For Examiner's Use

1 Electrons are emitted from a metal surface when it is illuminated with suitable electromagnetic radiation.

(a) Name the effect described above.

....[1]

(b) The variation with frequency f of the maximum kinetic energy E_k of the emitted electrons is shown in Fig. 7.1.

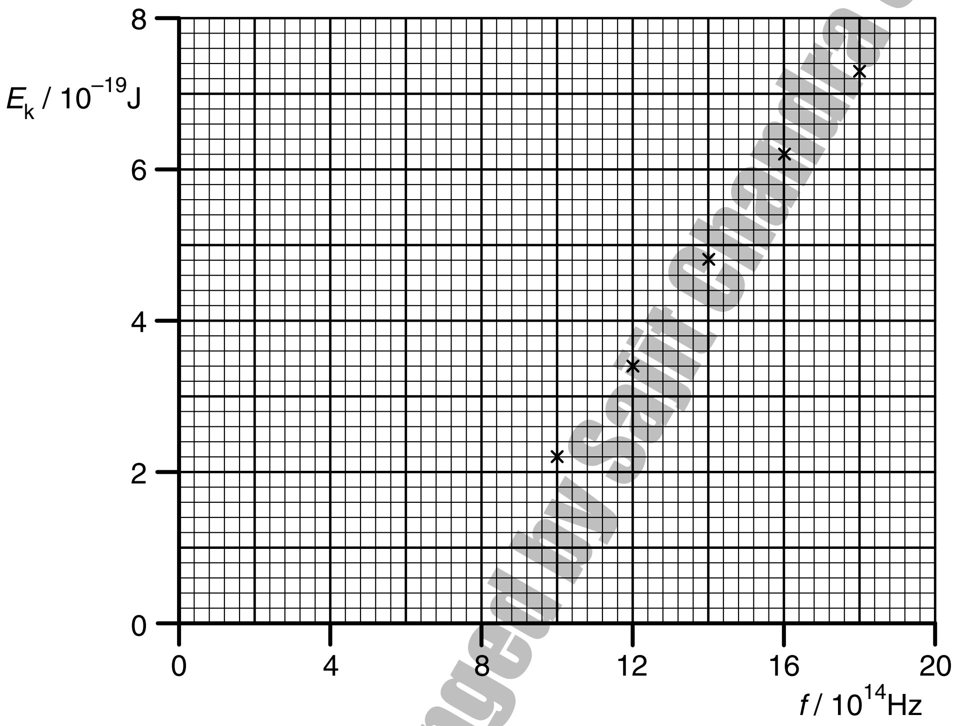

Fig. 7.1

Use Fig. 7.1 to determine

(i) the threshold frequency of the radiation,

threshold frequency = ... Hz

(ii) a value for the Planck constant.

Planck constant = ... J s
[4]

(c) On Fig. 7.1, draw a line to show the variation with frequency f of the maximum kinetic energy E_k of the emitted electrons for a second metal which has a lower work function than that in **(b)**. [2]

(d) The kinetic energy of the electrons is described as the maximum. Suggest why emitted electrons are likely to have a range of values of kinetic energy for any one frequency of the electromagnetic radiation.

....

....

....[2]

For Examiner's Use

2 **(a)** State the de Broglie relation, explaining any symbols you use.

....

....

.... [2]

(b) An electron of mass m has kinetic energy E. Show that the de Broglie wavelength λ of this electron is given by

$$\lambda = \frac{h}{\sqrt{2mE}}.$$

[2]

(c) Calculate the potential difference through which an electron, initially at rest, must be accelerated so that its de Broglie wavelength is equal to 0.40 nm (the diameter of an atom).

potential difference = ... V [3]

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

....

.... [1]

(ii) Show that the photon energy of light of wavelength 350 nm is 5.68×10^{-19} J. [1]

(iii) State the value of the ratio

$$\frac{\text{energy of photon of light of wavelength 700 nm}}{\text{energy of photon of light of wavelength 350 nm}}.$$

ratio = …………….. [1]

(b) Two beams of monochromatic light have similar intensities. The light in one beam has wavelength 350 nm and the light in the other beam has wavelength 700 nm.

The two beams are incident separately on three different metal surfaces. The work function of each of these surfaces is shown in Fig. 5.1.

metal	work function / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

Fig. 5.1

(i) Explain what is meant by the *work function* of the surface.

....

....

.... [2]

For Examiner's Use

(ii) State which combination, if any, of monochromatic light and metal surface could give rise to photo-electric emission. Give a quantitative explanation of your answer.

....

....

....

....

....

.... [3]

4 **(a)** Explain why, for the photoelectric effect, the existence of a threshold frequency and a very short emission time provide evidence for the particulate nature of electromagnetic radiation, as opposed to a wave theory.

....

....

....

....

....

