22. Quantum Physics

22.1 Energy and momentum of a photon

Paper 4

Question Paper

1 **(a)** State what is meant by a photon.

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..... [2]

(c) For an accelerating voltage of 32 kV in Fig. 8.1, determine:

(i) the maximum energy, in MeV, of an X-ray photon produced at the target

maximum photon energy = ... MeV [1]

(ii) the maximum momentum of an X-ray photon produced at the target

maximum photon momentum = ... N s [2]

2 Fig. 8.1 shows part of the emission spectrum of visible radiation emitted by hydrogen gas in a star in a distant galaxy.

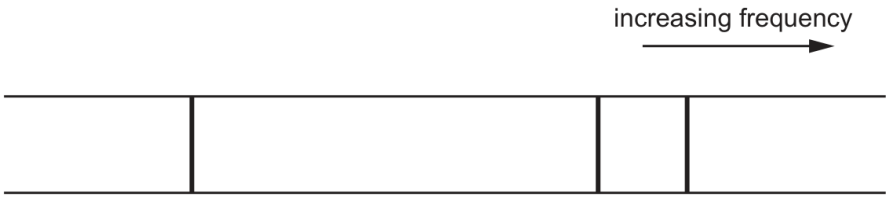


Fig. 8.1

The galaxy is moving away from the Earth at a speed of $6.2 \times 10^6\,\text{m s}^{-1}$.

(b) The lines in Fig. 8.1 correspond to electron transitions down to the energy level –3.40 eV. One of the lines represents emitted radiation of wavelength 488 nm.

(i) Calculate the energy of a photon of this radiation.

photon energy = ... J [2]

3 **(a)** **(i)** Show that the momentum p of a photon of electromagnetic radiation with wavelength λ is given by

$$p = \frac{h}{\lambda}$$

where h is the Planck constant.

[2]

(ii) Use the expression in **(a)(i)** to show that a photon in free space that has a momentum of 9.5×10^{-28} N s is a photon of red light.

[1]

(b) A beam of red light of intensity 160 W m^{-2} is incident normally on a plane mirror, as shown in Fig. 8.1. The momentum of each photon in the beam is 9.5×10^{-28} N s.

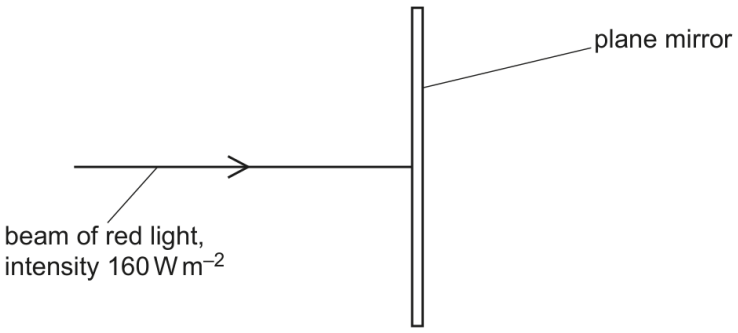


Fig. 8.1

All of the light is reflected by the mirror in the opposite direction to its original path.
The cross-sectional area of the beam is 2.5×10^{-6} m^2.

(i) Show that the number of photons incident on the mirror per unit time is $1.4 \times 10^{15}\,s^{-1}$.

[2]

(ii) Use the information in **(b)(i)** to determine the pressure exerted by the light beam on the mirror.

pressure = ... Pa [3]

(c) The beam of red light in **(b)** is now replaced with a beam of blue light of the same intensity.

Suggest and explain whether the pressure exerted on the mirror by the beam of blue light is less than, the same as, or greater than the pressure exerted by the beam of red light.

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..... [2]

4 **(a)** State what is meant by a photon.

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5 **(b)** Ultraviolet radiation of frequency 1.36×10^{15} Hz is incident, in a vacuum, on a metal surface. The power of the radiation incident on the surface is 8.36 mW. Photoelectrons are emitted with a maximum kinetic energy of 3.09×10^{-19} J.

(i) Determine the number of photons incident on the surface per unit time.

number per unit time = ... s^{-1} [2]

6 **(b)** Ultraviolet radiation of wavelength 250 nm is incident on the surface of a sheet of zinc. The maximum kinetic energy of the emitted electrons is 1.4 eV.

Determine, in eV:

(i) the energy of a photon of the ultraviolet radiation

energy = ... eV [3]

7 **(a)** State what is meant by a *photon*.

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..... [2]

(b) A stationary nucleus of samarium-157 ($^{157}_{62}$Sm) emits a gamma-ray (γ-ray) photon of energy 0.57 MeV.

Determine, for one γ-ray photon:

(i) its wavelength

wavelength = ... m [2]

(ii) its momentum.

momentum = ... N s [2]

(c) **(i)** Using your answer to **(b)(ii)**, determine the speed of the samarium-157 nucleus after emission of the photon.

speed = ... $m\,s^{-1}$ [2]

(ii) By reference to your answer in **(c)(i)**, explain quantitatively why the speed of the samarium-157 nucleus may be assumed to be negligible compared with the speed of the photon.

