1. Nov/2023/Paper_9702/41/No.8

(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 $160\,\text{W m}^{-2}$ 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.

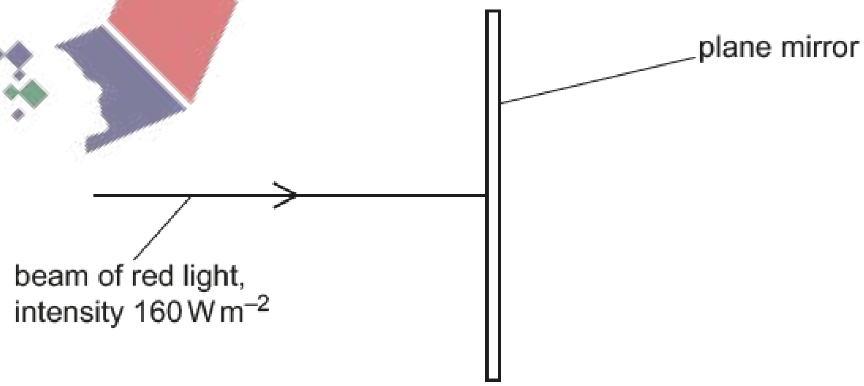

Fig. 8.1

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 $2.5 \times 10^{-6}\,\text{m}^2$.

(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.

....

....

....

.... [2]

[Total: 10]

2. Nov/2023/Paper_9702/42/No.8

(a) State what is meant by a photon.

....

....

.... [2]

(b) When the surface of a metal plate is illuminated with electromagnetic radiation, electrons are sometimes emitted from the metal.

(i) State the name of this phenomenon.

.... [1]

(ii) It is observed that this phenomenon occurs only when the frequency of the electromagnetic radiation is greater than a certain minimum value, regardless of the intensity of the radiation.

Explain how this observation provides evidence for the existence of photons.

....

....

....

....

.... [3]

(c) Fig. 8.1 shows the variation of the maximum kinetic energy of the emitted electrons in **(b)** with the frequency of the incident radiation.

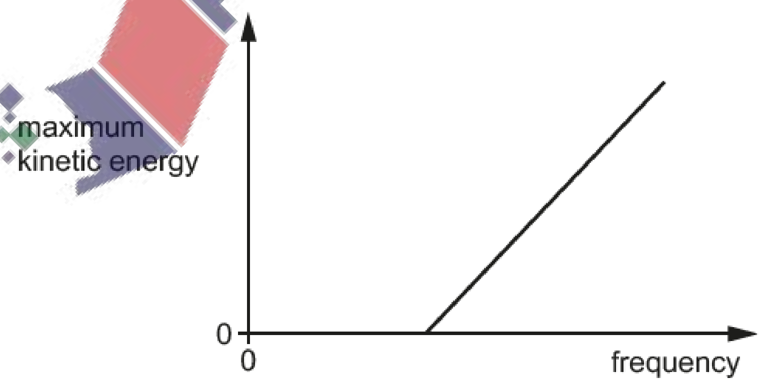

Fig. 8.1

State the name of the quantity represented by:

(i) the gradient of the line in Fig. 8.1

.... [1]

(ii) the *y*-intercept of the extrapolated line in Fig. 8.1.

.... [1]

[Total: 8]

3. June/2023/Paper_9702/41/No.7

(a) State what is meant by the de Broglie wavelength.

....

.... [1]

(b) Fig. 7.1 shows a glass tube in which electrons are accelerated through a high p.d. to form a beam that is incident on a thin graphite crystal.

