8 During radioactive decay, which is spontaneous and random, γ-ray (gamma ray) photons may be emitted. When these photons are incident on a sodium iodide crystal, some of the photons may be absorbed in the crystal. The absorption of a γ-ray photon causes the emission of a short pulse of light known as a scintillation. The scintillations may be detected and converted into electrical pulses using *a photomultiplier tube*, which, when connected to a counter, gives the *count rate* and enables γ-ray *activity* to be measured. The arrangement is illustrated in Fig. 8.1.

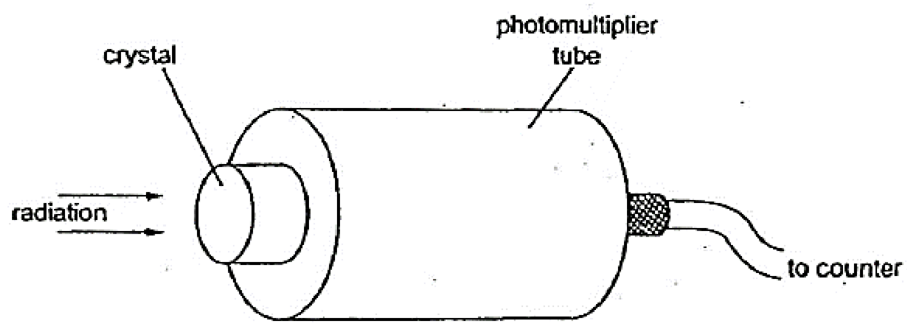

Fig. 8.1

The crystals used in such counters may be of different shapes. Fig. 8.2 shows a solid cylindrical crystal.

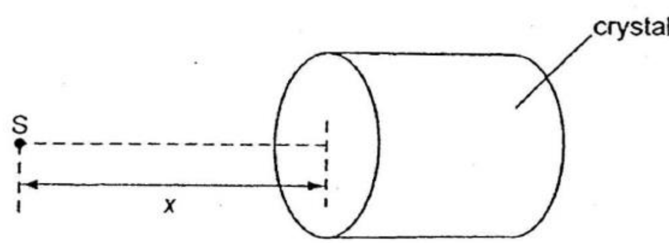

Fig. 8.2

The small γ-ray source S is placed a distance x in front of one face of the crystal. The source is assumed to emit photons uniformly in all directions. Not all of the emitted photons will be absorbed by the crystal. The efficiency Q of detection is defined by the equation

$$Q = \frac{\text{number of photons producing scintillations in the crystal}}{\text{total number of photons emitted by the source}}$$

(a) By reference to the passage, explain what is meant by

(i) *count rate*

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

…………………………………………………………………………….. [1]
.

(ii) *activity*

....

....

.... [1]

(b) Suggest two reasons why the γ-ray photons emitted by the source are not all absorbed in the crystal.

1. ....

....

....

.... [1]

2. ....

....

....

.... [1]

(c) Fig. 8.3 shows the variation with γ-ray photon energy E of the efficiency Q. Curves are drawn for various values of the distance x of the source S from the face of the crystal.

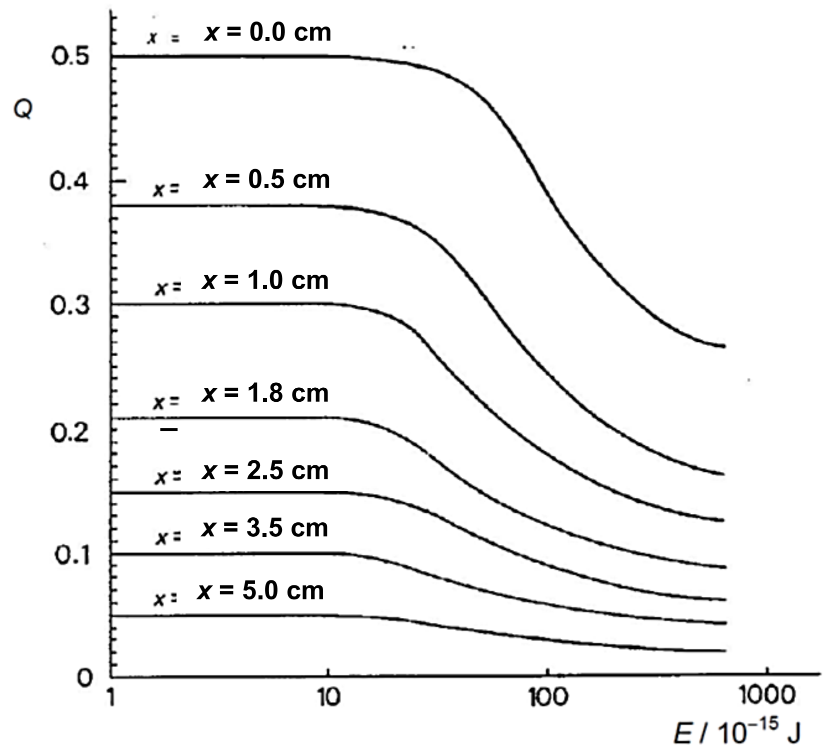

Fig. 8.3

(i) Suggest why at any one particular value of energy, the efficiency Q decreases as x increases.

....

