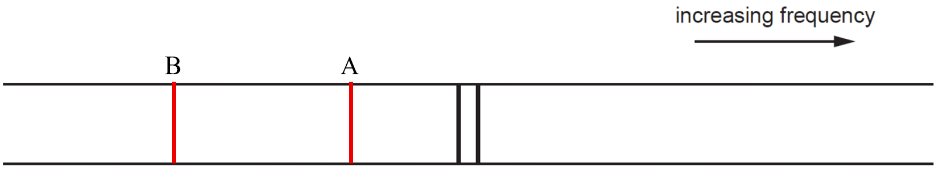
1

(a) Transition emits (one) photon with energy equal to the difference in energy between the two levels. Since photon energy is hf, there is only a single frequency of radiation for each transition.

(b) **(i)**
(ii)



(c) $\Delta E = E_{photon} = hf$
$(E_3 - E_1) = (E_2 - E_1) + (E_3 - E_2) = hf_A + hf_B$
$E_3 = E_1 + h(f_A + f_B)$

2

(a) **(i)** Diffraction of light when passes through a single slit

(ii) Photoelectric effect

(b) **(i)** The energies of the hydrogen atoms are quantized into discrete levels. When an atom transits from a higher energy level to a lower energy level, photons of energy equal to the difference in the two energy levels are emitted. Energy of photon is given by $E = \frac{hc}{\lambda}$. Hence, only photons of specific wavelengths are emitted.

(ii) Energy of photon of blue light $= \frac{hc}{\lambda}$

$$= \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{4.86 \times 10^{-7}}$$
$$= 4.093 \times 10^{-19}\ J$$
$$= 2.6\ eV$$

Since the energy of the photon is higher than the work function energy photoemission will be observed.

(iii) 1. Power of red light $= intensity \times Area$
$= 6.80 \times 10^{3} \times 3.00 \times 10^{-4}$
$= 2.04\ W$

(iii) 2. Number of photons per unit time $= \frac{Power}{Energy\ per\ photon}$
$$= \frac{2.04}{\frac{hc}{\lambda}}$$
$$= \frac{2.04 \times 4.86 \times 10^{-7}}{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}$$
$= 4.98 \times 10^{18}$

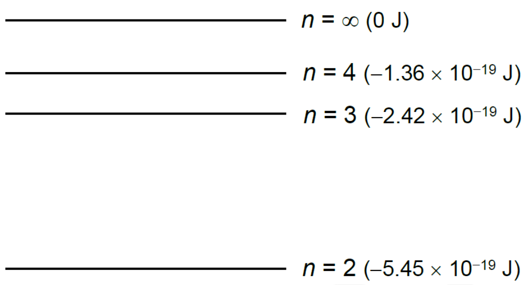
Momentum of each photon $= \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{4.86 \times 10^{-7}} = 1.364 \times 10^{-27}\ kg\ \ m\, s^{-1}$
Total force $= 1.364 \times 10^{-27} \times 4.98 \times 10^{18}$
$= 6.80 \times 10^{-9}\ N$

(c) **(i) 1.** $\frac{1}{6.56 \times 10^{-7}} = 1.097 \times 10^{7}\left(\frac{1}{4} - \frac{1}{n^2}\right)$
$n = 3$

(i)
2.
$$\frac{1}{4.86 \times 10^{-7}} = 1.097 \times 10^{7}\left(\frac{1}{4} - \frac{1}{n^2}\right)$$
$n = 4$

(ii) For shortest wavelength, $n = \infty$
$$\frac{1}{\lambda_{\min}} = R\left(\frac{1}{4} - \frac{1}{\infty}\right)$$
$\lambda_{min} = 3.65 \times 10^{-7}\ m$

(iii)
E_∞ to E_2, $\Delta E = -\frac{hc}{\lambda} = -\frac{(6.63\times10^{-34})(3.0\times10^{8})}{3.646\times10^{-7}} = -5.455 \times 10^{-19}\ J$
E_3 to E_2, $\Delta E = -\frac{hc}{\lambda} = -\frac{(6.63\times10^{-34})(3.0\times10^{8})}{6.56\times10^{-7}} = -3.032 \times 10^{-19}\ J$
E_4 to E_2, $\Delta E = -4.093 \times 10^{-19}\ J$



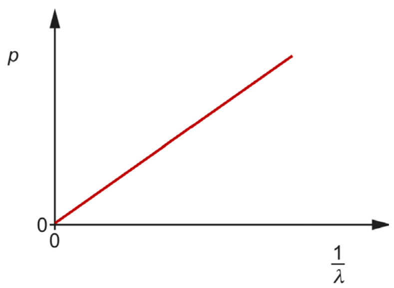
3

(a) diffraction is the characteristic of wave behaviour so it shows that electrons can behave like waves

(b)
$$qV = \frac{1}{2}mv^2$$
$$\rho = mv$$
$$qV = \frac{\rho^2}{2m}$$
$$\rho = \sqrt{2mqV}$$

(c) As the p.d. increases, the momentum increase. The de Broglie wavelength decreases. This results in fringes closer together from $d \sin\theta = n\lambda$.

