Section A

Level-I

1. $v_0 = 7.0 \times 10^{14}\ s^{-1}$

$$v = 1.0 \times 10^{15}\ s^{-1}$$

$$KE = h(v - v_0) = 6.62 \times 10^{-34}\ (3.0 \times 10^{14})$$

$$= 1.986 \times 10^{-19}\ \text{J}$$

2. Energy of the incident photon = $E = \dfrac{hc}{\lambda}$

$$E = \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{3.0 \times 10^{-7}}$$

$$E = 6.62 \times 10^{-19}\ \text{J}$$

$$KE = 1.68 \times 10^{5}\ \text{J mol}^{-1}$$

$$= \frac{1.68 \times 10^{5}}{6.02 \times 10^{23}}\ J = 2.79 \times 10^{-9}\ \text{J}$$

Minimum energy required to remove an electron, W

$$= E - KE$$

$$= 6.62 \times 10^{-19} - 2.79 \times 10^{-19}$$

$$W = 3.83 \times 10^{-19}\ \text{J}$$

Maximum wavelength, $\lambda = \dfrac{hc}{W}$

$$\lambda = \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{3.83 \times 10^{-9}}$$

$$\lambda = 5.185 \times 10^{-7}\ \text{m}$$

$$= 518.5\ \text{nm}$$

3. λ = 4.0 19×–34 8

$1 \times 4.0 \times 10^{-}$

$6.62 \times 10^{-} \quad \times 3.0 \times 10$

$= 2.01 \times 10^{16}$ photons

4. Wavelength of the incident photon = 4×10^{-7} m
Work function = 2.13 eV

(i) Energy of the photon $E = \dfrac{hc}{\lambda}$

$$= \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{4.0 \times 10^{-7}}$$

$$= 4.965 \times 10^{-19} \text{ J}$$

$$= \frac{4.965 \times 10^{-19}}{1.60 \times 10^{-19}} \text{ eV} = 3.10 \text{ eV}$$

(ii) $KE = E$ – Work function

$$KE = 3.10 - 2.13 = 0.97 \text{ eV}$$

$$= 1.552 \times 10^{-19} \text{ J}$$

(iii) $KE = \dfrac{mv^2}{2}$

$$v = \sqrt{\frac{2KE}{m}} \sqrt{\frac{2 \times 1.552 \times 10^{-19}}{9.1 \times 10^{-31}}} = \sqrt{0.341 \times 10^{12}}$$

$$v = 5.8 \times 10^{5}\ ms^{-1}$$

5. $\lambda = 242 \times 10^{-9}\ m$

$$E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{234 \times 10^{-9}}$$

$$E = 8.207 \times 10^{-19} \text{ J}$$

$$E = 494 \times 10^{3} \text{ J mol}^{-1}$$

$$E = 494 \text{ kJ mol}^{-1}$$

6. Number of lines = $\dfrac{n(n-1)}{2}$

$$= \frac{6 \times (6-1)}{2} = 15 \text{ lines}$$

7. Energy required to remove an electron completely from the $n = 2$ orbit

$$= \frac{2.18 \times 10^{-18}}{2^2} = 5.45 \times 10^{-19} \text{ J}$$

Longest wavelength $\lambda = \dfrac{hc}{E}$

$$= \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{5.45 \times 10^{-9}} = 3.644 \times 10^{-7} \text{ m}$$

$$= 3644 \text{ Å}$$

$$\lambda = 589\ nm = 5.89 \times 10^{-7} \text{ m}$$

Mass equivalence of one photon of this wavelength is equal to $h\ \dfrac{c}{\lambda}$

$$= \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{5.89 \times 10^{-9}} = 3.37 \times 10^{-19} \text{ J}$$

9. $\Delta x = 10^{-15}$ m

$$m = 9.1 \times 10^{-31} \text{ kg}$$

$$\Delta x\ .\ m\Delta\ v\ \geq \frac{h}{4\pi}$$

$$\Delta v \geq \frac{6.62 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31} \times 10^{-15}}$$

$$\Delta v \geq 5.87 \times 10^{10} \text{ m/s}$$

As Δv is greater than the speed of light. Hence, the electron cannot exist within the atomic nucleus.

