9 **(a)** State what is meant by the photoelectric effect.

....

....

.... [2]

(b) The photoelectric effect is investigated using two clean metal plates. One plate is made from metal X and the other is made from metal Y.

Metal X has work function energy Φ. Metal Y has work function energy 2Φ.
Metal X has threshold frequency F.

State expressions, in terms of either or both of Φ and F, for

(i) the threshold frequency of metal Y

threshold frequency = ... [1]

(ii) the Planck constant.

Planck constant = ... [1]

(c) The maximum kinetic energy E_K of photoelectrons is determined for each of the plates in **(b)** for different frequencies f of incident radiation.

On Fig. 9.1, sketch the variation of E_K with f for each plate. Label your lines X and Y to identify which line relates to which plate.

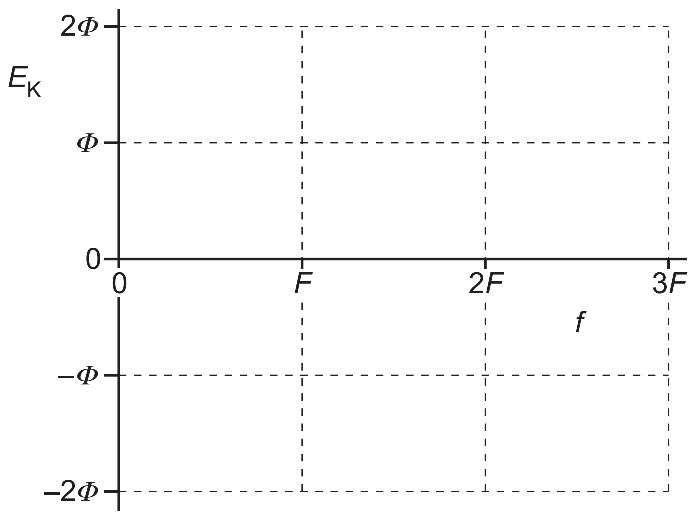

Fig. 9.1

[4]

8 Fig. 8.1 shows the three lowest-frequency lines in the part of the emission spectrum for hydrogen that relates to electron transitions to the ground state (level $n = 1$).

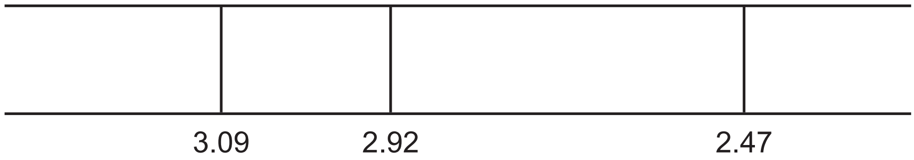

Fig. 8.1 (not to scale)

The numbers represent the frequencies, in 10^{15} Hz, associated with the spectral lines.

(a) Use the photon model of electromagnetic radiation to explain how the existence of spectral lines in the emission spectrum provides evidence for discrete electron energy levels in the hydrogen atom.

....

....

....

....

.... [3]

(b) The energy of the ground state (level $n = 1$) in a hydrogen atom is –13.6 eV.

(i) Calculate the energy, in J, of the ground state.

energy = ... J [1]

(ii) Show that the energy difference between levels $n = 1$ and $n = 2$ is 10.2 eV.

[2]

(iii) Complete Table 8.1 to show the energy differences from the ground state, and the energies of the levels up to $n = 4$, in the hydrogen atom. Use the space for any working.

Table 8.1

level	(energy difference from $n = 1$) / eV	energy / eV
$n = 4$		
$n = 3$		
$n = 2$	10.2	
$n = 1$	0.0	–13.6

[4]

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

....

....

.... [2]

(b) A stationary nucleus of uranium-238 ($^{238}_{92}U$) undergoes alpha decay to produce a nucleus of thorium-234 ($^{234}_{90}Th$). The kinetic energy of the emitted alpha particle is 4.200 MeV. A gamma-ray photon is also emitted during the decay.

Assume that the rebound kinetic energy of the thorium nucleus is negligible.

Table 8.1 shows the masses of the nuclides involved in the decay reaction. The mass of the uranium-238 nuclide is missing.

Table 8.1

nuclide	nuclide mass / u
$^{4}_{2}\alpha$	4.000 407
$^{234}_{90}Th$	233.915 174
$^{238}_{92}U$	

The total energy released in the decay of the nucleus of uranium-238 is 4.274 MeV.

(i) Calculate the mass, in u, of the uranium-238 nuclide. Give your answer to five decimal places.

mass = ... u [3]

(ii) Determine a value for the wavelength of the gamma radiation emitted during the decay of the uranium-238 nucleus.

wavelength = ... m [3]

(iii) In practice, the rebound kinetic energy of the thorium nucleus is **not** negligible.

