

37.1. a) Using Wien's law,

$$\lambda_p = \frac{(2.9 \times 10^{-3} \text{ m K})}{T} = \frac{2.90 \times 10^{-3} \text{ m K}}{273 \text{ K}} = 1.06 \times 10^{-5} \text{ m}$$

The wavelength corresponds to far infrared.

$$b) \lambda_p = \frac{2.9 \times 10^{-3} \text{ m K}}{3500 \text{ K}} = 8.29 \times 10^{-7} \text{ m}$$

This wavelength is in infrared.

$$c) \lambda_p = \frac{2.9 \times 10^{-3} \text{ m K}}{4.2 \text{ K}} = 6.9 \times 10^{-4} \text{ m}$$

The wavelength is in ~~mic~~ microwave region.

$$d) \lambda_p = \frac{2.9 \times 10^{-3} \text{ m K}}{2.725 \text{ K}} = 1.06 \times 10^{-3} \text{ m}$$

This wavelength is also in microwave region.

37.7. The energy in a wave packet is -

$$E_1 = h f_1 = \frac{h c}{\lambda_1} = \frac{(6.63 \times 10^{-34} \text{ J s}) (3 \times 10^8 \text{ m/s})}{410 \times 10^{-9} \text{ m}} = 4.85 \times 10^{-19} \text{ J} \left( \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} \right) = 3.03 \text{ eV}$$

$$E_2 = h f_2 = \frac{h c}{\lambda_2} = \frac{(6.63 \times 10^{-34} \text{ J s}) (3 \times 10^8 \text{ m/s})}{750 \times 10^{-9} \text{ m}} = 2.65 \times 10^{-19} \text{ J} \left( \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} \right) = 1.66 \text{ eV}$$

The range of energy is  $2.7 \times 10^{-19} \text{ J} < E < 4.9 \times 10^{-19} \text{ J}$

$$\text{OR } 1.7 \text{ eV} < E < 3.0 \text{ eV}$$

$$37.8. \lambda = \frac{c}{f} = \frac{h c}{h f} = \frac{h c}{E} = \frac{(6.63 \times 10^{-34} \text{ J s}) (3 \times 10^8 \text{ m/s})}{(1.6 \times 10^{-19} \text{ J/eV}) (380 \times 10^3 \text{ eV})} = 3.27 \times 10^{-12} \text{ m}$$

Diffraction would take place when the wavelength is of the order of the opening of the door which is not the case in real life.

37.14. We know that energy is carried by the photons in a wave. If there are  $n$  photons, the min. energy carried by them is -

$$E_{\text{min}} = n h f$$

$$n = \frac{E_{\text{min}}}{h f} = \frac{E_{\text{min}}}{h} \times \frac{\lambda}{c} = \frac{(10^{-18} \text{ J}) (550 \times 10^{-9} \text{ m})}{(6.63 \times 10^{-34} \text{ J s}) (3 \times 10^8 \text{ m/s})} = 2.77 \approx 3$$

37.17. The max. energy will be emitted when the associated wavelength is min.

$$K_{\text{max}} = hf - W_0 = \frac{hc}{\lambda} - W_0 = \frac{1240 \text{ eV} \cdot \text{nm}}{410 \text{ nm}} - 2.48 \text{ eV} = 0.54 \text{ eV}$$

37.42. From De Broglie's wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad \therefore v = \frac{h}{m\lambda}$$

$$= \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{(9.11 \times 10^{-31} \text{ kg})(0.21 \times 10^{-9} \text{ m})} = 3.466 \times 10^6 \text{ m/s}$$

The change in kinetic energy occurs due to change in potential energy -

$$K = eV = \frac{1}{2} mv^2 = \frac{1}{2} \frac{(9.11 \times 10^{-31} \text{ kg})(3.466 \times 10^6 \text{ m/s})^2}{(1.6 \times 10^{-19} \text{ J/eV})}$$

$$= 34.2 \text{ eV}$$

$$\text{Thus the potential associated is } = \frac{34.2 \text{ eV}}{1 \text{ e}} = 34.2 \text{ V}$$

37.46. The de Broglie eq. gives -

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$v = \frac{h}{m\lambda} = \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{(1.67 \times 10^{-27} \text{ kg})(0.3 \times 10^{-9} \text{ m})} = 1300 \text{ m/s}$$

The speed obtained is much smaller compared to relativistic speeds.

