22. Quantum Physics

22.2 Photoelectric effect

Paper 4

Question Paper

1 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.

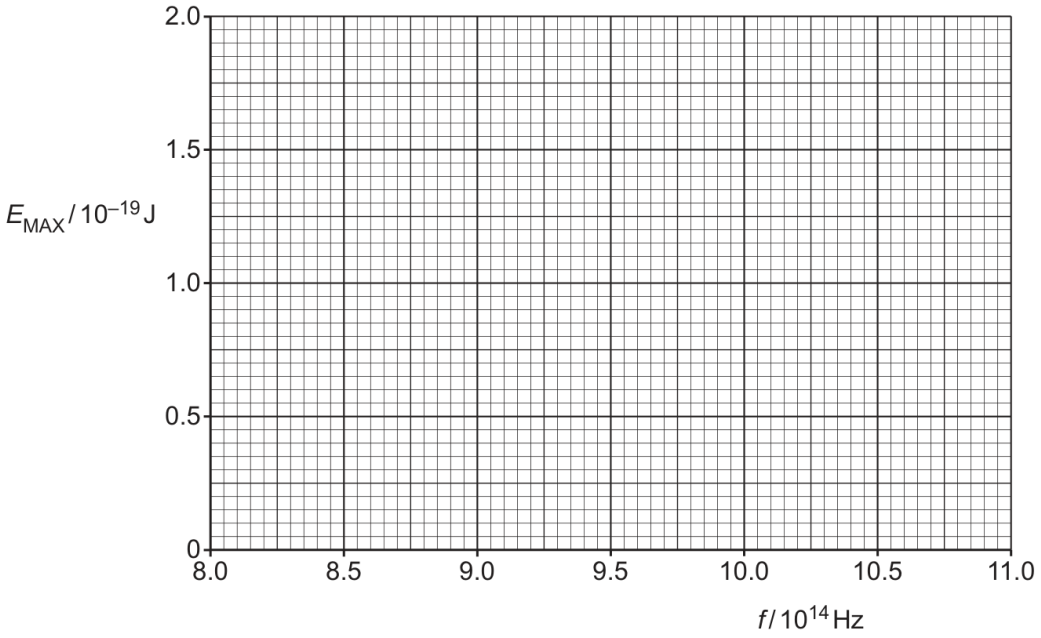


Fig. 8.1

[3]

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.

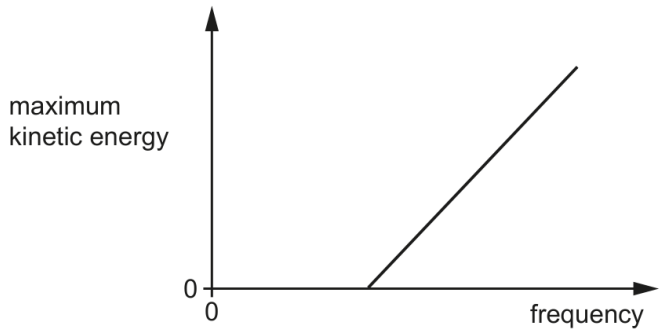


Fig. 8.1

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]

3 **(b)** Electromagnetic radiation of a varying frequency f and constant intensity I is used to illuminate a metal surface. At certain frequencies, electrons are emitted from the surface of the metal. The variation with f of the maximum kinetic energy E_{MAX} of the emitted electrons is shown in Fig. 7.1.