Explain, without further calculation, how your answer in **(b)(ii)** compares with the true wavelength of gamma radiation emitted during the decay of the uranium-238 nucleus.

....

....

.... [1]

(c) Gamma radiation emitted during the decay of a sample of uranium-238 has a single wavelength.

Nuclei of cobalt-60 ($^{60}_{27}Co$) decay by beta emission, and also emit gamma radiation in the process.

Suggest why there is **not** a single wavelength for the gamma radiation emitted during the decay of a sample of cobalt-60.

....

....

.... [2]

9 **(a)** **(i)** Describe what is meant by wave–particle duality.

....

....

.... [2]

(ii) State the relationship between the de Broglie wavelength λ of a particle and its momentum p. State the meaning of any other symbols that you use.

....

.... [2]

(b) A narrow beam of electrons, all with the same speed, is incident normally on a carbon film. The electrons then move on to a fluorescent screen, as illustrated in Fig. 9.1.

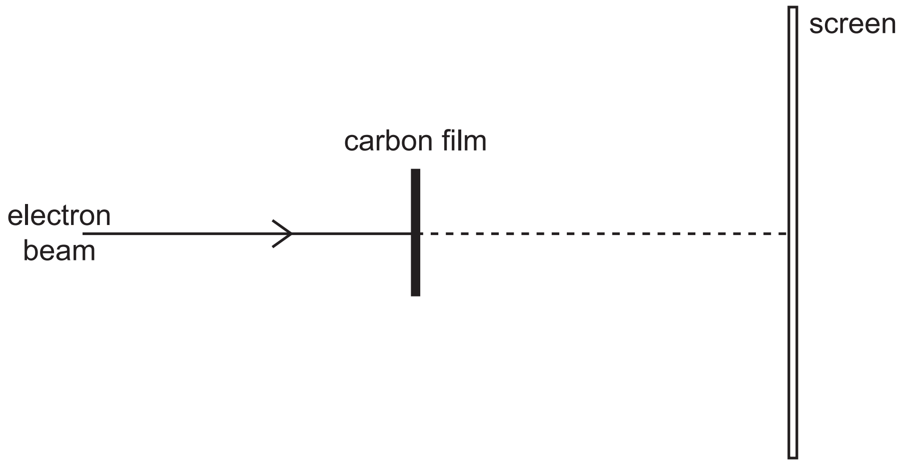

Fig. 9.1

The apparatus is in a vacuum.
The pattern produced on the screen is shown in Fig. 9.2.

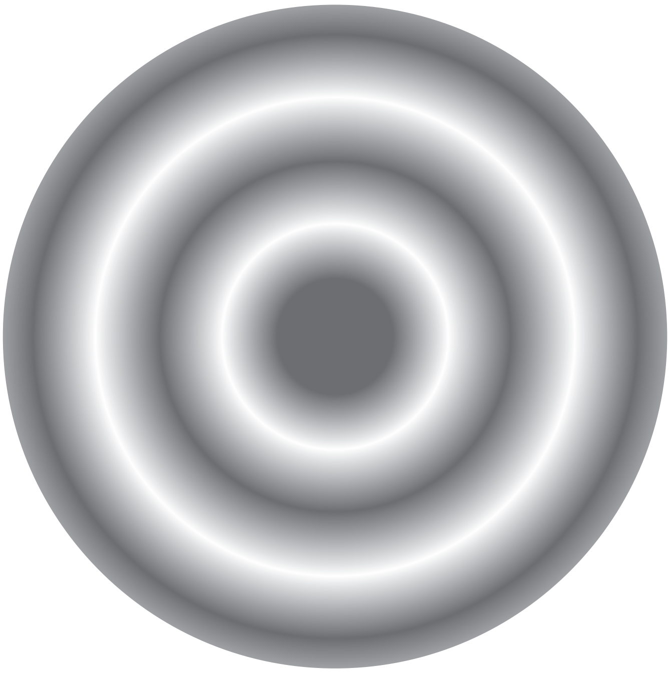

Fig. 9.2 (not to scale)

(i) Explain why the pattern in Fig. 9.2 provides experimental evidence to indicate a wave nature for the electrons.

....

....

.... [2]

(ii) The speed of the electrons is increased.

Suggest, with a reason, how this change affects the pattern observed on the screen.

....

....

.... [2]

9 **(a)** State what is meant by the photoelectric effect.

....

....

.... [2]

(b) The photoelectric effect is investigated in two stages using the circuit shown in Fig. 9.1.