37.57. Doubly ionised lithium has same no. of electrons as hydrogen but three positive charges ( $Z=3$ ) instead. We use the result of ionisation as that of hydrogen by replacing  $e^2$  by  $Ze^2$ .

$$E_{\text{ion}} = 0 - E_1 = \frac{1}{2} m v^2 = \left( - \frac{Z^2 (13.6 \text{ eV})}{n^2} \right)$$

$$= \frac{3^2 (13.6 \text{ eV})}{(1)^2} = 122 \text{ eV}$$

37.69. The energy emitted is difference in two energy levels.

$$\Delta E = E_U - E_L$$

$$E_U = - \frac{13.6 \text{ eV}}{n^2} = E_L + \Delta E$$

$$\therefore n = \sqrt{\frac{-13.6 \text{ eV}}{E_L + \Delta E}} = \sqrt{\frac{-13.6 \text{ eV}}{-13.6 \text{ eV} + 12.75 \text{ eV}}} = 4$$

The possible transitions from  $n=4$  excited state are -  
 $(4 \rightarrow 3)$ ,  $(4 \rightarrow 2)$ ,  $(4 \rightarrow 1)$ ,  $(3 \rightarrow 2)$ ,  $(3 \rightarrow 1)$ ,  $(2 \rightarrow 1)$ .

The wavelengths associated are -

$$\frac{1}{\lambda} = (1.097 \times 10^7 \text{ m}^{-1}) \left( \frac{1}{n_i^2} - \frac{1}{n_f^2} \right)$$

$n_i, n_f$  being the initial and final state of the system.

$$\frac{1}{\lambda_{43}} = 1.097 \times 10^7 \text{ m}^{-1} \left( \frac{1}{3^2} - \frac{1}{4^2} \right)$$

$$\therefore \lambda_{43} = 1875 \text{ nm}$$

Similarly others are  $\lambda_{42} = 486.2 \text{ nm}$ ,  $\lambda_{41} = 97.23 \text{ nm}$ ,  $\lambda_{32} = 656.3 \text{ nm}$ ,  
 $\lambda_{31} = 102.6 \text{ nm}$ ,  $\lambda_{21} = 121.5 \text{ nm}$

38.8.  $\Delta x \Delta p \geq \hbar$        $\hbar = h/2\pi$

$$\Delta x \geq \frac{\hbar}{\Delta p} = \frac{\hbar}{m \Delta v} = \frac{1.055 \times 10^{-34} \text{ J.s}}{1.67 \times 10^{-27} \text{ kg} (1200 \text{ m/s})} = 5.3 \times 10^{-11} \text{ m}$$

38.13. a)  $\Delta E \Delta t \geq \hbar$

$$\Delta E \geq \frac{\hbar}{\Delta t} = \frac{1.055 \times 10^{-34} \text{ J.s}}{10^{-8} \text{ s}} = 1.055 \times 10^{-26} \text{ J} \left( \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} \right)$$

$$= 6.59 \times 10^{-8} \text{ eV} \approx 10^{-7} \text{ eV}$$

b) The transition energy -

$$\Delta E = E_2 - E_1 = -13.6 \text{ eV} \left( \frac{1^2}{2^2} - \frac{1^2}{1^2} \right) = 10.2 \text{ eV}$$

$$E_n = -13.6 \text{ eV} \frac{Z^2}{n^2}$$

$$\frac{\Delta E}{E_2 - E_1} = \frac{6.59 \times 10^{-8} \text{ eV}}{10.2 \text{ eV}} = 6.46 \times 10^{-9}$$

c) The wavelength emitted in this transition -

$$\Delta E = hf = \frac{hc}{\lambda}$$

$$\therefore \lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34} \text{ J.s}) (3 \times 10^8 \text{ m/s})}{10.2 \text{ eV} \left( \frac{1.6 \times 10^{-19} \text{ J}}{\text{eV}} \right)} = 1.22 \times 10^{-7} \text{ m} = 122 \text{ nm}$$