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..... [1]

8 An electron, at rest, has mass m_e and charge $-q$.

A positron is a particle that, at rest, has mass m_e and charge $+q$.

A positron interacts with an electron. The electron and the positron may be considered to be at rest.
The outcome of this interaction is that the electron and the positron become two gamma-ray (γ-ray) photons, each having the same energy.

(a) Calculate, for one of the γ-ray photons:

(ii) its momentum.

momentum = ... N s [2]

9 A photon of wavelength 540 nm collides with an isolated stationary electron, as illustrated in Fig. 11.1.

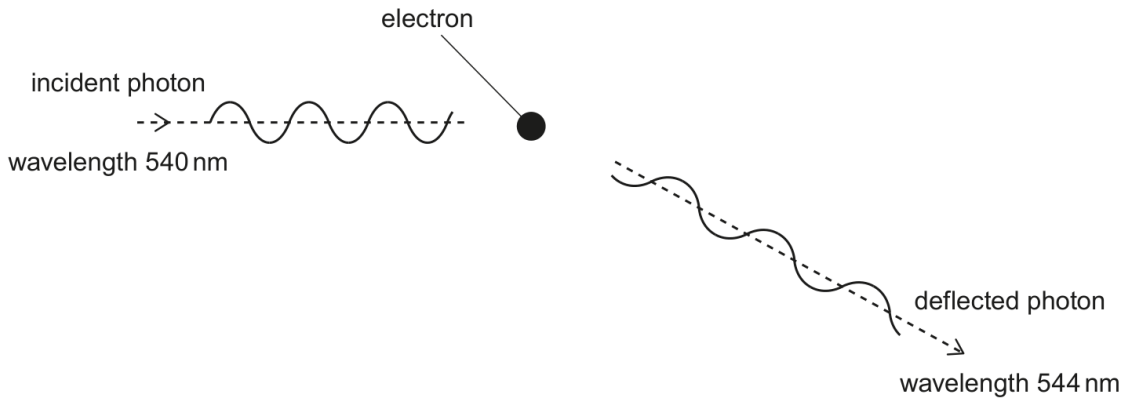


Fig. 11.1

The photon is deflected elastically by the electron.
The wavelength of the deflected photon is 544 nm.

(a) (i) State what is meant by a *photon*.

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..... [2]

(ii) On Fig. 11.1, draw an arrow to indicate the approximate direction of motion of the deflected electron. [1]

(b) Calculate:

(i) the momentum of the deflected photon

momentum = ... N s [2]

(ii) the energy transferred to the deflected electron.

energy = ... J [2]

(c) Another photon of wavelength 540 nm collides with an isolated stationary electron.

Explain why it is not possible for the deflected photon to have a wavelength less than 540 nm.

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..... [2]

10 (b) The work function energies of some metals are shown in Fig. 11.1.

	work function energy / eV
sodium	2.4
calcium	2.9
zinc	3.6
silver	4.3

Fig. 11.1

Each metal is irradiated with electromagnetic radiation of wavelength 380 nm.

(i) Calculate the energy, in eV, of a photon of electromagnetic radiation of wavelength 380 nm.

energy = ...eV [3]

(c) Photons of wavelength 380 nm are incident normally on a metal surface at a rate of $7.6 \times 10^{14}\,s^{-1}$.
All the photons are absorbed in the surface and no photoelectrons are emitted.

Calculate the force exerted on the metal surface by the incident photons.

force = ... N [3]

11 **(a)** State what is meant by a *photon*.

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.....[2]

(b) A stationary cobalt-60 ($^{60}_{27}$Co) nucleus emits a γ-ray photon of energy 1.18 MeV.

(i) Calculate the wavelength of the photon.

wavelength = ... m [2]

(ii) Show that the momentum of the photon is 6.3×10^{-22} N s.

[2]

(c) Use information in **(b)(ii)** to determine the recoil speed of the cobalt-60 nucleus when the γ-ray photon is emitted.

speed = ... m s^{-1} [2]

12 (b) The work function energy of a clean metal surface is 5.5×10^{-19} J.

Electromagnetic radiation of wavelength 280 nm is incident on the metal surface. The metal is in a vacuum.

(i) Calculate:

1. the photon energy

photon energy = ... J [2]

2. the maximum speed v_{MAX} of the electrons emitted from the surface.

v_{MAX} = ... $m\,s^{-1}$ [3]

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

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.....[2]

14 (b) Data for the work function energy Φ of two metals are shown in Fig. 10.1.

	Φ/ J
sodium	3.8×10^{-19}
zinc	5.8×10^{-19}

Fig. 10.1

Light of wavelength 420 nm is incident on the surface of each of the metals.

(i) State what is meant by a *photon*.

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.....[2]

(ii) Calculate the energy of a photon of the incident light.

energy = ... J [2]

15 A stationary isolated nucleus emits a γ-ray photon of energy 0.51 MeV.

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

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.....[2]

(b) For the γ-ray photon, calculate

(i) its wavelength,

wavelength = ... m [2]

(ii) its momentum.

momentum = ...N s [2]

(c) (ii) Explain why, after the decay, the nucleus is no longer stationary.

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