10. (1) The energy of an electron in a *H*-atom depends only on the principal of quantum number while in case of many electron atoms, the energy depends on principal quantum number and azimuthal quantum number.
    (2) The size of an orbital depends on principal quantum number
    (3) The shape of an orbital depends on azimuthal quantum number
    (4) The orientation of an orbital in space depends

11. (1) $2s > 1s$ (2) $3p > 2p$ (3) $3dxy = 3dyz$ (4) $3s = 3d$
    (5) 4f < 5s

12. (1) $1s$ (2) $3p$ (3) $4d$ (4) $4f$

13. (1) 16 electron (2) 2 electrons

14. $\dfrac{1}{\lambda} = RZ^2 \left[\dfrac{1}{n_L^2} - \dfrac{1}{n_H^2}\right]$

$$\frac{1}{\lambda_H} = R(1)^2 \left[\frac{1}{n_L^2} - \frac{1}{n_H^2}\right] \qquad ...(1)$$

$$\frac{1}{\lambda_{He^+}} = R(2)^2 \left[\frac{1}{2^2} - \frac{1}{4^2}\right]$$

$$\frac{1}{\lambda_{He^+}} = R(4)\left[\frac{3}{16}\right] = R\ \frac{3}{4} \qquad ...(2)$$

Equating equation (1) and (2) gives

$$\frac{1}{n_L^2} - \frac{1}{n_H^2} = \frac{3}{4}$$

Solving for n_L and n_H gives

$$n_L = 1 \text{ and } n_H = 2$$

15. IE_2 for He = (IE for H) × 4

$$= 2.18 \times 10^{-18} \times 4$$

$$= 8.72 \times 10^{-18} \text{ J}$$

Level-II

1. Second spectral line of Paschen Series is $n_L = 3$ to $n_H = 5$

$$\Delta E = 2.179 \times 10^{-19} \left[\frac{1}{3^2} - \frac{1}{5^2}\right]$$

$$= 2.179 \times 10^{-19} \left[\frac{16}{225}\right] = 1.55 \times 10^{-20} \text{ J}$$

$$v = \frac{\Delta E}{\lambda} = \frac{1.55 \times 10^{-20}}{6.62 \times 10^{-34}} = 2.34 \times 10^{13}\ s^{-1}$$

$$\lambda = \frac{c}{v} = \frac{3.8 \times 10^{-8}}{2.34 \times 10^{-13}} = 1.28 \times 10^{-5} \text{ m}$$

2. $\lambda = 434 \text{ nm} = 4.34 \times 10^{-7}$ m

$$n_L = 1$$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left[\frac{1}{n_L^2}\ \frac{1}{n_H^2}\right] m^{-1}$$

$$\frac{1}{4.34 \times 10^{-7}} = 1.097 \times 10^7 \left[\frac{1}{2^2}\ \frac{1}{n_H^2}\right]$$

$$\frac{1}{4} - \frac{1}{n_2^H} = \frac{1}{4.76}$$

$$n^2{}_H = 0.25 - \frac{1}{1.76} = 0.25 - 0.21 = 0.04$$

$$\frac{1}{n_H^2} = \frac{1}{0.04} = 25$$

$$n_H = 5$$

3. (1) $\Delta E = 54.38 \left[\frac{1}{n_L^2} - \frac{1}{n_H^2}\right]$

$$= 54.38 \left[\frac{1}{2^2} - \frac{1}{5^2}\right]$$

$$= 54.38 \left[\frac{1}{4} - \frac{1}{25}\right] = 54.38 \times \frac{21}{100} = 11.42 \text{ eV}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$\Delta E = 11.42 \times 1.6 \times 10^{-19} \text{ J}$$

$$= 18.27 \times 10^{-19} \text{ J}$$

$$= 1.83 \times 10^{-18} \text{ J}$$

(2) $\Delta E = hv$

$$v = \frac{\Delta E}{h} = \frac{1.83 \times 10^{-18}}{6.62 \times 10^{-34}} = 2.76 \times 10^{-15} s^{-1}$$

$$\lambda = \frac{c}{v} = \frac{3.0 \times 10^8}{2.76 \times 10^{15}} = 1.087 \times 10^{-7} \text{ m}$$

$$= 108.7 \text{ nm}$$

It belongs to ultraviolet region of the spectrum.

4. $\lambda = 12.5 \text{ cm} = 12.5 \times 10^{-2}$ m

Energy of radiation, $E_1 = \frac{hc}{h}$

$$E_1 = \frac{6.62 \times 10^{-34} \times 3.0 \times 10^8}{12.5 \times 10^{-2}} = 1.59 \times 10^{-24} \text{ J}$$