~~$\Delta \lambda =$~~

$$d\lambda = -\frac{hc}{(\Delta E)^2} d\Delta E \quad \left( \because E = \frac{hc}{\lambda} \right)$$

$$\Delta \lambda = -\frac{hc}{(\Delta E)^2} \Delta E = -\frac{\lambda \Delta E}{E}$$

$$|\Delta \lambda| = \lambda \frac{\Delta E}{E} = (122 \text{ nm}) (6.46 \times 10^{-9}) = 7.88 \times 10^{-7} \text{ nm}$$

38.24. The energy levels for a particle in a box is given by -

$$E_n = \frac{n^2 h^2}{8ml^2}$$

$$\Delta E = h\nu = \frac{hc}{\lambda} = E_4 - E_1 = \frac{h^2}{8ml^2} (4^2 - 1^2) = \frac{15h^2}{8ml^2}$$

$$l = \sqrt{\frac{15h\lambda}{8mc}} = \sqrt{\frac{15(6.63 \times 10^{-34} \text{ J s})(340 \times 10^{-9} \text{ m})}{8(9.11 \times 10^{-31} \text{ kg})(3 \times 10^8 \text{ m/s})}} = 1.2 \times 10^{-9} \text{ m}$$

38.1.  $l = 0, \dots, m-1$

$$= 0, 1, 2, 3, 4, 5, 6$$

38.2.  $m_l = -l, -l+1, \dots, l$

$$l=3, m_l = -3, -2, -1, 0, 1, 2, 3$$

$m_s = \pm \frac{1}{2}$  for hydrogen atom

39.15. The probability of finding an electron depends on  $|\psi_{100}|^2$ .

$$\frac{P(r=r_0)}{P(r=2r_0)} = \frac{\frac{4r^2}{r_0^2} e^{-\frac{2r}{r_0}} \Big|_{r=r_0}}{\frac{4r^2}{r_0^2} e^{-\frac{2r}{r_0}} \Big|_{r=2r_0}} = \frac{\frac{4r_0^2}{r_0^2} e^{-\frac{2r_0}{r_0}}}{\frac{4(2r_0)^2}{r_0^2} e^{-\frac{4r_0}{r_0}}} = \frac{e^{-2}}{4e^{-4}} = \frac{e^2}{4} \approx 1.85$$

39.28. For  $Z=8$ , we start with  $n=1$  and then go to  $n=2$  listing the quantum numbers as  $(n, l, m_l, m_s)$ .

$$(1, 0, 0, -\frac{1}{2}), (1, 0, 0, \frac{1}{2}), (2, 0, 0, -\frac{1}{2}), (2, 0, 0, \frac{1}{2}), (2, 1, -1, -\frac{1}{2}), (2, 1, 0, -\frac{1}{2}), (2, 1, -1, \frac{1}{2}), (2, 1, 0, \frac{1}{2})$$

However  $(2, 1, 1, \frac{1}{2}), (2, 1, 1, -\frac{1}{2})$  could replace last four choices as well.

39.35. The Bohr radius is given by -

$$r_n = \frac{n^2}{Z} (0.529 \times 10^{-10} \text{ m}) = \frac{1}{92} (0.529 \times 10^{-10} \text{ m}) = 5.75 \times 10^{-13} \text{ m}$$

The ionisation energy is given by -

$$|E_n| = (13.6 \text{ eV}) \frac{Z^2}{n^2} = (13.6 \text{ eV}) \frac{(92)^2}{(1)^2} = 1.15 \times 10^5 \text{ eV}$$

The energy required to remove the electron is the opposite of the total energy of the system.