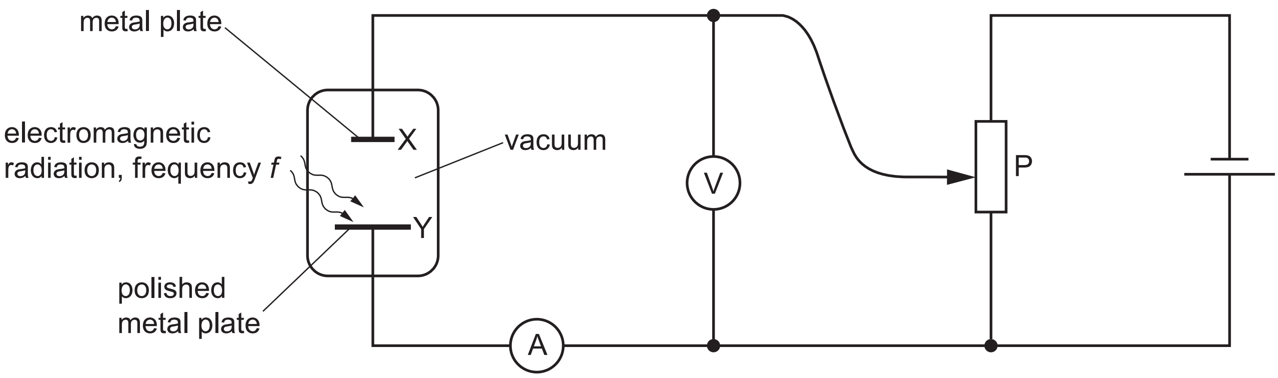

Fig. 9.1

The polished metal plate Y is illuminated with electromagnetic radiation of frequency f and constant power.

In stage 1 of the investigation, frequency f is set to a constant value of 2.5×10^{15} Hz. The current I in the ammeter is varied by adjusting the potentiometer P. Fig. 9.2 shows the variation of I with the voltmeter reading V. There is a value V_S of V at which the current just falls to zero.

In stage 2 of the investigation, stage 1 is repeated for different values of frequency. As frequency f is varied, the voltmeter reading V_S at which the current just falls to zero is measured. Fig. 9.3 shows the variation of V_S with f.

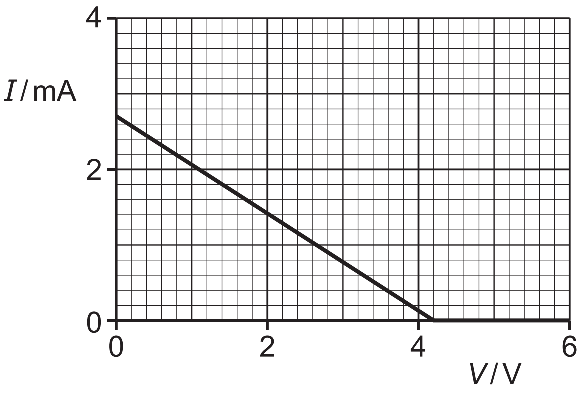

Fig. 9.2

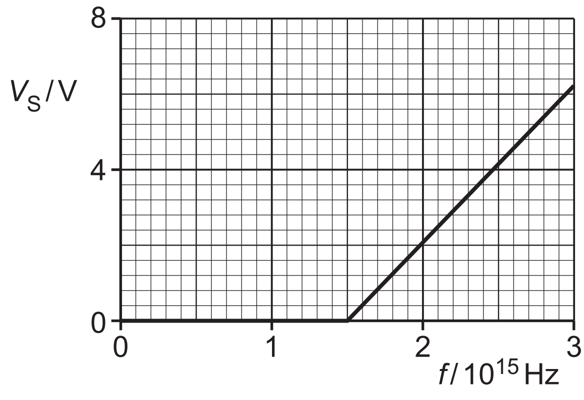

Fig. 9.3

(i) Explain, with reference to photons, why V_S depends on the frequency of the incident electromagnetic radiation.

....

....

....

....

....

.... [3]

(ii) State **three** quantitative conclusions that can be drawn from the results in Fig. 9.2 and Fig. 9.3. Use the space for any working.

1 ....

....

2 ....

....

3 ....

....

[3]

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

....

.... [1]

(b) Calculate the de Broglie wavelength of an electron moving at a speed of $4.9 \times 10^7\,\mathrm{m\,s^{-1}}$.

wavelength = ... m [2]

(c) State **one** similarity and **one** difference between an electron and a positron.

similarity: ....

....

difference: ....

....
[2]

(d) An electron moving at a speed of $4.9 \times 10^7\,\mathrm{m\,s^{-1}}$ collides with a positron that is travelling at the same speed in the opposite direction. As a result of the collision, two gamma-ray photons are produced.

(i) State the name of this type of reaction.

.... [1]

(ii) State what happens to the electron and to the positron.

....

....

.... [2]

(iii) Explain why two gamma-ray photons are produced, rather than just one.

....

.... [1]

(iv) Show that the kinetic energy of the electron before the collision is 1.1×10^{-15} J.