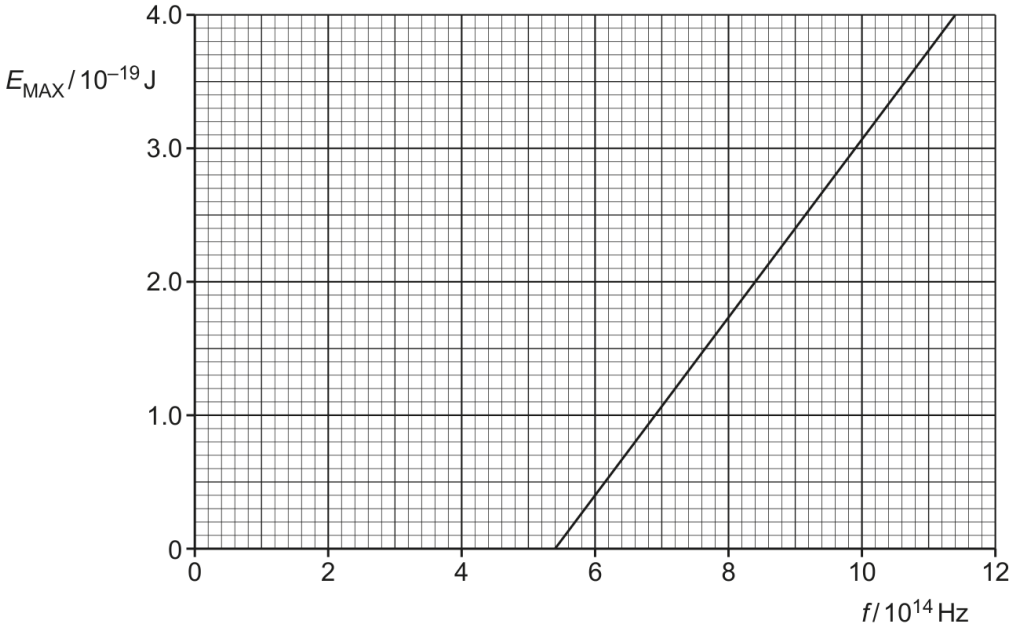


Fig. 7.1

(i) State the name of this phenomenon.

..... [1]

(ii) Describe **three** conclusions that can be drawn from the graph in Fig. 7.1. The conclusions may be qualitative or quantitative.

1 .....

.....

2 .....

.....

3 .....

.....

[3]

(c) The experiment in **(b)** is repeated twice, each time making one change.

State, with a reason, how the graph obtained would compare with Fig. 7.1 when:

(i) a different metal is used, but keeping the intensity I of the radiation the same

.....

.....

..... [2]

(ii) the same metal is used, but with electromagnetic radiation of intensity $2I$.

.....

.....

..... [2]

4 **(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.

(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]

5 **(a)** Electromagnetic radiation of a single constant frequency is incident on a metal surface. This causes an electron to be emitted.

Explain why the maximum kinetic energy of the electron is independent of the intensity of the incident radiation.

.....

.....

.....

.....

..... [3]

(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:

(ii) the work function energy of the surface of the zinc.

energy = ... eV [2]

6 **(b)** Photons having wavelength λ are incident on a metal surface.
The maximum wavelength for which there is emission of electrons is λ_0.
For photons of wavelength $\frac{\lambda_0}{2}$, the maximum kinetic energy of the emitted electrons is E_{MAX}.

On Fig. 5.2, sketch the variation with wavelength λ of the maximum kinetic energy for values of wavelength between $\lambda = \frac{\lambda_0}{3}$ and $\lambda = \lambda_0$.

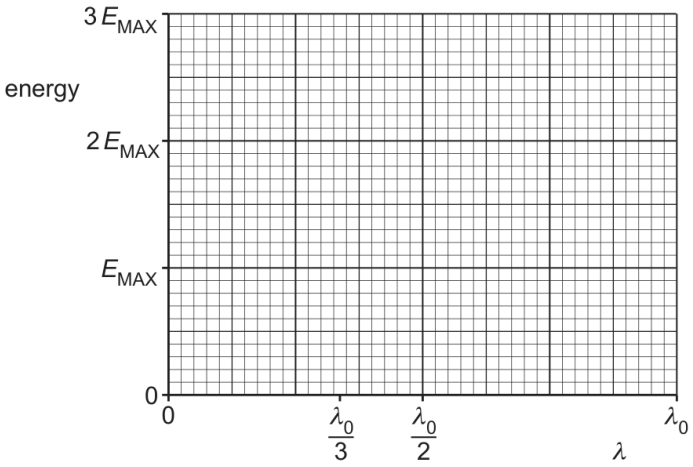


Fig. 5.2

[3]

7 **(a)** State what is meant by:

(i) the *photoelectric effect*

.....

.....

..... [2]

(ii) *work function energy*.

.....

..... [1]

(b) A polished calcium plate in a vacuum is investigated by illuminating the surface with light.

It is found that no photoelectric current is produced when the frequency of the light is less than 6.93×10^{14} Hz.

(i) State the name of the frequency below which no photoelectric current is produced.

..... [1]

(ii) Explain how the photon model of electromagnetic radiation accounts for this phenomenon.

.....

.....

.....

..... [3]

(iii) Calculate the work function energy, in eV, of calcium.

work function energy = ... eV [2]

8 **(a)** Electromagnetic radiation is incident on a metal surface.

It is observed that there is a minimum frequency of electromagnetic radiation below which emission of electrons does not occur.

This observation provides evidence for a particulate nature of electromagnetic radiation.

State **two** other observations associated with photoelectric emission that provide evidence for a particulate nature of electromagnetic radiation.

1. .....

.....

2. .....

.....

[2]

(b) The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is determined for different wavelengths λ of the electromagnetic radiation incident on the surface.

The variation with $\frac{1}{\lambda}$ of E_{MAX} is shown in Fig. 11.1.