But energy of the radiation converted to heat $Q = mc\text{D}t$

$$= 0.250 \times 4.2 \times 80$$

$$= 84 \text{ kJ} = 84.0 \times 10^{-3} \text{ J}$$

$\therefore$ $Q = NE_1$

where N = number of photons

and $N = \frac{Q}{E_1} = \frac{84.0 \times 10^3}{1.59 \times 10^{-24}}$

$$= 5.283 \times 10^{28}$$

5. $r_3 = 0.529 \left(\frac{3^2}{1}\right) \text{Å} = (3)^2 \times 0.529 \times 10^{-10}$ m

and $$v = \frac{n}{r}\left(\frac{h}{2\pi \text{m}}\right)$$

$$v = \frac{n}{r_n}\ (1.158 \times 10^{-4}) = \frac{3 \times (1.158 \times 10^{-4})}{0.529 \times 3^2 \times 10^{-10}}$$

$$v = 0.7296 \times 10^{-5}$$
$$= 7.296 \times 10^{+5}\ \text{ms}^{-1}$$

We know that $2\pi r = \lambda = \frac{\text{v}}{v}$

Number of revolution per second = $\frac{v}{2\pi r}$

$$= \frac{7.296 \times 10^5}{2 \times 3.14 \times 4.761 \times 10^{-10}} = 2.44 \times 10^{14}$$

6. For H-atom, line with lowest frequency in Lymne series corresponds to $n_L = 1 \rightarrow n_H = 2$

$\therefore$ $$\frac{1}{\lambda} = 1.097 \times 10^7\ (1)^2 \left[\frac{1}{I^2} - \frac{1}{2^2}\right] m^{-1}$$

$$= 1.097 \times 10^7 \times \frac{3}{4}$$

$$l = \frac{4}{3 \times 1.097} \times 10^{-7} \times 10^{-7} = 1.215 \times 10^{-7}\ m = 122 \text{ nm}$$

Frequency, $$v = \frac{c}{\lambda} = \frac{3.0 \times 10^8}{1.215 \times 10^{-7}} = 2.47 \times 10^{15}\ s^{-1}$$

$$\Delta E = hv = 6.62 \times 10^{-34} \times 2.47 \times 10^{15}$$
$$= 1.63 \times 10^{-18}\ \text{J}$$

Energy for the corresponding line ($n_L = 1 \rightarrow n_H = 2$) in the spectrum of Li^{2+} is

$$\Delta E = 2.178 \times 10^{-18}\ (3)^2 \left[\frac{1}{I^2} - \frac{1}{2^2}\right] \text{J}$$

$$= 2.178 \times 10^{-18} \times 9 \times \frac{3}{4}$$

$$= 1.47 \times 10^{-17}\ \text{J}$$

7. Number of moles of H-atom = 2.0 mol
and number of atoms of hydrogen = $2.0 \times 6.023 \times 10^{23}$
$= 12.046 \times 10^{23}$ atom

Line of lowest frequency in the visible region of H-spectrum corresponds to the first Balmer line i.e. n_L = 2 to $n_H = 3$

$$\therefore \qquad \Delta E = 2.178 \times 10^{-18} \times (1)^2 \left[\frac{1}{2^2} - \frac{1}{3^2}\right] \text{ J atom}^{-1}$$

$$\Delta E = 2.178 \times 10^{-18} \times \frac{5}{56} = 3.025 \times 10^{-19} \text{ J atom}^{-1}$$

Therefore, for 12.046×10^{23} atoms of hydrogen, the energy is

$12.046 \times 10^{23} \times 3.025 \times 10^{-19} = 3.64 \times 10^4$ J

$= 364$ kJ

8. When metal was irradiated by light of frequency $3.2 \times 10^{16}\ s^{-1}$, then

$$E_1 = h\nu = 6.62 \times 10^{-34} \times 3.2 \times 10^{15}$$

$$E_1 = 2.12 \times 10^{-18} \text{ J} = KE_1 + IE \qquad ...(1)$$

When metal was irradiated by light of frequency $2.0 \times 10^{16}\ s^{-1}$. Then.

$$E_2 = h\nu = 6.62 \times 10^{-34} \times 2.0 \times 10^{15}$$

$$E_2 = 1.32 \times 10^{-18} \text{ J} = KE_2 + IE \qquad ...(2)$$

But $\qquad KE_1 = 2\ KE_2$

Therefore $\qquad E_1 = 2KE_2 + IE$

or $\qquad 2KE_2 + IE = 2.12 \times 10^{-18} \qquad ...(3)$

and $\qquad KE_2 + IE = 1.32 \times 10^{-18} \qquad ...(4)$

Solving equation (3) and (4) gives

$$KE_2 = 8.0 \times 10^{-19} \text{ J}$$

Ionization energy of the metal $= 1.32 \times 10^{-18} - KE^2$

$= 1.32 \times 10^{-18} - 8.0 \times 10^{-19}$

$= 5.2 \times 10^{-19}$ J per atom

IE per mole of metal $= 5.2 \times 10^{-19} \times 6.023 \times 10^{23}$

$= 3.13 \times 10^5 \text{ J mol}^{-1}$

$= 313 \text{ kJ mol}^{-1}$

9. Energy of the incident photon $= 3.44 \times 10^{-19}$ J
Velocity of the photoelectron $= 1.03 \times 10^6 \text{ ms}^{-1}$
$\therefore$ Kinetic energy of the photo electron

$$\frac{1}{2} mv^2 = \frac{1}{2} \times 9.1 \times 10^{-31} \times (1.03 \times 10^6)^2$$

$$= 4.83 \times 10^{-19} \text{ J}$$

Ionization energy of the atom = Energy of the incident photon minus the kinetic energy of the photo-electron

