8 Read the following article and then answer the questions that follow.

Shielding from nuclear radiation

Since the beginning of the industrial age, the burning of fossil fuels such as coal and petroleum has elevated the atmospheric CO_2 concentration to unprecedented levels. As a consequence, the global average surface temperature has increased and the earth has experienced the hottest years ever recorded. If we continue to consume fossil fuels at the same rate, the resulting temperature increase will have dramatic effects on global climate.

One measure to mitigate global warming is the use of renewable energy. Unfortunately, they are heavily dependent on the weather. Even as the technology for utilising renewable energy such as solar and wind improve, there are reliability issues, which present important challenges to be overcome before the world can turn “100 per cent renewables”.

Nuclear fission reactors generate electricity without producing greenhouse emissions. However, these power plants can pose serious safety and security problems due to concerns over radioactivity. Dangers associated with exposure to radiation have been recognised for many years. As a result of these hazards, measures have been adopted to reduce exposure to radiation to as low a level as possible. One such measure is to shield individuals from radioactive sources using radiation absorbing materials.

Experiments have been carried out to investigate the effectiveness of materials as absorbers of γ-ray photons. One possible experiment is illustrated in Fig. 8.1.

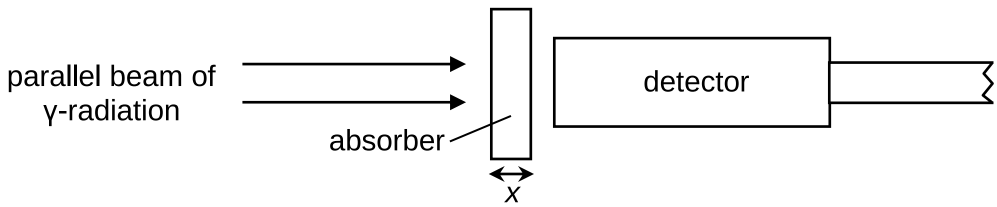

Fig. 8.1

The count-rate C_X of γ-ray photons is measured for various thickness x of the absorber, together with the count-rate C_0 for no absorber. Fig. 8.2 shows the variation with thickness x of the ratio C_X/C_0 for lead.

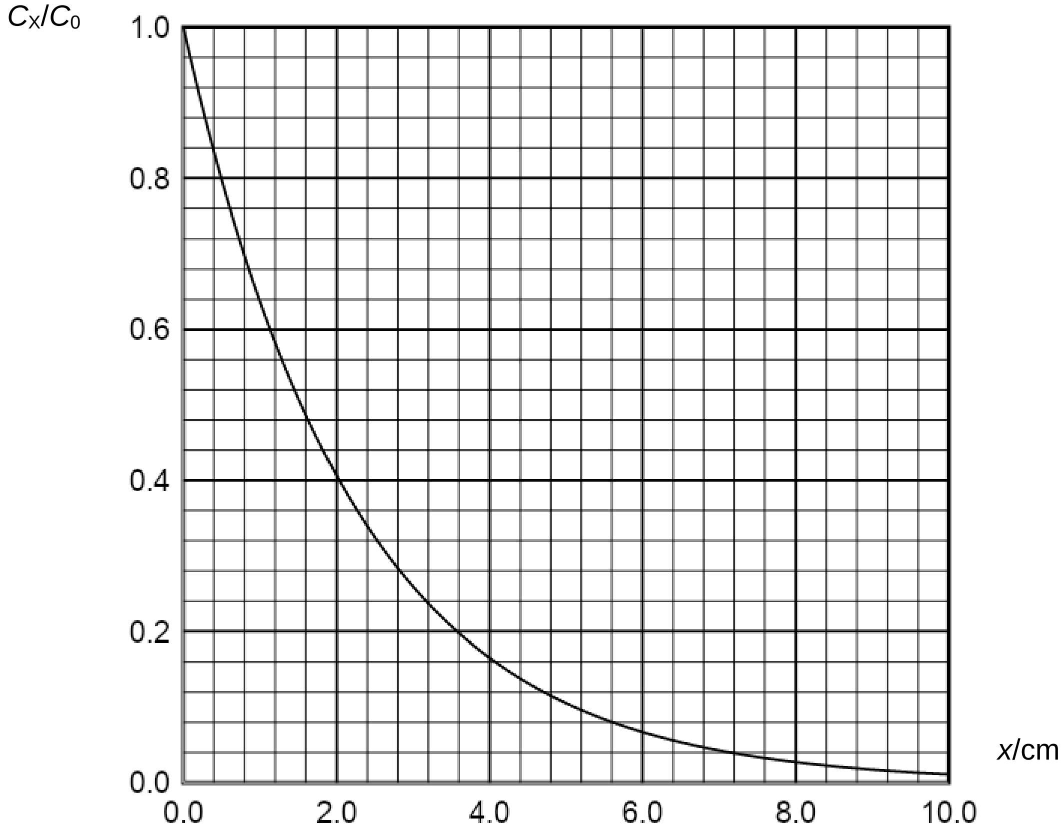

Fig. 8.2

(a) **(i)** By providing examples, suggest possible reliability issues faced by renewable energy sources.

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.... [2]

(ii) State what is meant by γ-radiation.

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.... [2]

(iii) Suggest how exposure to γ-radiation could be dangerous.