.... [4]

(b) State and explain two relations in which the Planck constant *h* is the constant of proportionality.

1. ....

....

....

....

2. ....

....

....

....

[6]

For Examiner's Use

5 The photoelectric effect may be summarised in terms of the word equation

photon energy = work function energy + maximum kinetic energy of emitted electrons.

(a) Explain

(i) what is meant by a *photon*,

....

....

.... [2]

(ii) why most electrons are emitted with kinetic energy less than the maximum.

....

....

.... [2]

(b) Light of constant intensity is incident on a metal surface, causing electrons to be emitted.

State and explain why the rate of emission of electrons changes as the frequency of the incident light is increased.

....

....

.... [2]

For Examiner's Use

6 **(a)** State three pieces of evidence provided by the photoelectric effect for a particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

3. ....

....
[3]

(b) **(i)** Briefly describe the concept of a photon.

....

....

.... [2]

(ii) Explain how lines in the emission spectrum of gases at low pressure provide evidence for discrete electron energy levels in atoms.

....

....

.... [2]

(c) Three electron energy levels in atomic hydrogen are represented in Fig. 7.1.

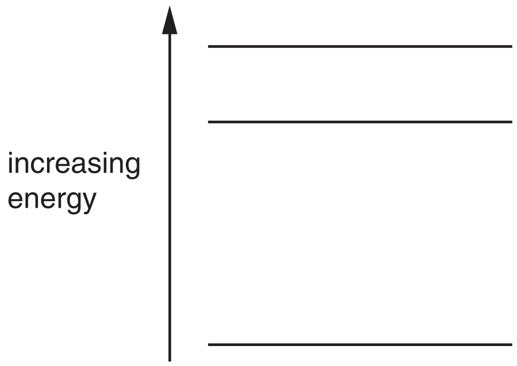

Fig. 7.1

The wavelengths of the spectral lines produced by electron transitions between these three energy levels are 486 nm, 656 nm and 1880 nm.

(i) On Fig. 7.1, draw arrows to show the electron transitions between the energy levels that would give rise to these wavelengths.
Label each arrow with the wavelength of the emitted photon. [3]

(ii) Calculate the maximum change in energy of an electron when making transitions between these levels.

energy = ... J [3]

For Examiner's Use

7 **(a)** Explain how a line emission spectrum leads to an understanding of the existence of discrete electron energy levels in atoms.

....

....

....

.... [3]

(b) Some of the lines of the emission spectrum of atomic hydrogen are shown in Fig. 7.1.

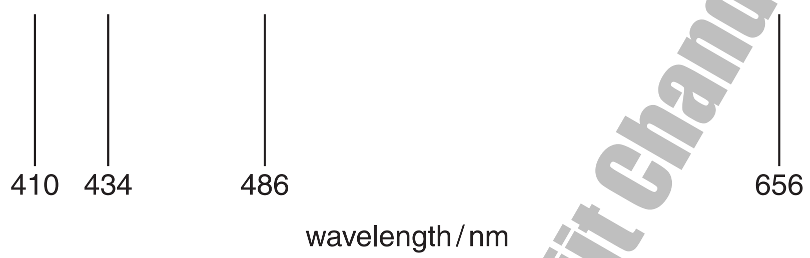

Fig. 7.1

The photon energies associated with some of these lines are shown in Fig. 7.2.

wavelength / nm	photon energy / 10^{-19} J
410	4.85
434	4.58
486	……………
656	3.03

Fig. 7.2

(i) Complete Fig. 7.2 by calculating the photon energy for a wavelength of 486 nm.

[2]

(ii) Energy levels of a single electron in a hydrogen atom are shown in Fig. 7.3.