39.42. The wavelength associated with X ray emission is given by -

$$\frac{1}{\lambda} = \left( \frac{e^4 m}{8\epsilon_0^2 h^3 c} \right) (Z-1)^2 \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) = (1.097 \times 10^7 \text{ m}^{-1}) (27-1)^2 \left( \frac{1}{1^2} - \frac{1}{2^2} \right)$$

$$= 5.562 \times 10^9 \text{ m}^{-1}$$

$$\lambda = 1.798 \times 10^{-10} \text{ m}$$

41.12. The kinetic energy initially should be equal to the potential energy on the surface of uranium as it comes to rest there.

$$K_i + U_i = K_f + U_f$$

$$K_\alpha + 0 = 0 + \frac{1}{4\pi\epsilon_0} \frac{q_\alpha q_U}{(r_\alpha + r_U)}$$

$$K_\alpha = \frac{(8.988 \times 10^9 \text{ Nm}^2/\text{C}^2) (2)(92)(1.6 \times 10^{-19} \text{ C})^2}{(4^{1/3} + 238^{1/3})(1.2 \times 10^{-15} \text{ m})(1.6 \times 10^{-19} \text{ J/eV})}$$

$$= 2.832 \times 10^7 \text{ eV} \approx 28 \text{ MeV}$$

41.16. a)  ${}^7_3\text{Li}$  has three protons and four neutrons.

$$\text{Binding energy} = [3m({}^1_1\text{H}) + 4m({}^1_0\text{n}) - m({}^7_3\text{Li})]c^2$$

$$= [3(1.007825 \text{ u}) + 4(1.008665 \text{ u}) - (7.016005 \text{ u})]c^2 (931.5 \frac{\text{MeV}}{c^2})$$

$$= \cancel{37.24 \times 10^6 \text{ eV}} \quad \cancel{37.24}$$

$$= 39.24 \text{ MeV}$$

$$\text{Binding energy per nucleon} = \frac{39.24}{7} = 5.61 \text{ MeV/nucleon}$$

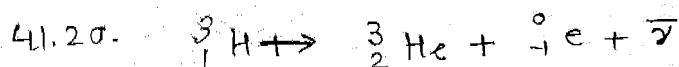
b)  ${}^{197}_{79}\text{Au}$  has 79 protons and 118 neutrons.

$$\text{Binding energy} = [79m({}^1_1\text{H}) + 118m({}^1_0\text{n}) - m({}^{197}_{79}\text{Au})]c^2$$

$$= [79(1.007825 \text{ u}) + 118(1.008665 \text{ u}) - (196.966569 \text{ u})]c^2 (931.5 \text{ MeV}/c^2)$$

$$= 1559 \text{ MeV}$$

$$\text{Binding energy per nucleon} = \frac{1559 \text{ MeV}}{197} = 7.91 \text{ MeV/nucleon}$$



On adding an electron to both sides, if we use the atomic masses, we see that the mass of  $\beta$  particle is included in mass of  ${}^3_2\text{He}$ .

$$\text{Energy released} = [m({}^3_1\text{H}) - m({}^3_2\text{He})]c^2$$

$$= [(3.016049 \text{ u}) - (3.016029 \text{ u})]c^2 (931.5 \text{ MeV}/c^2)$$

$$= 0.019 \text{ MeV}$$

41.27. a) By balancing charge and mass numbers -

$$Z(X) = Z(U) - Z(\text{He}) = 92 - 2 = 90$$

$$X = {}^{234}_{90}\text{Th}$$

$$A(X) = A(U) - A(\text{He}) = 238 - 4 = 234$$

b) The kinetic energy of  $\alpha$  particle will be the  $Q$  value of the reaction.

$$K = Q = [m({}^{238}_{92}\text{U}) - m({}^{234}_{90}\text{Th}) - m({}^4_2\text{He})]c^2$$

$$m({}^{234}_{90}\text{Th}) = m({}^{238}_{92}\text{U}) - m({}^4_2\text{He}) - \frac{K}{c^2}$$

$$= [238.0507880 - 4.0026030 - \frac{4.20\text{MeV}}{c^2} \left(\frac{1\text{U}}{931.5\text{MeV}/c^2}\right)]$$

$$= 234.04368\text{U}$$

$$41.40. \quad R = R_0 e^{-\lambda t} = R_0 e^{-\frac{\ln 2}{T_{1/2}} t}$$

$$T_{1/2} = -\frac{\ln 2}{\ln \frac{R}{R_0}} t = -\frac{\ln 2}{\ln \frac{320}{1280}} (3.6\text{h}) = 1.8\text{h}$$