[1]

(v) Use the information in **(d)(iv)** to determine, to three significant figures, the wavelength associated with the gamma radiation emitted in the collision.

wavelength = ... m [3]

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

....

....

.... [2]

(b) A laser emits red light of a single wavelength. The light is produced when electrons move from a higher energy level to a lower energy level. The difference in energy between the two levels is 1.96 eV.

(i) Calculate the wavelength of the light.

wavelength = ... m [3]

(ii) The power of the beam emitted by the laser is 1.0×10^{-2} W.

Calculate the number of photons emitted per unit time by the laser.

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

(iii) The photons are incident normally on a surface. Half of the number of photons are absorbed by the surface, and half are reflected.

Determine the average force exerted by the beam of photons on the surface.

average force = ... N [4]

9 Electrons in a vacuum are accelerated from rest through a potential difference (p.d.) V to form a beam. The electrons each have mass m and charge q.

The beam is incident on a graphite crystal that acts as a diffraction grating. After passing through the crystal, the beam reaches a fluorescent screen. An interference pattern is observed on this screen.

(a) Explain what this observation shows about the nature of electrons.

....

....

.... [1]

(b) Determine an expression, in terms of m, q and V, for the momentum p of an electron in the beam.

p = ... [3]

(c) The p.d. through which the electrons are accelerated is now increased to a greater value.

Describe and explain the effect of this change on the interference pattern observed.

....

....

.... [2]

(d) The electrons are now accelerated through different values of *V*, resulting in pairs of corresponding values for *p* and the de Broglie wavelength λ.

(i) On Fig. 9.1, sketch the variation of *p* with $\frac{1}{\lambda}$.

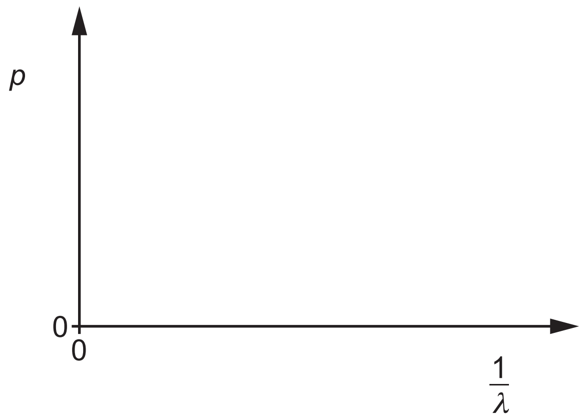

Fig. 9.1

[2]

(ii) State the name of the quantity represented by the gradient of the line in Fig. 9.1.

.... [1]

8 A polished sheet of magnesium in a vacuum emits electrons when it is illuminated by ultraviolet radiation.

(a) State the name of this phenomenon.

.... [1]

(b) For emission of electrons to occur, the frequency of the ultraviolet radiation must be at least 8.8×10^{14} Hz.

(i) Calculate the work function energy of magnesium.

work function energy = ... J [2]

(ii) For ultraviolet radiation with a frequency of 11×10^{14} Hz, calculate the maximum speed of the emitted electrons.

maximum speed = ... $m\,s^{-1}$ [3]

(c) The frequency f of the ultraviolet radiation incident on the magnesium sheet is varied between 8.0×10^{14} Hz and 11×10^{14} Hz.

On Fig. 8.1, sketch the variation with f of the maximum kinetic energy E_{MAX} of the emitted electrons. Use the space below for any working that you need.