$= 3.44 \times 10^{-18} - 4.83 \times 10^{-19}$

$= 2.957 \times 10^{-18}$ J

But $\qquad IE = \dfrac{hc}{\lambda}$

$\therefore \quad \lambda = \frac{hc}{IE} = \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{2.957 \times 10^{-18}}$

$\lambda = 6.72 \times 10^{-8}$ m

$= 67.2$ nm

10. The ionization energy of H-atom = 13.6 eV

The energy of the incident photon = 1.5 times *IE*

$= 1.5 \times 13.6$ eV

$\therefore$ *KE* of the photoelectron = $(1.5 \times 13.6 \quad 13.6)$ eV

$= 6.8$ eV

$= 6.8 \times 1.6 \times 10^{-19}$ J

$= 1.09 \times 10^{-18}$ J

But $\quad KE = \frac{mv^2}{2}$

$\therefore$ Velocity of the photoelectron = $\sqrt{\frac{2KE}{m}}$

$= \sqrt{\frac{2 \times 1.09 \times 10^{-18}}{9.1 \times 10^{-31}}} = 1.55 \times 10^{6}$ ms^{-1}

As photoelectron shows wave nature, therefore

$$\frac{1}{\lambda} = \bar{v} = \frac{mv}{h}$$

$$\bar{v} = \frac{9.1 \times 10^{-31} \times 1.55 \times 10^{6}}{6.62 \times 10^{9} \text{ m}^{-1}}$$

$$\bar{v} = 2.13 \times 10^{9} \text{ m}^{-1}$$

11. $v = \frac{nh}{2\pi mr}$

$n = 1$

$r = 0.0529$ nm $= 0.0529 \times 10^{-9}$ m

$\therefore$ velocity of an electron in the innermost orbit of the *H*-atom is equal to

$$= \frac{1 \times 6062 \times 10^{-34}}{2 \times 3.14 \times 9.1 \times 10^{-31} \times 0.0529 \times 10^{-9}}$$

$= 2.19 \times 10^{6}$ ms^{-1}

12. $\Delta x \cdot m\Delta v = \frac{h}{4\pi}$

$m = 0.5$ kg and $\Delta x = 10^{-6}$ m

$\therefore \qquad \Delta v = \dfrac{h}{4\pi m \Delta x}$

$$\Delta v \geq \frac{6.62 \times 10^{-34}}{4 \times 3.14 \times 0.5 \times 10^{-6}}$$

$$\Delta v \geq 1.05 \times 10^{-28} \text{ ms}^{-1}$$

13. $\lambda = 590 \text{ nm} = 590 \times 10^{-9}$ m

$\therefore \qquad \text{Energy} = \dfrac{hc}{\lambda}$

$$= \frac{6.62 \times 10^{-34} \times 3.0 \times 10^{8}}{590 \times 10^{-9}}$$

$$= 3.37 \times 10^{-19} \text{ J}$$

But $\qquad E = \text{eV}$

$\therefore$ Accelerating potential needed to excite this yellow line

$$= \frac{3.37 \times 10^{-19}}{1.60 \times 10^{-19}}$$

$$= 2.11 \text{ V}$$

14. $\overline{P.E.} = -w$

$$= -F \,.\, a_0$$

$$= -\frac{e^2}{4\pi\varepsilon_0 a_0} \,.\, a_0$$

$$\overline{PE} = \frac{-e^2}{4\pi\varepsilon_0 a_0}$$

Given: $\qquad \overline{KE} = \dfrac{1}{2}\overline{KE}$

$\therefore$ Total average energy $= \overline{KE} + \overline{PE}$

$$= +\frac{1}{2}\frac{e^2}{4\pi\varepsilon_0 a_0} \,.+ \left(\frac{-e^2}{4\pi\varepsilon_0 a_0}\right)$$

$$= -\frac{1}{2}\left(\frac{e^2}{4\pi\varepsilon_0 a_0}\right)$$

$$\overline{TE} = +\frac{1}{2}\overline{PE}$$

15. We know that $mvr = \frac{nh}{2\pi}$

$\therefore \qquad 2\pi r = n\frac{h}{mv}$

But $\qquad \frac{h}{mv} = \lambda$(de-Broglie equation)

$2\pi r = n\lambda$

Number of waves in the 3rd Bohr orbit = $2\pi r = 3\lambda$