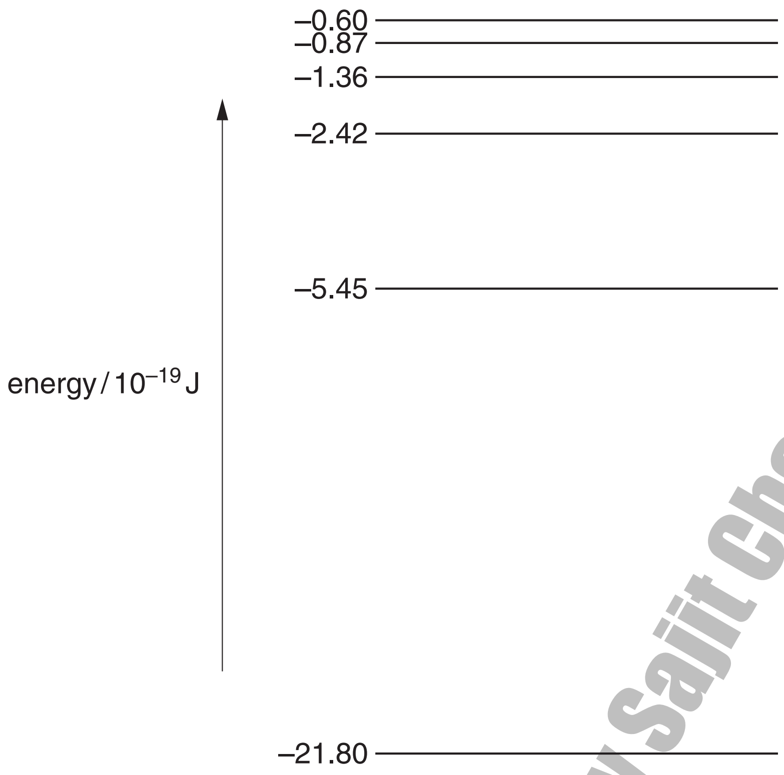

Fig. 7.3 (not to scale)

Use data from **(i)** to show, on Fig. 7.3, the transitions associated with each of the four spectral lines shown in Fig. 7.1. Show each transition with an arrow. [2]

7 **(a)** State an effect, one in each case, that provides evidence for

(i) the wave nature of a particle,

.... [1]

(ii) the particulate nature of electromagnetic radiation.

.... [1]

(b) Four electron energy levels in an atom are shown in Fig. 7.1.

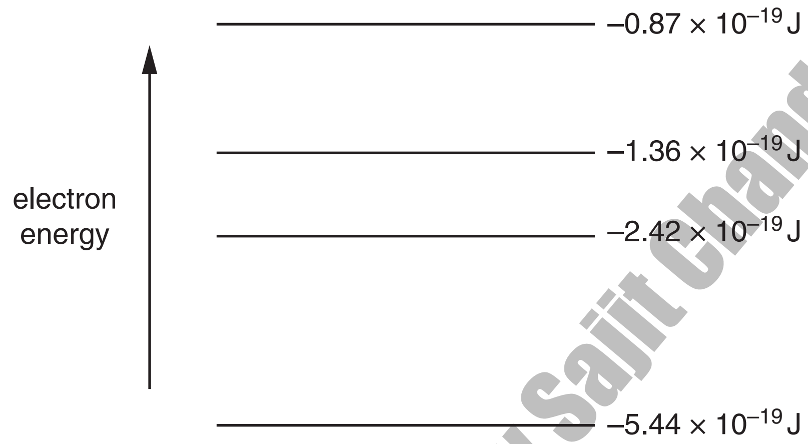

Fig. 7.1 (not to scale)

An emission spectrum is associated with the electron transitions between these energy levels.
For this spectrum,

(i) state the number of lines,

.... [1]

(ii) calculate the minimum wavelength.

wavelength = ... m [2]

8 **(a)** By reference to the photoelectric effect, state what is meant by the *threshold frequency*.

....

....

.... [2]

(b) The surface of a zinc plate has a work function of 5.8×10^{-19} J.
In a particular laboratory experiment, ultraviolet light of wavelength 120 nm is incident on the zinc plate. A photoelectric current I is detected.
In order to view the apparatus more clearly, a second lamp emitting light of wavelength 450 nm is switched on. No change is made to the ultraviolet lamp.

Using appropriate calculations, state and explain the effect on the photoelectric current of switching on this second lamp.

....

.... [4]

For Examiner's Use

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

....

....

.... [2]

(b) An electron is accelerated in a vacuum from rest through a potential difference of 850 V.

(i) Show that the final momentum of the electron is 1.6×10^{-23} N s.

[2]

(ii) Calculate the de Broglie wavelength of this electron.

wavelength = ... m [2]

(c) Describe an experiment to demonstrate the wave nature of electrons.
You may draw a diagram if you wish.

For Examiner's Use

....

....

....

....

....

.... [5]

For Examiner's Use

7 Experiments are conducted to investigate the photoelectric effect.

(a) It is found that, on exposure of a metal surface to light, either electrons are emitted immediately or they are not emitted at all.

Suggest why this observation does not support a wave theory of light.

....

....

....

.... [3]

(b) Data for the wavelength λ of the radiation incident on the metal surface and the maximum kinetic energy E_K of the emitted electrons are shown in Fig. 7.1.

λ / nm	E_K / 10^{-19} J
650	–
240	4.44

Fig. 7.1

(i) Without any calculation, suggest why no value is given for E_K for radiation of wavelength 650 nm.

....

.... [1]

(ii) Use data from Fig. 7.1 to determine the work function energy of the surface.

work function energy = ... J [3]

For Examiner's Use

(c) Radiation of wavelength 240 nm gives rise to a maximum photoelectric current I. The intensity of the incident radiation is maintained constant and the wavelength is now reduced.

State and explain the effect of this change on

(i) the maximum kinetic energy of the photoelectrons,

....

....

.... [2]

(ii) the maximum photoelectric current I.

....

....

.... [2]