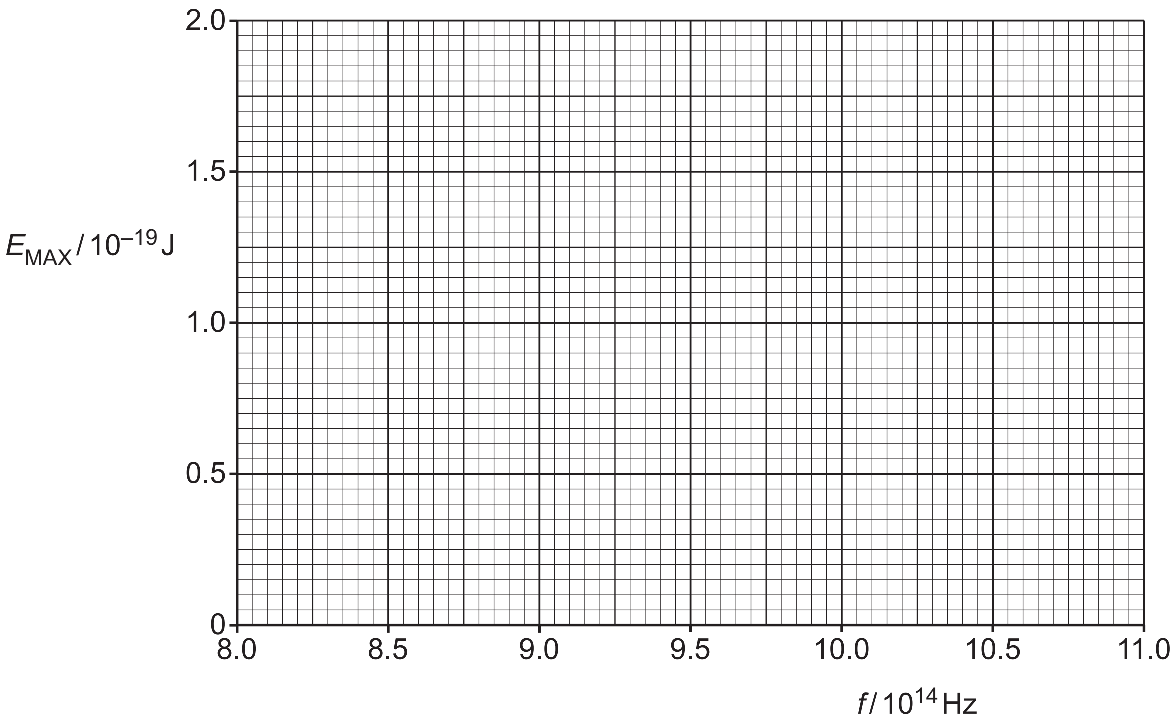

Fig. 8.1

[3]

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

....

....

.... [2]

(b) Fig. 8.1 shows a tube in which X-rays are produced at a metal target.

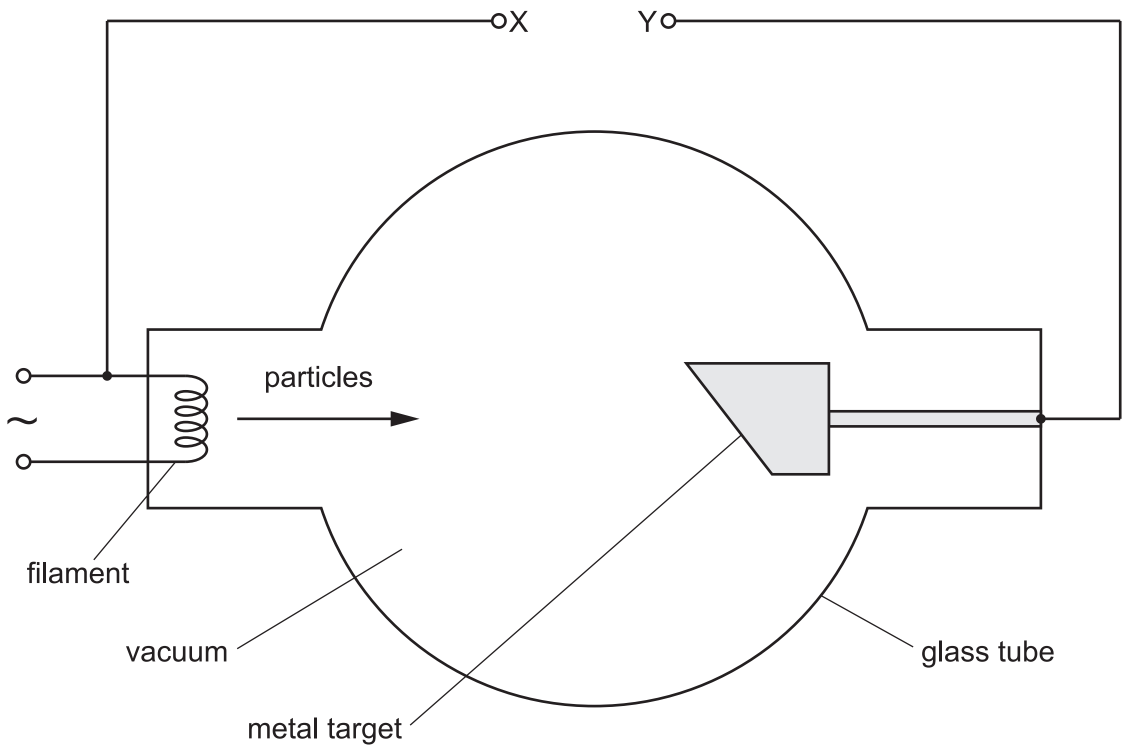

Fig. 8.1

Particles are accelerated from the filament to the target by a constant high voltage applied across the terminals X and Y.

(i) State the name of the particles.

.... [1]

(ii) On Fig. 8.1, use + and – signs to label terminals X and Y to indicate the polarity of the high voltage. [1]

(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]

(iii) the minimum wavelength of X-rays produced at the target.

minimum wavelength = ... m [3]

(d) Explain why X-rays can be used to produce images of internal body structures that have good contrast.