41.43. After  $\rho$  every half life we are left with half of original sample.

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^\rho = 0.015625$$

41.44. By equating equal activity, we have-

$$\lambda_1 N_1 = \lambda_{Co} N_{Co}$$

$$\lambda_1 N_0 e^{-\lambda_1 t} = \lambda_{Co} N_0 e^{-\lambda_{Co} t} \quad \frac{\lambda_1}{\lambda_{Co}} = e^{(\lambda_1 - \lambda_{Co})t}$$

$$t = \frac{\ln(\lambda_1/\lambda_{Co})}{\lambda_1 - \lambda_{Co}} = \frac{\ln\left(\frac{T_{Co}/2}{T_{1/2}}\right)}{\frac{\ln 2}{T_{1/2}} - \frac{\ln 2}{T_{Co}/2}} = \frac{\ln\left[\frac{(5.271\text{y})(365.25\text{d/y})}{8.0233\text{d}}\right]}{\ln 2 \left[\frac{1}{8.0233\text{d}} - \frac{1}{(5.271\text{y})(365.25\text{d/y})}\right]}$$

$$= 63.703\text{d}$$

41.47. The decay constant is-

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{(8.0233\text{days})(24\text{h/day})(3600\text{s/h})} = 9.99905 \times 10^{-7} \text{s}^{-1}$$

$N_0$  being the no. of nuclei initially.

$$N_0 = \frac{782 \times 10^{-6} \text{g}}{130.906 \text{g/mol}} \times (6.023 \times 10^{23} \text{atoms/mol})$$

↓  
Avogadro's no. - no. of atoms in a mol.

$$= 3.596 \times 10^{18} \text{ nuclei}$$

$$a) \quad \left.\frac{dN}{dt}\right|_0 = 9.99905 \times 10^{-7} (3.596 \times 10^{18}) = 3.5957 \times 10^{12} \text{ decays/s}$$

$$b) \frac{dN}{dt} \Big|_{1h} = (3.95957 \times 10^{12} \text{ decay/s}) e^{- (9.99905 \times 10^{-7} \text{ s}^{-1}) (3600 \text{ s})}$$

$$\approx 3.58 \times 10^{12} \text{ decays/s}$$

$$c) \frac{dN}{dt} \Big|_{1/3 \text{ yr}} = (3.5957 \times 10^{12} \text{ decays/s}) e^{- (9.99905 \times 10^{-7} \text{ s}^{-1}) (0.333 \text{ yr}) (3.156 \times 10^7 \text{ yr})}$$

$$\approx 9.72 \times 10^7 \text{ decays/s}$$

41.60. We use atomic weight of  $^{12}_6\text{C}$  as atomic weight (85g) due to its abundance. We use the activity to find age of club.

$$N_{^{12}_6\text{C}} = \frac{85 \text{ g}}{(12 \text{ g/mol})} \times 6.02 \times 10^{23} \text{ atoms/mol} = 4.264 \times 10^{24} \text{ atoms}$$

$$N_{^{14}_6\text{C}} = (1.3 \times 10^{-12}) (4.264 \times 10^{24}) = 5.543 \times 10^{12} \text{ nuclei}$$

$$\lambda N_{^{14}_6\text{C}} = (\lambda N_{^{14}_6\text{C}})_0 e^{-\lambda t}$$

$$t = - \frac{1}{\lambda} \ln \left( \frac{\lambda N_{^{14}_6\text{C}} \text{ tod.}}{\lambda N_{^{14}_6\text{C}}_0} \right) = - \frac{5730 \text{ yr}}{\ln 2} \ln \left[ \frac{7 \text{ decays/s}}{\ln 2 (5.543 \times 10^{12} \text{ nuclei})} \right]$$

$$= - \frac{5730 \text{ yr}}{\ln 2} \ln \left[ \frac{7 \text{ decays/s}}{(5730 \text{ yr}) (3.156 \times 10^7 \text{ s/yr})} \right]$$

$$= 9178 \text{ yr}$$