....

....

....

....

....

.... [3]

(ii) With reference to Fig. 8.3 and considering γ-ray photons of energy 8×10^{-15} J, complete Fig. 8.4 with corresponding values of Q with for γ-ray photons of this energy.

Q	x / cm

[2]

Fig. 8.4

(d) **(i)** Use your values in Fig. 8.4 to draw a graph of Q against x in Fig. 8.5.

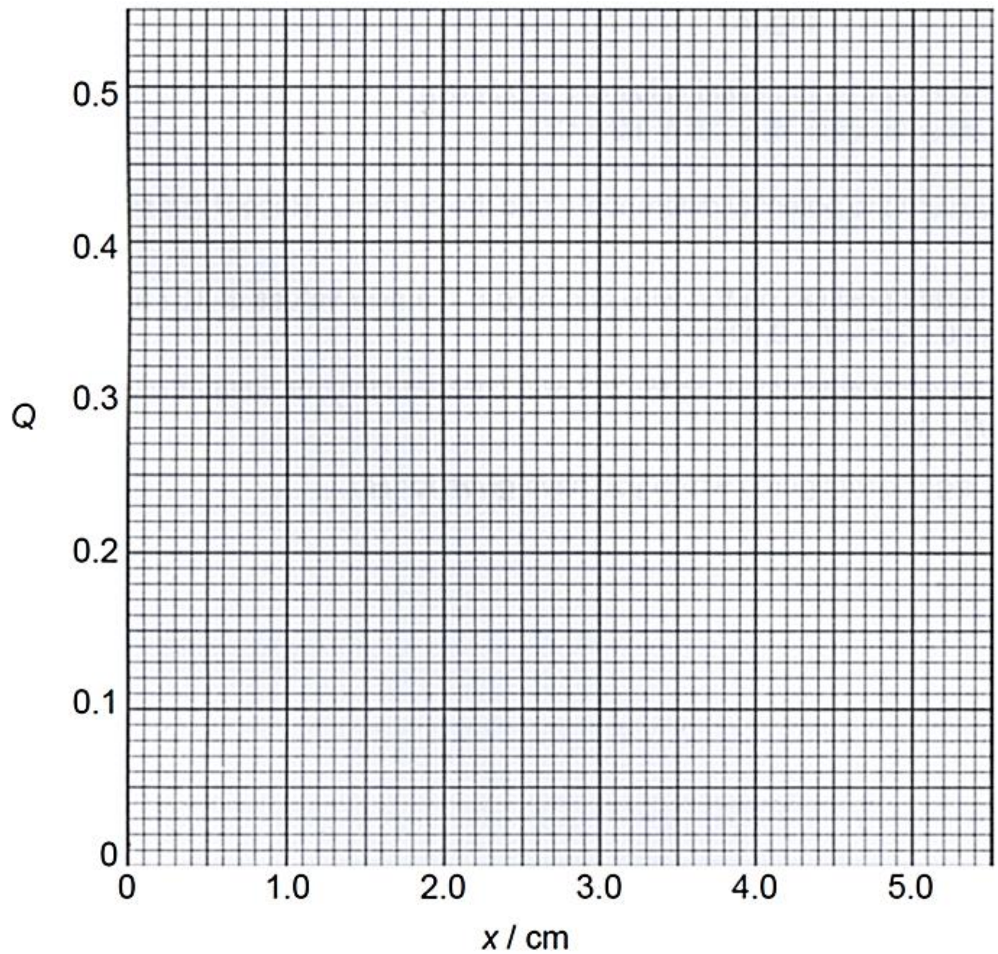

Fig. 8.5

[2]

(ii) Use Fig. 8.5 to determine the rate of change of Q with x when x = 0.5 cm.

rate of change = ………………… cm^{-1} [4]

(iii) It may be deduced from Fig. 8.5 that Q is related to x by an expression of the form

$$Q = \mathrm{a}e^{-\mathrm{b}x}$$

where a and b are constants.

Explain how Fig. 8.5 shows this.

…………………………………………………………………………………………...

…………………………………………………………………………………………...

…………………………………………………………………………………………...

…………………………………………………………………………………………...

……………………………………………………………………………………. [2]

(e) (i) Suggest why the maximum efficiency that can be achieved with low-energy γ-ray photons using the crystal illustrated in Fig. 8.2 is 0.50.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………………..

……………………………………………………………………………………. [2]

(ii) A second crystal consists of a hollow cylinder, as shown in Fig. 8.6.

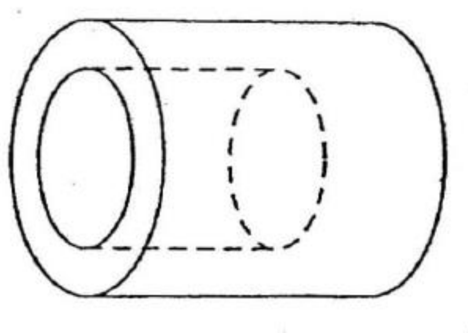

Fig. 8.6

State the effect of this change of shape on the maximum efficiency *Q* of the detector if the source is placed inside the hollow region.

…………………………………………………………………………………………………..

…………………………………………………………………………………………. [1]

END OF PAPER