln N against d.

Show that this should give a straight line with gradient = $-\mu$ and y-intercept = $\ln N_0$.

[1]

2. Complete the missing value of ln N in the table, including the absolute uncertainty.

Show your calculation of the absolute uncertainty in the space below.

[2]

3. In Fig. 2.2, five of the data points have been plotted, including error bars for ln N.

- Plot the missing data point and error bar.
- Draw a straight line of best fit and one of worst fit. **[2]**

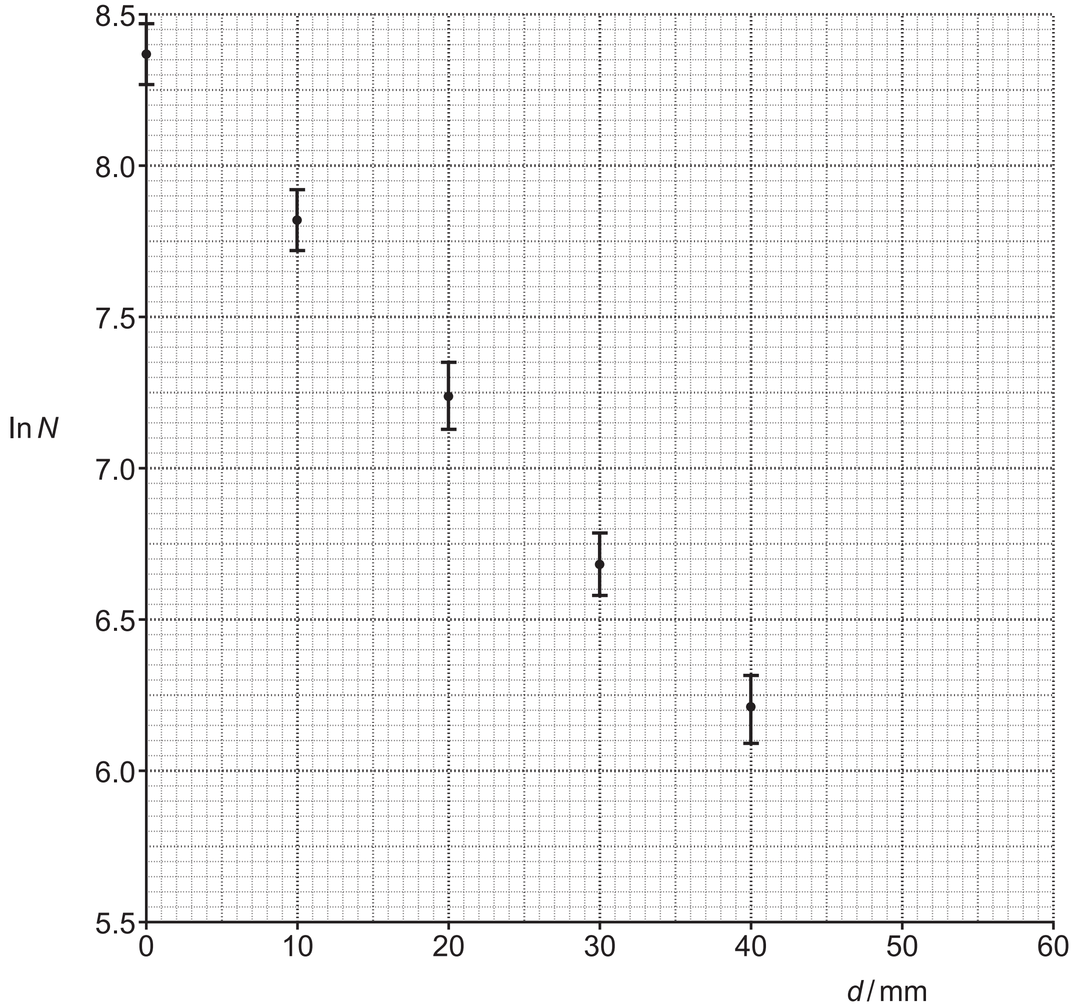

Fig. 2.2

Question 2 continues on page 8

4. Use Fig. 2.2 to determine the value of μ in m^{-1}, including the absolute uncertainty.

μ = ... ± .... m^{-1} **[4]**

5. Determine the thickness, $d_{½}$, of lead which halves the number of gamma photons reaching **T**.

$d_{½}$ = ... m **[2]**

3 This question is about the Sun and its radiation.

(a) **(i)** Use the data below to show that the luminosity of the Sun is about 4×10^{26} W.

