Mark scheme for Extension Worksheet – Topic 6, Worksheet 2

1 **a** See page 390 of *Physics for the IB Diploma* or page 72 of *Physics for the IB Diploma Exam Preparation Guide*. [3]

b One observation is that the energy of the electrons increases as the frequency of the light incident on the metal increases; this cannot be explained by the electromagnetic theory of light because the energy of an electromagnetic wave does not depend on the frequency. [2]

c According to the photon theory of light the energy of a photon is proportional to its frequency; hence as the frequency increases the energy absorbed by an electron increases. [2]

d The minimum energy required to eject an electron from the metal. [1]

e The charge of an electron times the stopping voltage gives the kinetic energy of the emitted electron. [1]

f The stopping voltage is about $(-)0.65\ \text{V}$; hence the kinetic energy of the electrons is $0.65\ \text{eV} = 0.65 \times 1.6 \times 10^{-19} = 1.04 \times 10^{-19}\ \text{J}$; hence

$\frac{1}{2} \times 9.1 \times 10^{-31} v^2 = 1.04 \times 10^{-19} \Rightarrow v = 4.8 \times 10^5\ \text{m s}^{-1}$ [3]

g From $eV_S = hf - \phi$ it follows that $hf = eV_S + \phi = 0.65 + 1.2 = 1.85\ \text{eV}$;

$\frac{hc}{\lambda} = 1.85 \times 1.6 \times 10^{-19} \Rightarrow \lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{1.85 \times 1.6 \times 10^{-19}} = 6.7 \times 10^{-7}\ \text{m}$ [2]

h The current reaches a saturation value because every single emitted electron is collected at the collecting plate when the collecting plate has a sufficiently high positive potential. [1]

i Deceasing the wavelength increases the energy and so speed of the emitted electrons but the current only depends on the number of electrons emitted per second not their speed. [1]

j The new photon energy will be: $\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{4.0 \times 10^{-7} \times 1.6 \times 10^{-19}} = 3.11\ \text{eV}$; and so the electron energy is $3.11 - 1.2 = 1.9\ \text{eV}$, i.e. the stopping voltage is $(-)1.9\ \text{V}$; so we need a similar curve to the one given that begins at the new stopping voltage and has the same saturation current as before. [3]

2 **a** The diagram shows a diffraction pattern; diffraction patterns are obtained with waves; and so in this experiment electrons behave as waves. [3]

b A beam of electrons is accelerated to high speeds; the beam is incident on a crystal and a diffraction pattern is obtained from which a wavelength may be determined (by measurements the separation of rings); which agrees with the de Broglie formula for the electron wavelength. [3]

3 **a** The momentum of the ball is $p = mv = 0.20 \times 12 = 2.4\,\text{N s}$; and so the de Broglie wavelength is $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{2.4} \approx 3 \times 10^{-34}\,\text{m}$ [2]

b This is much smaller than the size of the window (0.50 m); so no diffraction is expected. [2]

4 The force on the electron is $\frac{ke^2}{r^2}$ and this plays the role of the centripetal force; i.e. $\frac{ke^2}{r^2} = \frac{mv^2}{r} \Rightarrow mv^2 = \frac{ke^2}{r}$; hence the kinetic energy of the electron is $E_K = \frac{1}{2}mv^2 = \frac{ke^2}{2r}$; simplifying for the total energy: $E_T = \frac{1}{2}\frac{ke^2}{r} - \frac{ke^2}{r} = -\frac{ke^2}{2r}$ [4]

5 **a** It means that the electron is bound to the nucleus; and so cannot move very far away/cannot escape to infinity. [2]

b Combining $E_T = -\frac{ke^2}{2r}$ with $E_T = -\frac{C}{n^2}$ gives $-\frac{ke^2}{2r} = -\frac{C}{n^2} \Rightarrow r = \frac{ke^2 n^2}{2C}$ [1]

c It is not; the Heisenberg principle says that it is not possible to know the position of the electron to arbitrary precision and the result in **b** says that the distance of the electron form the nucleus is precisely known. [2]

6 The energy of the electron in the hydrogen atom is negative; in the box model it is positive; the separation of the energy levels in the hydrogen atom decreases as energy increases; in the box model the separation increases. [4]

7 The lowest energy of an electron in the box model is given by $E = \frac{h^2}{8mL^2}$; and this is not zero. [2]

8 An electron in the box model would have an uncertainty in position of $\Delta x \approx L$ and so an uncertainty in momentum of $\Delta p \approx \frac{h}{4\pi\Delta x} \approx \frac{h}{4\pi L}$; this means a minimum kinetic energy of order $E \approx \frac{\Delta p^2}{2m} \approx \frac{h^2}{16\pi^2 mL^2}$; which is not zero (and interestingly of the same order of magnitude as the energy of the electron in the box model). [2]