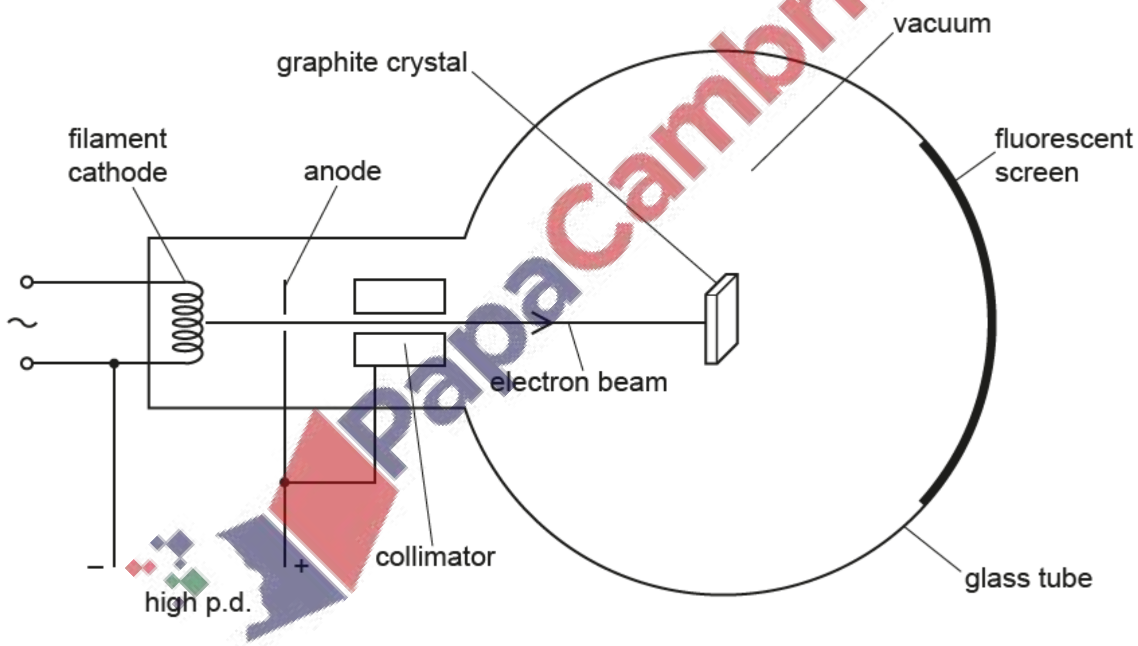

Fig. 7.1 (not to scale)

After passing through the graphite crystal, the electrons reach the fluorescent screen. The screen glows where the electrons strike it.

Fig. 7.2 shows the fluorescent screen viewed end-on, from the right-hand side of Fig. 7.1.

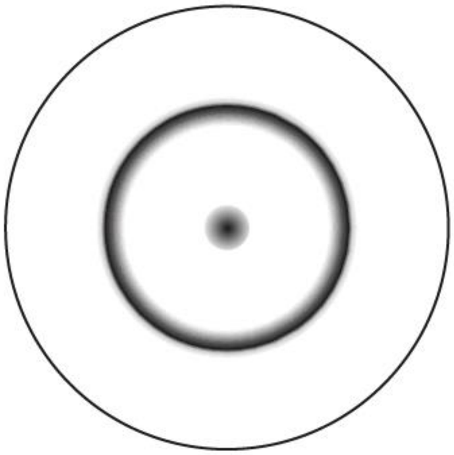

Fig. 7.2

(i) State the name of the phenomenon demonstrated by the pattern shown in Fig. 7.2.

.... [1]

(ii) Explain what can be concluded from the pattern in Fig. 7.2 about the nature of electrons.

....

....

.... [2]

(c) The electrons in **(b)** are now accelerated through a greater potential difference between the cathode and the anode.

(i) On Fig. 7.3, sketch the pattern that is now seen on the fluorescent screen in Fig. 7.1.

Fig. 7.3

[2]

(ii) Explain, with reference to de Broglie wavelength, the change in the pattern on the fluorescent screen.

....

....

....

....

.... [3]

[Total: 9]

4. June/2023/Paper_9702/42/No.8

Fig. 8.1 shows the lowest four energy levels of an electron in an isolated atom.