....

....

....

....

.... [3]

7 **(a)** A photon has an energy of 3.11×10^{-19} J.

Calculate the momentum of the photon.

momentum = ... N s [2]

(b) A laser beam has a power of 350 mW. The light from the laser has a wavelength of 640 nm.

(i) Determine the number of photons emitted by the laser in a time of 1.0 s.

number = ... [2]

(ii) The laser beam is incident normally on a surface that absorbs all of the photons.

Show that the force F exerted on the surface by the laser beam is given by

$$F = \frac{P}{c}$$

where P is the power of the laser beam and c is the speed of light.

[2]

(c) Light of a single wavelength is incident on the surface of different metals. The work function energy of the metals is given in Table 7.1.

Table 7.1

metal	work function energy / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

(i) Explain the term threshold wavelength.

....

....

.... [1]

(ii) For the metals in Table 7.1, calculate the value of the largest threshold wavelength.

threshold wavelength = ... m [2]

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.

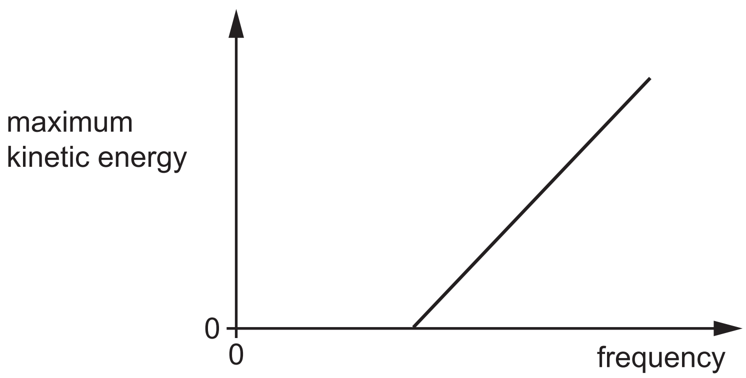

Fig. 8.1

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]

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 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.

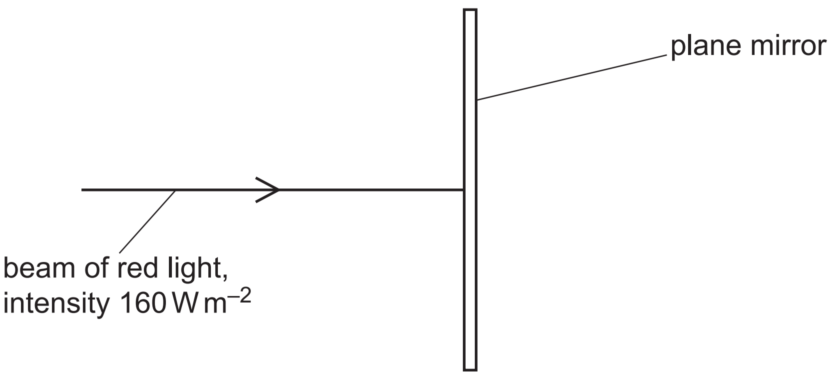

Fig. 8.1

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.

....

....

....

.... [2]

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

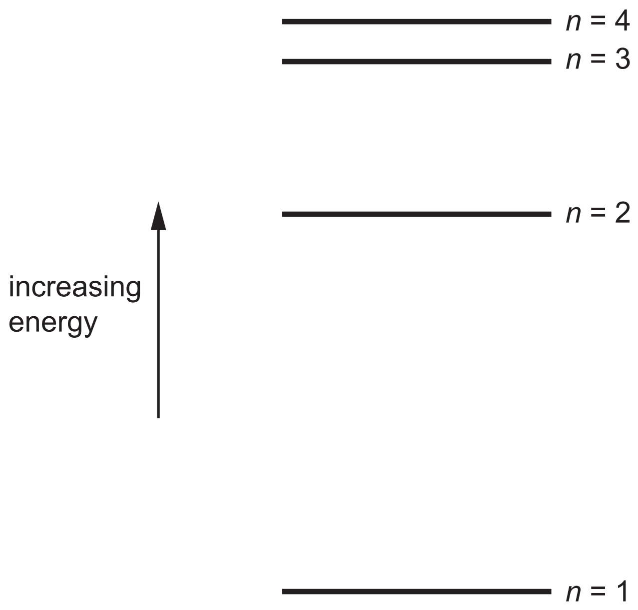

Fig. 8.1

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.