- radius of Sun = 7.0×10^{8} m
- surface temperature of Sun = 5800 K

[1]

(ii) Sirius, the brightest star in the night sky, has a luminosity 25 times greater than that of the Sun. It has diameter 1.7 times greater than that of the Sun.

Calculate the surface temperature *T* of Sirius.

T = ... K **[3]**

***(b)** A student attends a lecture about the Sun and makes the following notes.

1. The Sun loses more than 4×10^9 kg of its mass every second to maintain its luminosity.
2. Treating hydrogen nuclei (protons) as an ideal gas, a temperature of 10^{10} K provides a kinetic energy of about 1 MeV, which is necessary for fusion.
3. However, the Sun's core temperature is only 10^7 K, so the chance of protons fusing on collision is very small. This explains why the Sun has such a long lifetime.

Explain the principles of physics which are involved in each of the three points.
You should include relevant formulae, but no numbers or calculations are required.

[6]

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3 This question is about a space probe which is in orbit around the Sun.

(a) Define **gravitational potential energy** of an object at a point in a gravitational field.

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.... **[1]**

(b) The space probe has mass 810 kg. The orbital radius of the space probe is 1.5×10^{11} m. The orbital period of the space probe around the Sun is 3.16×10^{7} s.
The mass of the Sun is 2.0×10^{30} kg.

(i) Show that the magnitude of the gravitational potential energy of the space probe is about 7×10^{11} J.

[2]

(ii) Show that the kinetic energy of the space probe is half the value of your answer to **(b)(i)**.

[3]

(iii) Calculate the total energy of the space probe.

total energy = ... J **[1]**

(c) The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.

Plutonium-238 decays by α-particle emission with a half-life of 88 years.
The kinetic energy of each α-particle is 8.8×10^{-13} J.

(i) Calculate the number *N* of plutonium-238 nuclei needed to provide the power of 470 W.

N = ... **[3]**

(ii) Calculate the power *P* still available from the plutonium-238 source 100 years later.

P = ... W **[3]**

3 **(a)** In beta-plus decay, a proton decays into three other particles.

Write a nuclear equation for this process.

[2]

(b)* A student, supervised by their teacher, carries out an experiment with three unlabelled radioactive sources.

The student is told that each source emits only one type of radiation. One emits gamma rays, one emits beta-minus particles and one emits beta-plus particles.

The student has the following equipment:

- a selection of materials with different thicknesses
- a strong magnet
- a radiation counter (GM tube and counter).

Explain how the student can use this equipment to determine safely which radiation each source emits.

You may use the space below to draw a diagram. **[6]**

5 Large power stations generate an electrical power of about 1 GW.

Current methods of energy production that use nuclear fusion are unable to produce enough energy for large-scale energy production. A proposed method of controlling nuclear fusion is inertial confinement fusion (ICF). ICF uses a large number of powerful lasers to create the high temperatures required for nuclear fusion to occur.

One ICF experiment uses a network of capacitors to store the energy needed to power the lasers. When the network is fully charged:

- potential difference across the network = 24 kV
- total energy stored in the network = 400 MJ

(a) **(i)** Calculate the total capacitance, *C*, of the network.

C = ... F **[2]**

(ii) Explain why the individual capacitors in the network should be connected in parallel in order to produce this total capacitance.

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.... **[1]**

(b) The total stored energy must be released in a time of less than 1 millisecond.

Explain, using a calculation, why the lasers are powered by the network of capacitors instead of being connected directly to the mains electricity supply.

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.... **[2]**

(c) The fusion reaction in the ICF experiment is

deuterium + tritium $\rightarrow$ alpha particle + neutron

Calculate the number of fusion reactions that must occur for the energy released by fusion to be equal to the electrical energy stored in the network of capacitors.

- mass of deuterium = 2.014102 u
- mass of tritium = 3.016049 u
- mass of alpha particle = 4.002603 u
- mass of neutron = 1.008665 u

number of fusion reactions = ... **[4]**