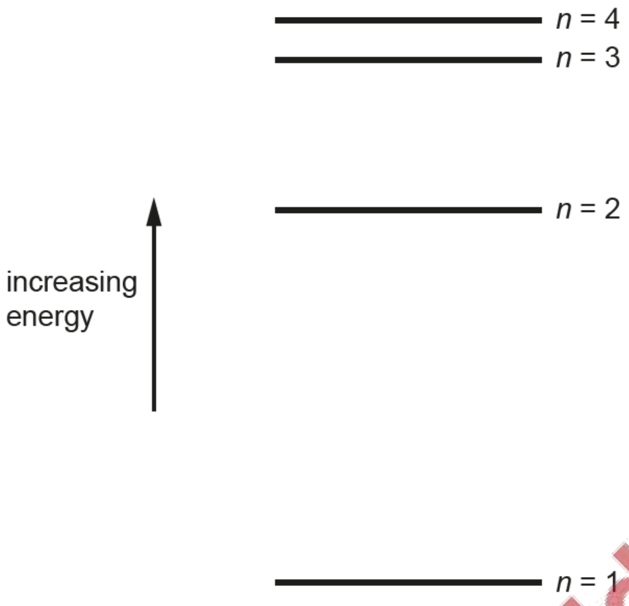

Fig. 8.1

Fig. 8.2 shows the lines in the emission spectrum of the atom that correspond to the transitions of the electron from $n = 3$ to $n = 1$ and from $n = 4$ to $n = 1$.

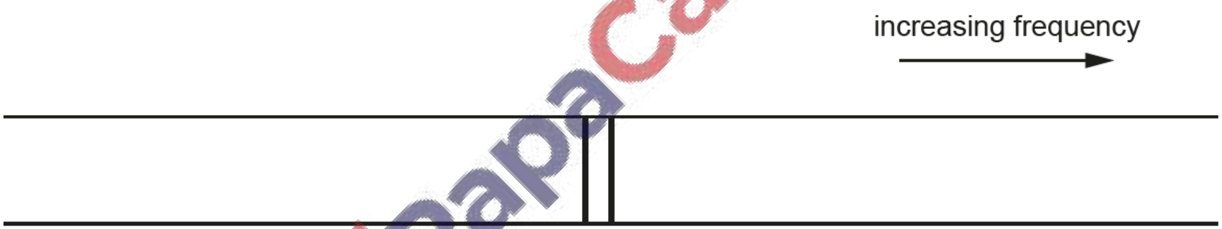

Fig. 8.2

(a) Explain, with reference to photons, why there is a single frequency of electromagnetic radiation that corresponds to each of these transitions.

....

....

.... [2]

(b) **(i)** On Fig. 8.2, draw a line that corresponds to the transition of the electron from $n = 2$ to $n = 1$. Label this line A. [2]

(ii) On Fig. 8.2, draw a line that corresponds to the transition of the electron from $n = 3$ to $n = 2$. Label this line B. [2]

(c) The frequency of radiation represented by line A is f_A.
The frequency of radiation represented by line B is f_B.
The energy of the ground state ($n = 1$) is E_1.

Determine an expression, in terms of f_A, f_B, E_1 and the Planck constant h, for the energy E_3 of the energy level $n = 3$.

E_3 = ... [2]

[Total: 8]

5. March/2023/Paper_9702/42/No.7

(a) A beam of white light passes through a cloud of cool gas. The spectrum of the transmitted light is viewed and contains a number of dark lines.

Explain why these dark lines occur.

....

....

....

....

....

....

....

....

.... [4]

(b) Some energy levels for the electron in an isolated hydrogen atom are illustrated in Fig. 7.1.

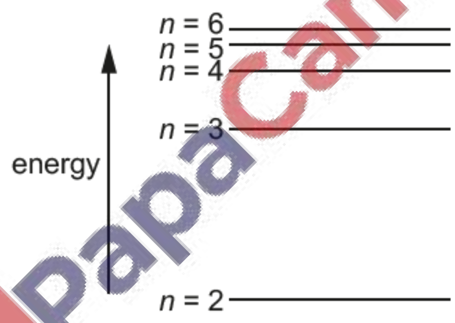

Fig. 7.1

Table 7.1 shows the wavelengths of photons that are emitted in the transitions to n = 2 from the other energy levels shown in Fig. 7.1.

Table 7.1

wavelength / nm
412
435
488
658

The energy associated with the energy level n = 2 is –3.40 eV.

Calculate the energy, in J, of energy level $n = 3$.

energy = ... J [3]

[Total: 7]