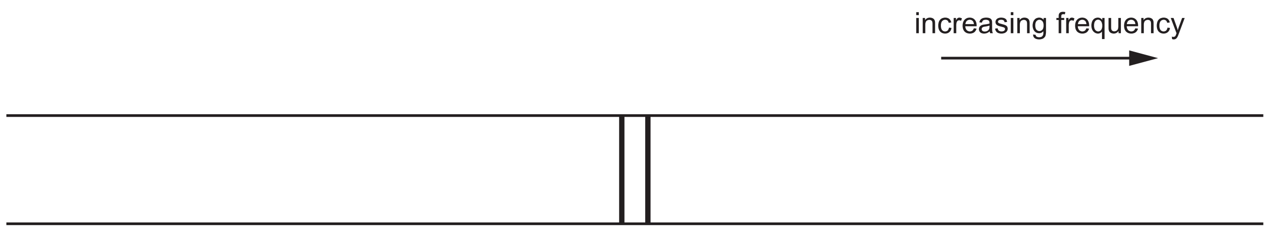

Fig. 8.2

(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]

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.

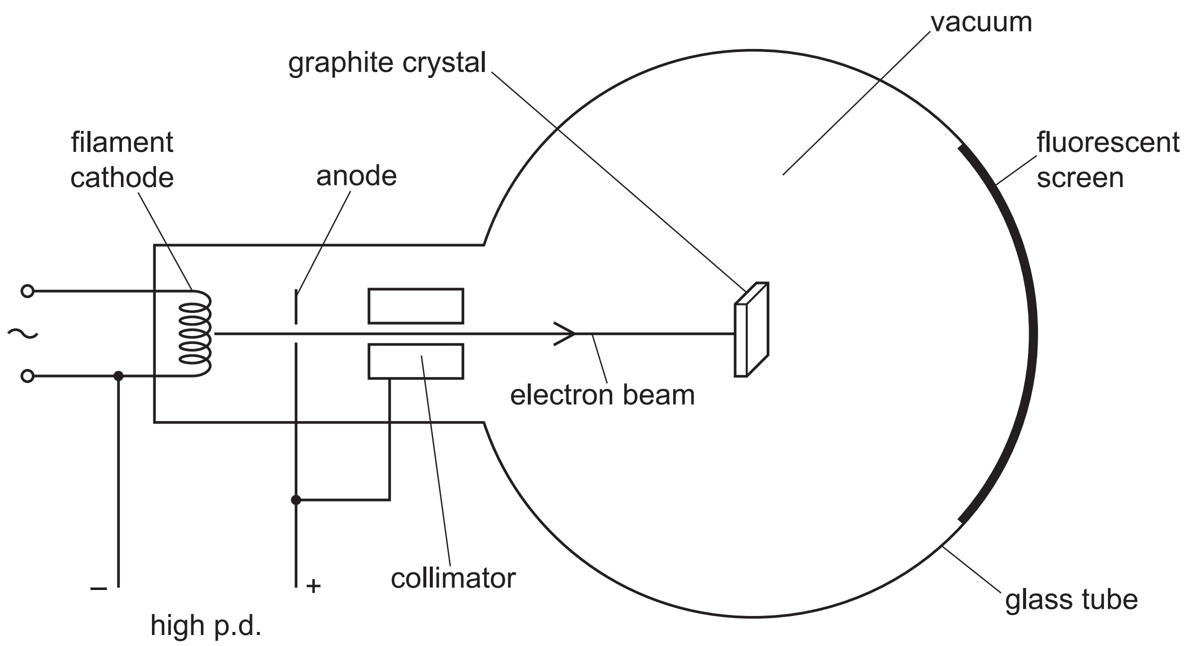

Fig. 7.1 (not to scale)

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.

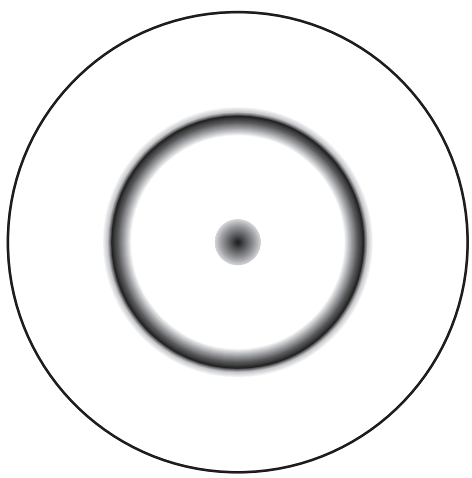

Fig. 7.2

(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.

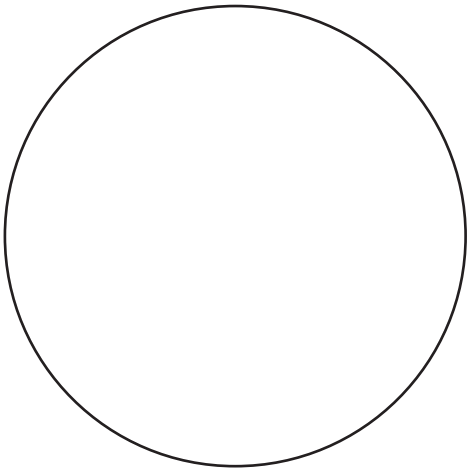

Fig. 7.3

[2]

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

....