(d) **(i)**



(ii) Planck constant

4

(a) A photon is a quantum (i.e. a discrete amount) of energy of electromagnetic radiation and its energy E, is given by E = hf where h is the Planck's constant and f the frequency of the radiation.

(b) **(i)** Discrete bright coloured lines on a dark background.

(ii) Each line in the emission spectrum corresponds to a specific frequency f, of the photons emitted.

(c) **(i)** An atom is said to be in its ground state when the electrons in the atom occupies all the lowest energy states available.

(ii) Ionisation energy

$$E = -\frac{13.6}{\infty^2} - \left(-\frac{13.6}{1^2}\right)$$
$$= 13.6\ eV$$
$$= 2.18 \times 10^{-18}\ J$$

(d) **(i)**

$$\Delta E = \left(-\frac{2.176 \times 10^{-18}}{m^2}\right) - \left(-\frac{2.176 \times 10^{-18}}{2^2}\right)$$
$$\frac{hc}{\lambda} = 2.176 \times 10^{-18}\left(\frac{1}{2^2} - \frac{1}{m^2}\right)$$
$$R = \frac{2.176 \times 10^{-18}}{6.63 \times 10^{-34} \times 3.00 \times 10^8}$$
$$= 1.09 \times 10^7 m^{-1}$$

(ii) Longest wavelength is when $m = 3$

$$\frac{1}{\lambda} = 1.09 \times 10^7 \left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$
$$= 1.514 \times 10^6$$
$$\lambda = \frac{1}{1.514 \times 10^6}$$
$$= 6.61 \times 10^{-7}\ m$$

(iii) Visible red light

(e) **(i)** Electron diffraction

(ii)

$$2\pi r = 3\lambda_e$$
$$\lambda_e = \frac{h}{m_e v}$$
$$v = \frac{3h}{2\pi r m_e}$$
$$= \frac{3(6.63 \times 10^{-34})}{2\pi(4.78 \times 10^{-10})(9.11 \times 10^{-31})}$$
$$= 7.27 \times 10^5\ m\ s^{-1}$$

(iii)

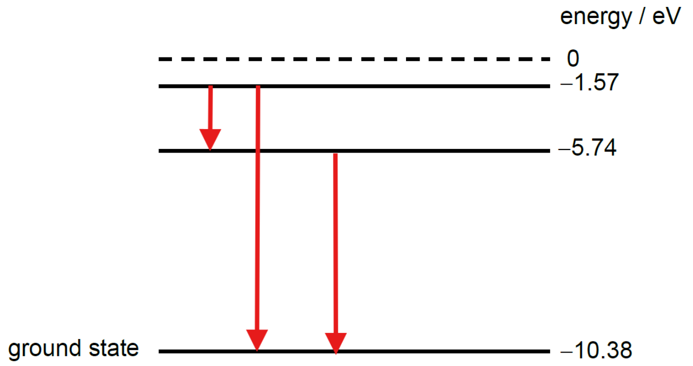
$$\Delta x \Delta \rho \geq h$$
$$\Delta v \geq \frac{h}{m_e \Delta x}$$
$$\geq \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31}(0.0100 \times 10^{-9})}$$
$$\geq 7.28 \times 10^7\ m\ s^{-1}$$

5

(c) **(i)** Negative energy levels indicate that the atom is a bound system - electron cannot escape from the atom.

(ii) $10.38\ eV$

(iii) 1.



(iii) 2. Longest wavelength corresponds to the lowest transition energy:

$-1.57-(-5.74)=4.17\ eV$

$\Delta E=\dfrac{hc}{\lambda}$

$4.17\times 1.6\times 10^{-19}=\dfrac{6.63\times 10^{-34}\times 3\times 10^{8}}{\lambda}$

$\lambda=298\ nm$

(iv) Since the energy of the photon 8.9 eV does not match the energy difference between any two of energy levels, the electrons will not be excited. Hence, there is no spectral lines.

6

(a) (i) The spread of the electron beam to form bright rings due to diffraction, The presence of dark regions between bright rings indicate that destructive interference is taking place

(ii) 1. $E_K=eV=\dfrac{\rho^2}{2m}$

$\lambda=\dfrac{h}{\rho}$

$=\dfrac{h}{\sqrt{2meV}}$

(ii) 2. $\dfrac{h}{\sqrt{2meV}}$

$=\dfrac{6.63\times 10^{-34}}{\sqrt{2(9.11\times 10^{-31})(1.60\times 10^{-19})(250)}}$

$=7.77\times 10^{-12}\ m$

(iii) As potential difference V increases, the de Broglie wavelength decreases since $\lambda\propto\frac{1}{\sqrt{V}}$. Since $d\sin\theta=n\lambda$, the angles at which the maxima are produced decrease. The rings become smaller/closer together.

