9 **(a)** Some data for the work function energy Φ and the threshold frequency f_0 of some metal surfaces are given in Fig. 9.1.

metal	Φ / 10^{-19} J	f_0 / 10^{14} Hz
sodium	3.8	5.8
zinc	5.8	8.8
platinum	9.0	

Fig. 9.1

(i) State what is meant by the *threshold frequency*.

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

……………………………………………………………………………………………… [2]

(ii) Calculate the threshold frequency for platinum.

threshold frequency = ……………………….……………… Hz [2]

(iii) Electromagnetic radiation having a continuous spectrum of wavelengths between 300 nm and 600 nm is incident, in turn, on each of the metals listed in Fig. 9.1. Determine which metals, if any, will give rise to the emission of electrons.

……………………………………………………………………………………………..

……………………………………………………………………………………………..

……………………………………………………………………………………………..

……………………………………………………………………………………………..

…………………………………………………………………………………………… [2]

(iv) Some data for the variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from a metal surface are shown in Fig. 9.2.

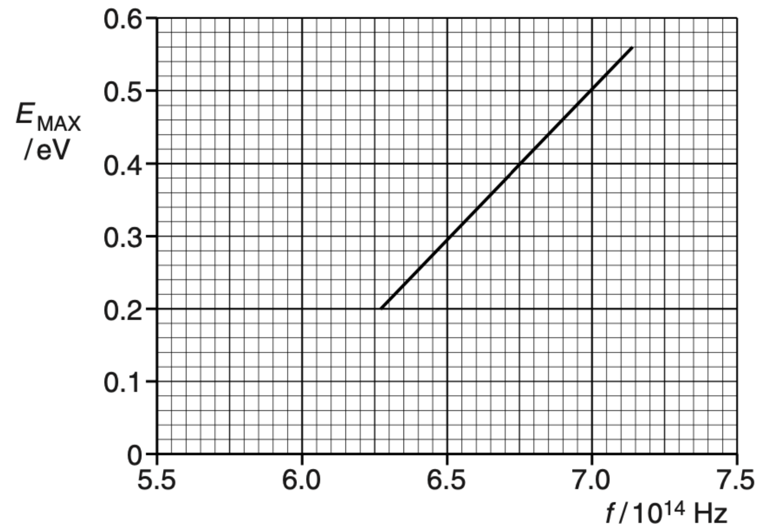

Fig. 9.2

1. Explain why emitted electrons may have kinetic energy less than the maximum at any particular frequency.

....

....

....

....

.... [2]

2. Determine which metal listed in Fig. 9.1 is used to collect the data in Fig. 9.2.

metal is ………………………………………….. [2]

(b) The first theory of the atom to meet with any success was put forward by Niels Bohr in 1913.

A hydrogen atom consists of a proton, of charge +*e*, and an electron, of charge –*e*. The electron of mass *m* orbits the proton at constant speed *v*. The whole system looks like the Earth orbiting around the Sun.

(i) For the electron in orbit at a distance *r* from the proton, show that

1. its kinetic energy E_K is given by:

$$E_K = \frac{e^2}{8\pi\varepsilon_0 r}$$

[2]

2. its total energy E_T is given by:

$$E_T = -\frac{e^2}{8\pi\varepsilon_0 r}$$

[1]

(ii) Show that the de Broglie wavelength of the orbiting electron is given by:

$$\lambda = \frac{h}{e}\sqrt{\frac{4\pi\varepsilon_0 r}{m}}$$

[1]

(iii) The electron wave in **(b)(ii)** forms a circular standing wave such that only an integer multiples *n* of wavelength λ could fit exactly within the orbit of radius r_n, as shown in Fig. 9.3.

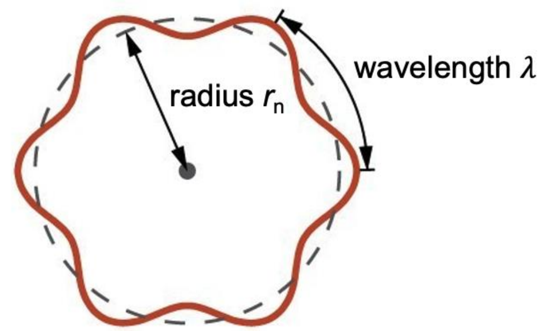

Fig. 9.3

Applying the condition in Fig. 9.3, it can be shown that the orbital radii in Bohr's atom is given by:

$$r_n = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2}$$

Show that the total energy of the electron can be expressed as:

$$E_n = -\frac{k}{n^2}$$

where *k* is a constant.

Determine the value of *k*, in J.

k = …………………………..………………… J [3]

(iv) The expression you have derived in **(b)(iii)** is the discrete energy levels in the hydrogen atom. Transition of the electron from higher energy levels ($n > 2$) to the energy level $n = 2$ gives rise to the Balmer series line spectra.

Show that the Balmer series line spectra correspond to visible light between 350 nm and 700 nm.

[3]

[Total: 20]