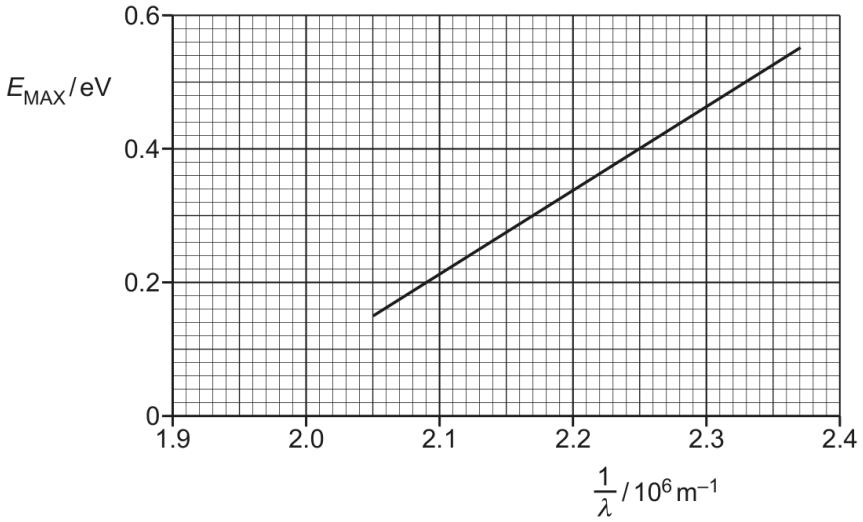


Fig. 11.1

(i) Use Fig. 11.1 to determine the threshold frequency f_0.

f_0 = ... Hz [2]

(ii) Use the gradient of the line on Fig. 11.1 to determine a value for the Planck constant h. Explain your working.

h = ... J s [4]

(c) The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in **(b)**.

On Fig. 11.1, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}. [2]

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

1. .....

.....

2. .....

.....

3. .....

.....

[3]

(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.

(ii) Determine which metals will give rise to the emission of photoelectrons. Explain your answer.

.....

..... [2]

10 (a) With reference to the photoelectric effect, state what is meant by *work function energy*.

.....

.....

..... [2]

(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]

(ii) Explain why most of the emitted electrons will have a speed lower than v_{MAX}.

.....

..... [1]

(c) The electromagnetic radiation incident on the metal surface may change in intensity or in frequency.

Complete Fig. 11.1 by inserting either '*increases*' or '*decreases*' or '*no change*' to describe the effects of the changes shown on the maximum speed and on the rate of emission of electrons.

change	maximum speed of electrons	rate of emission of electrons
reduced intensity at constant frequency	.....	.....
increased frequency at constant intensity	.....	.....

Fig. 11.1

[4]

11 (a) (ii) By reference to intensity of light, state one piece of evidence provided by the photoelectric effect for a particulate nature of light.

.....

.....[1]

12 (a) Describe the *photoelectric effect*.

.....

.....

.....[2]

(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.

(iii) State whether photoelectric emission will occur from each of the metals.

sodium: .....

zinc: .....
[1]

13 (c) The lowest electron energy levels in an isolated hydrogen atom are shown in Fig. 11.1.

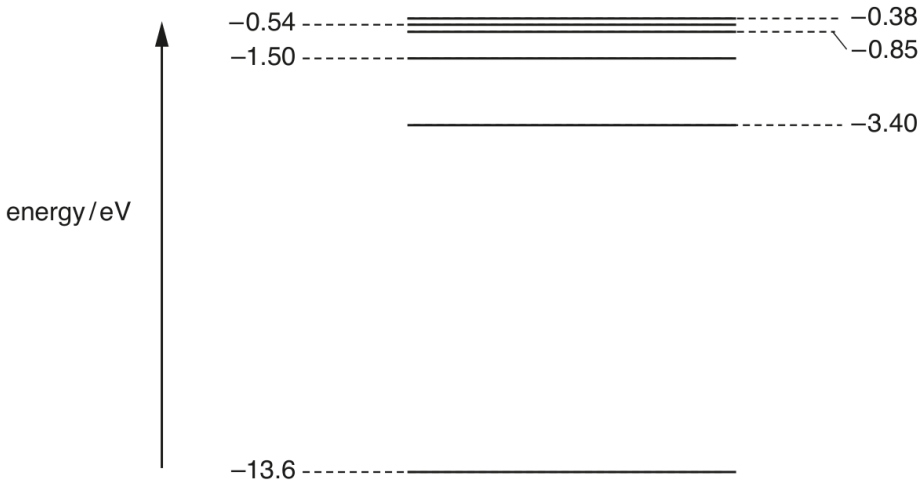


Fig. 11.1 (not to scale)

(ii) Photons resulting from electron de-excitation from the –0.85 eV energy level are incident on the surface of a sample of platinum.

Platinum has a work function energy of 5.6 eV.

Determine

1. the maximum kinetic energy, in eV, of a photoelectron emitted from the surface of the platinum,

maximum energy = ... eV [2]

2. the wavelength of the photon producing the photoelectron in **(ii) part 1**.

wavelength = ... m [3]