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.... [2]

(iv) Suggest why it is necessary to have a parallel beam of γ-radiation in this experiment.

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.... [1]

(v) Suggest how Fig. 8.2 shows that complete shielding does not take place.

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.... [1]

(b) Data from Fig. 8.2 are used to obtain values of ln (C_X/C_0). These are used to plot the graph of Fig. 8.3.

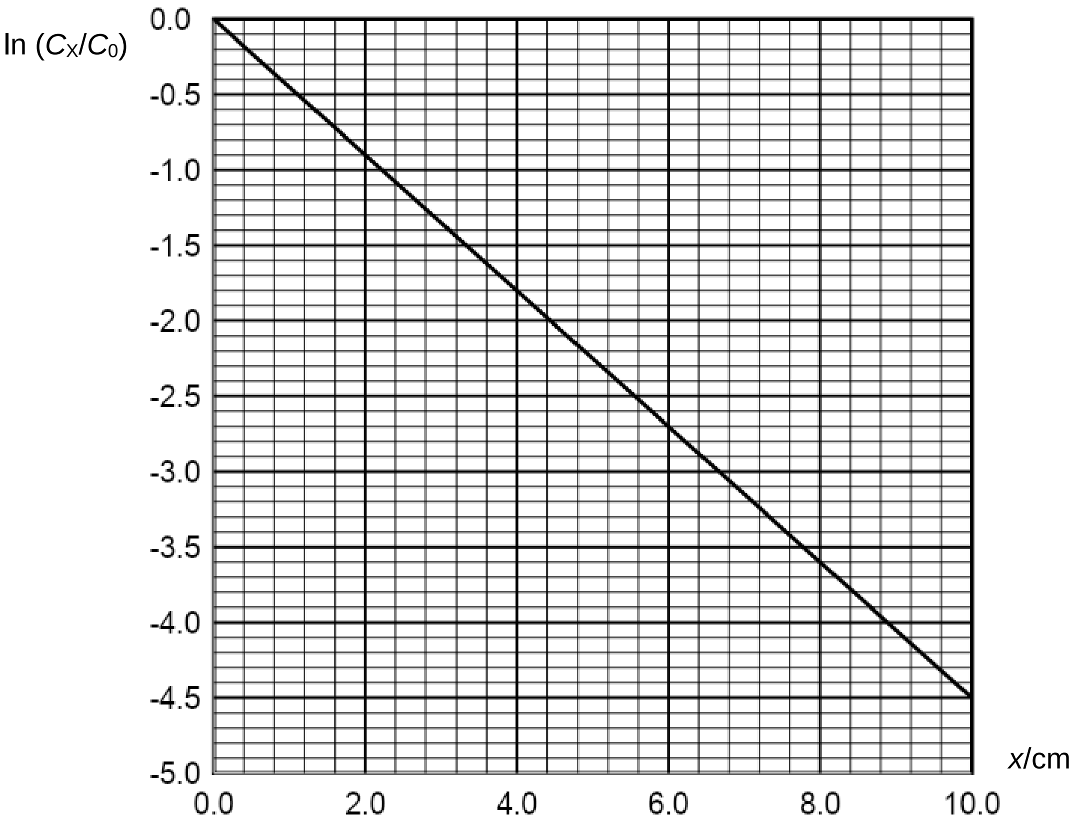

Fig. 8.3

(i) It is proposed that the count-rate C_X changes with the thickness x of the absorber according to an expression of the form

$$C_X = C_0\, e^{-\mu x},$$

where μ is a constant.

Explain why the graph of Fig. 8.3 supports this proposal.

[3]

(ii) The constant μ is known as the linear absorption coefficient. Use Fig. 8.3 to calculate a value of μ for lead.

μ = ……………………………cm^{-1} [2]

(c) The linear absorption coefficient μ has been found to depend on photon energy and on the absorbing material itself. For γ-ray photons of one energy, μ is different for different materials.

In order to assess absorption of γ-ray photons in matter such that the material of the absorber does not have to be specified, a quantity known as the mass absorption coefficient μ_m is calculated. μ_m is given by the expression

$$\mu_m = \frac{\mu}{\rho}$$

where ρ is the density of the absorbing material.

Values of μ for 2.75 MeV photons and of ρ for different materials are given in Fig. 8.4.

material	μ / cm^{-1}	ρ / g cm^{-3}	μ_m / ……..
aluminium	0.095	2.70	0.035
tin	0.267	7.28	0.037
lead	……………..	11.3	……………

Fig. 8.4

On Fig. 8.4,

(i) give an appropriate unit for μ_m, [1]

(ii) use your answer to **(b)(ii)** to complete the table of values for lead. [1]

(d) Concrete is a common building material which is sometimes used for shielding. The density of concrete is 2.4×10^3 kg m^{-3}.

(i) Use the information given in Fig. 8.4 to calculate an average value for μ_m and hence show that the linear absorption coefficient μ for 2.75 MeV photons in concrete is approximately 0.09 cm^{-1}.

[3]

(ii) Calculate the approximate thickness of concrete which would provide the same level of shielding, for 2.75 MeV photons, as a thickness of 4.0 cm of lead.

thickness of concrete = …………………………….cm [2]

(iii) Suggest two reasons why concrete may be used, in preference to lead, where radioactive sources of high activity are to be shielded.

1. ....

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2. ....

....[2]

[End of Paper]