7 In the first half of the last century, numerous experiments were conducted to investigate the absorption and scattering of X-rays by matter.

It was discovered that when a monochromatic beam of X-rays is incident on a light element such as carbon, the scattered X-rays have wavelengths dependent on the angle of scattering.

Compton (1923) assumed that the scattering process could be treated as an elastic collision between an X-ray photon and a 'free' electron, and that energy and momentum would be conserved.

(a) Explain what is meant by a *photon*.

……

……

…… [2]

(b) The elastic collision between a photon and a stationary electron may be represented as in Fig. 7.1.

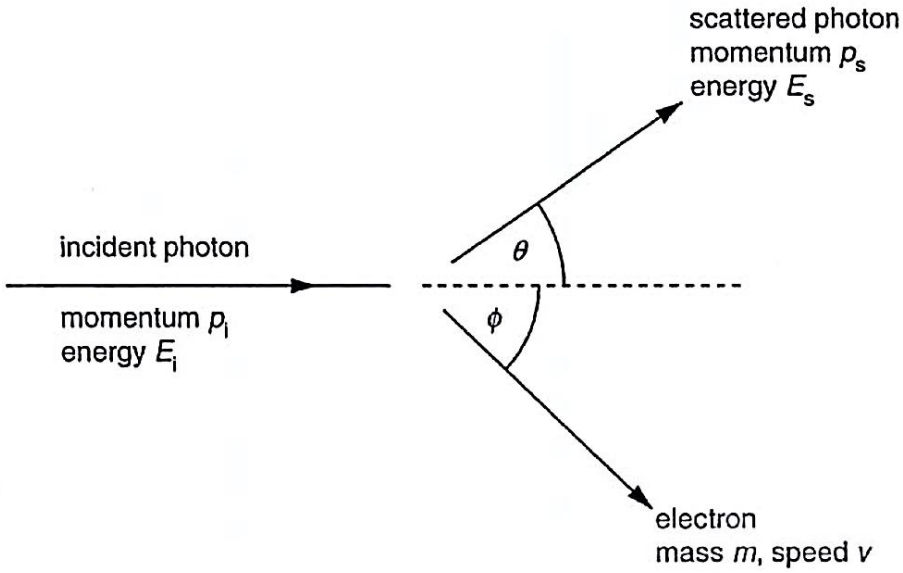

Fig. 7.1

The incident photon has momentum p_i and energy E_i. The photon is scattered through an angle θ and, after scattering has momentum p_s and energy E_s. The electron of mass m, which was originally stationary, moves off with speed v at an angle ϕ to the original direction of the incident photon.

(i) Write down equations, in terms of p_i, p_s, E_i, E_s, m, v, θ and ϕ, that represent, for this interaction,

1. conservation of energy,

…… [1]

2. conservation of momentum along the direction of the incident photon.

…… [1]

(ii) Suggest, with a reason, whether the scattered photon will have a wavelength that is greater or less than that of the incident photon.

……

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…… [3]

(c) In an experiment to provide evidence to justify Compton's theory, measurements were made of the wavelength λ_i of the incident photon, the wavelength λ_s of the scattered photon and the angle θ of scattering. Some data from this experiment are given in Fig. 7.2.

λ_i / 10^{-12} m	λ_s /10^{-12} m	θ / °
191.92	193.27	57
153.30	154.65	57
965.04	966.84	75

Fig. 7.2

Use the data in Fig. 7.2 to show that, when a photon is scattered, the change in wavelength produced is independent of the wavelength of the incident photon.

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…… [2]

(d) In this experiment, the uncertainty in the measurement of θ is $\pm 5°$.
Determine the value of $\cos\theta$, with its uncertainty, for the angle $\theta = 75° \pm 5°$.

$\cos\theta$ = ... ± ..... [3]

(e) Compton's theory suggests that the change in wavelength $\Delta\lambda$ is related to the angle θ of the scattering by this expression

$$\Delta\lambda = k(1 - \cos\theta)$$

where k is a constant.

Experimental data for the variation with $\cos\theta$ of $\Delta\lambda$ are shown in Fig. 7.3.