(c) $\Delta x\Delta\rho\geq h$

$\Delta\rho\geq\dfrac{6.63\times 10^{-34}}{1.2}$

$\rho=80(2.0)=16-kg\ m\ s^{-1}$

$\tan\theta=\dfrac{\Delta\rho}{\rho}=\dfrac{5.53\times 10^{-34}}{160}=3.46\times 10^{-36}\approx 0$

Hence, angle of deflection is negligible.

7

(a) **(i)** Particle property: Each electron registers as a single point/dot on the screen.

Wave property: Regular maxima and minima (or bright and dark regions) indicates an interference pattern associated with waves

(ii)
$$qV = \frac{\rho^2}{2m}$$
$$\rho = \sqrt{2mqV}$$
$$= \sqrt{2(9.11 \times 10^{-31})(1.60 \times 10^{-19})(600)}$$
$$= 1.322 \times 10^{-23}$$

$$\lambda = \frac{h}{\rho}$$
$$= \frac{6.63 \times 10^{-34}}{1.322 \times 10^{-23}}$$
$$= 5.02 \times 10^{-11}\ m$$

(iii)
$$x = \frac{\lambda D}{a}$$
$$= \frac{(5.02 \times 10^{-11})(1.2)}{280 \times 10^{-9}}$$
$$= 2.15 \times 10^{-4}\ m$$

(iv) Since velocity affects the de Broglie wavelength ($\lambda = \frac{h}{mv}$) of the electron, a single de Broglie wavelength is needed to get a clear/observable interference pattern (so distance x can be similar)

(b) **(i)** Photons have momentum. When photons scattered by the electron, a collision occurs and momentum is transferred to the electron by the principle of conservation of momentum, causing the electron's momentum to change.

(ii) Since $p = h\lambda$, shorter wavelength of EM radiation leads to greater momentum transfer and change imparted to the electron.

From $\Delta x \Delta p \geq h$, there is greater uncertainty in momentum Δp so uncertainty in position Δx is minimised, allowing for more precise measurement of position to be made.

8

(a) **(i)** Discrete packet of energy of electromagnetic radiation of energy $E = hf$.

(ii) Wavelength $= \frac{6.63\times10^{-34}}{9.5\times10^{-28}} = 700 \times 10^{-9}\ m$ (red)

(iii) Pressure = force / area
$$force = rate\ of\ change\ of\ momentum$$
$$= 2 \times 9.5 \times 10^{-28} \times 1.4 \times 10^{15}$$

Pressure $= \frac{2\times9.5\times10^{-28}\times1.4\times10^{15}}{2.5\times10^{-6}}$
$$= 1.1 \times 10^{-6}\ Pa$$

(c) **(i)** Electron diffraction

(ii) Diffraction is a wave phenomenon and electron can behave as a wave.

(d) photon absorbed (by electron) and electron excited

photon energy equal to difference in energy of two discrete energy levels
photon energy relates to a single wavelength / single frequency
electron de-excites and emits photon in any direction (only some reach the screen)

(e) $\Delta E = E_3 - E_2 = \frac{hc}{\lambda}$

$\frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{658 \times 10^{-9}} = E_3 - (-3.40 \times 1.6 \times 10^{-19})$

$E_3 = -2.42 \times 10^{-19}\ J$

9

(a) The particle is trapped within a fixed region of space, and the potential energy outside this region is infinite, so the particle cannot escape.

(b) Since the wave has nodes at both ends of the box, the box length must contain a whole number of half-wavelengths:

$L = \frac{n\lambda}{2}$

$\lambda = \frac{2L}{n}$

(c) Using $\lambda = \frac{h}{\rho}$

$\rho = \frac{h}{\left(\frac{2L}{n}\right)}$

$= \frac{nh}{2L}$

Hence, momentum can only take certain discrete values.

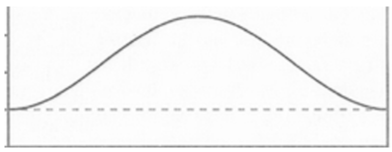
(d) Using $E_K = \frac{\rho^2}{2m}$

$E_n = \frac{\left(\frac{nh}{2L}\right)^2}{2m}$

$= \frac{n^2h^2}{8mL^2}$

(e) **(i)** $n = 1$

(ii)



(f) $\Delta E = E_3 - E_1$

$= \frac{9h^2}{8mL^2} - \frac{h^2}{8mL^2}$

$= \frac{h^2}{mL^2}$

(g) $E_1 \propto \frac{1}{L^2}$

Since L is doubled, E_1 will be decreased to $\frac{1}{4}$ of its original value.

10

(a) **(i)** From Fig 6.1 it can be observed that at specific wavelengths there were dips in the intensity meaning that the energy at these wavelengths were being absorbed.
So this is an absorption spectrum.

(ii) Transition from n = 3 to 2 should corresponds to the least energetic transition
i.e. transition giving rise to $656\ nm$ line.

$$\Delta E = \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{656 \times 10^{-9}}$$
$= 3.03 \times 10^{-19}\ J$
$E_3 = E_2 + \Delta E$
$= -5.44 \times 10^{-19} + 3.03 \times 10^{-19}$
$= -2.41 \times 10^{-19}$
$= -1.51\ eV$