....

....

....

.... [3]

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.

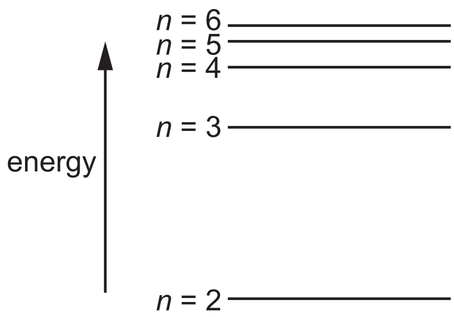

Fig. 7.1

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]

9 **(a)** Fig. 9.1 shows the visible part of the emission spectrum from hydrogen gas in a laboratory on the Earth. The numbers indicate the wavelength, in nm, represented by each line.

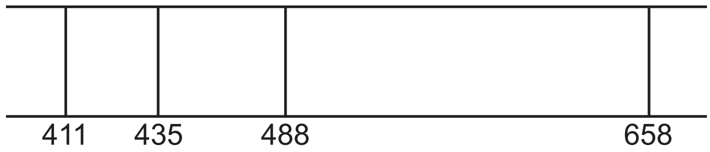

Fig. 9.1

(i) Explain how the emission spectrum provides evidence for the existence of discrete energy levels for the electron in a hydrogen atom.

....

....

....

.... [3]

(ii) Fig. 9.2 shows five of the energy levels in the hydrogen atom. The wavelengths of radiation shown in Fig. 9.1 relate to transitions to the –3.400 eV level in Fig. 9.2.

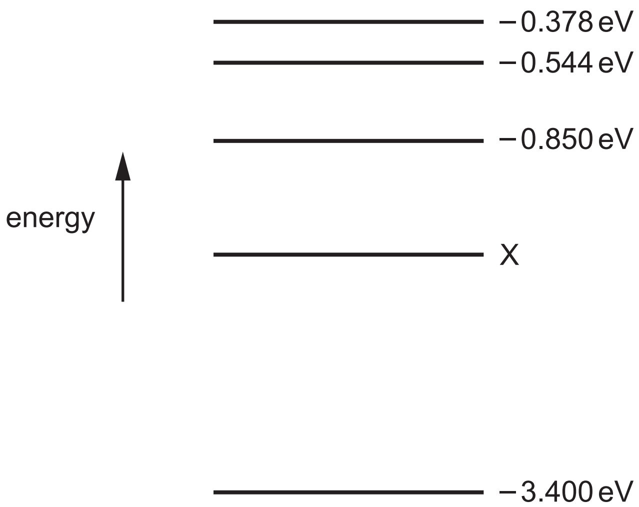

Fig. 9.2 (not to scale)

Show that the energy level X is –1.51 eV.

[3]

(b) The same part of the emission spectrum from hydrogen as in **(a)**, observed in light from stars in a distant galaxy, is shown in Fig. 9.3. The numbers indicate the wavelengths in nm.

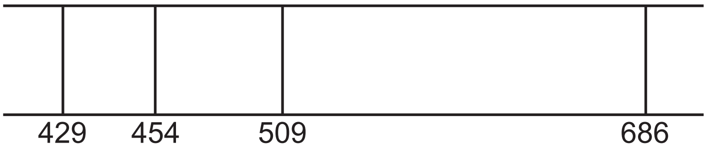

Fig. 9.3

The spectrum shows the same pattern as Fig. 9.1 but with different wavelengths.

(i) State the name of the phenomenon that gives rise to the change in the wavelengths.

.... [1]

(ii) State what this phenomenon shows about the motion of the galaxy.

.... [1]

(iii) Use one of the lines in Fig. 9.1, and the corresponding line in Fig. 9.3, to determine the speed of the distant galaxy relative to the observer.

speed = ... $\mathrm{m\,s^{-1}}$ [3]

(c) The galaxy in **(b)** is known to be a distance of 5.7×10^{24} m from the Earth.

Use your answer in **(b)(iii)** to determine a value for the Hubble constant H_0.

H_0 = ... $\mathrm{s^{-1}}$ [2]

8 **(a)** State what is meant by the work function energy of a metal.

....

....

.... [2]

(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]

(ii) Calculate the work function energy Φ of the metal.

Φ = ... J [2]

(c) The frequency of the radiation incident on the surface in **(b)** is increased while the power remains constant.

State and explain the effect of this change on:

(i) the maximum kinetic energy of the photoelectrons

....

....

.... [2]

(ii) the rate of emission of photoelectrons.

....

....

.... [2]