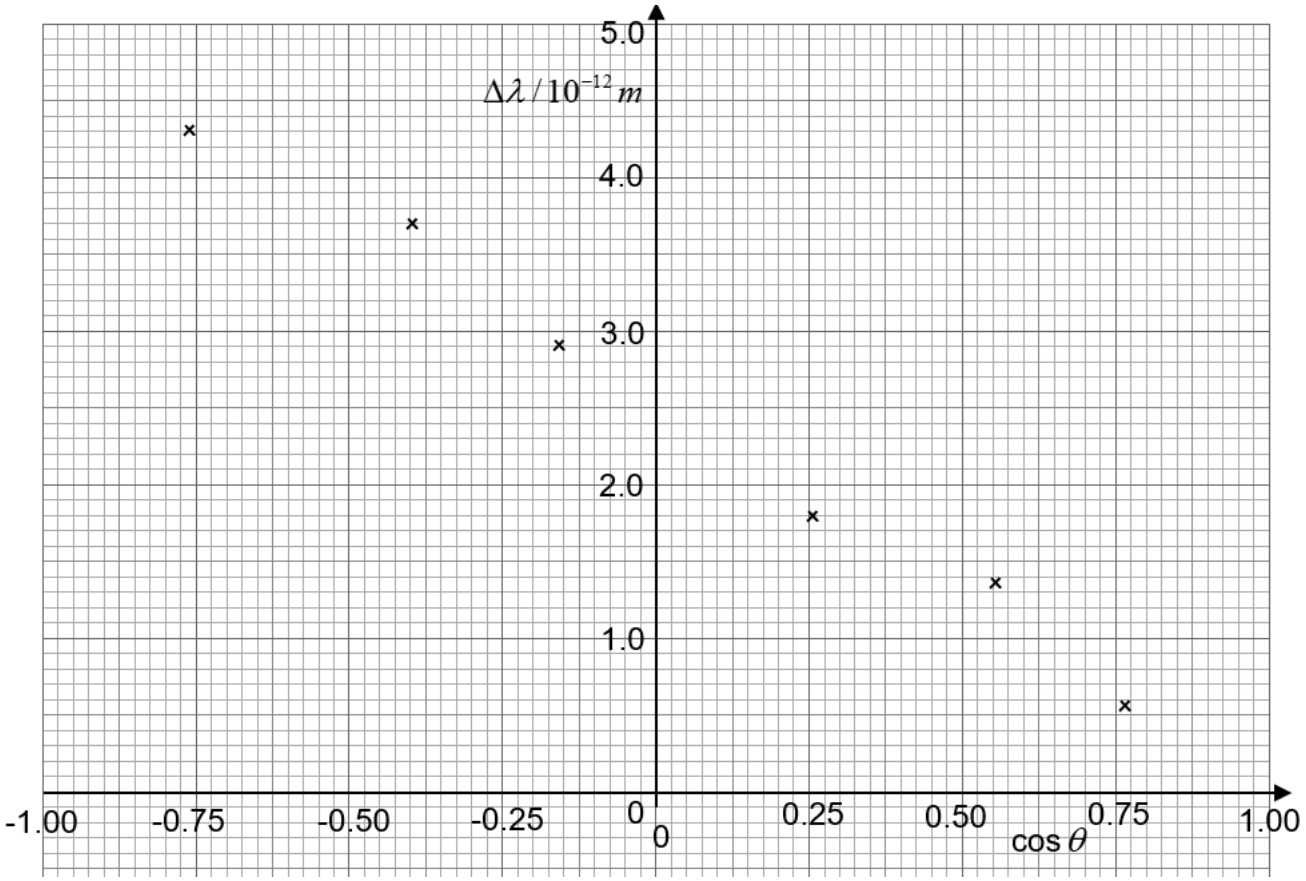

Fig. 7.3

(i) On Fig. 7.3, draw the best-fit line for the points. [1]

(ii) State and explain two different ways by which the constant *k* may be determined from the graph of Fig. 7.3.

……

……

……

…… [3]

(iii) Determine the constant *k,* with its unit.

k = …… [2]

(f) For a carbon atom, the binding energy of an electron is of the order of a few electronvolts.

Compton's theory assumes that the electrons are not bound in the atoms but are free.

Suggest whether, for 30 keV photons, this assumption is justified.

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……

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…… [2]

[Total: 20]

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