Chapter 40

2. (a) From Fig. 40-10 and Eq. 40-18,

$$\Delta E = 2\mu_B B = \frac{2\left(9.27\times10^{-24}\text{ J/T}\right)\left(0.15\text{ T}\right)}{1.60\times10^{-19}\text{ J/eV}} = 17.38\,\mu\text{eV} \approx 17\,\mu\text{eV}.$$

(b) From $\Delta E = hf$ and with SI units we get

$$f = \frac{\Delta E}{h} = \frac{2.78\times10^{-24}\text{ J}}{6.63\times10^{-34}\text{ J}\cdot\text{s}} = 4.2\times10^{19}\text{ Hz} = 4.2\text{ GHz} .$$

(c) The wavelength is

$$\lambda = \frac{c}{f} = \frac{2.998\times10^{8}\text{ m/s}}{4.2\times10^{9}\text{ Hz}} = 7.1\text{ cm}.$$

(d) The wave is in the short radio wave region.

4. (a) An electron must be removed from the *K*-shell, so that an electron from a higher energy shell can drop. This requires an energy of 69.5 keV. The accelerating potential must be at least 69.5 kV.

(b) After it is accelerated, the kinetic energy of the bombarding electron is 69.5 keV. The energy of a photon associated with the minimum wavelength is 69.5 keV, so its wavelength is

$$\lambda_{\min} = \frac{1240\ \text{eV}\cdot\text{nm}}{69.5\times10^{3}\ \text{eV}} = 1.78\times10^{-2}\ \text{nm} = 17.8\ \text{pm}\ .$$

(c) The energy of a photon associated with the K_α line is 69.5 keV – 11.3 keV = 58.2 keV and its wavelength is

$$\lambda_{K\alpha} = (1240\ \text{eV}\cdot\text{nm})/(58.2 \times 10^{3}\ \text{eV}) = 2.13 \times 10^{-2}\ \text{nm} = 21.3\ \text{pm}.$$

(d) The energy of a photon associated with the K_β line is

$$E = 69.5\ \text{keV} - 2.30\ \text{keV} = 67.2\ \text{keV}$$

and its wavelength is, using hc = 1240 eV·nm,

$$\lambda_{K\beta} = hc/E = (1240\ \text{eV}\cdot\text{nm})/(67.2 \times 10^{3}\ \text{eV}) = 1.85 \times 10^{-2}\ \text{nm} = 18.5\ \text{pm}.$$

18. The total magnetic field, $B = B_{\text{local}} + B_{\text{ext}}$, satisfies $\Delta E = hf = 2\mu B$ (see Eq. 40-22). Thus,

$$B_{\text{local}} = \frac{hf}{2\mu} - B_{\text{ext}} = \frac{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(36\times10^{6}\ \text{Hz}\right)}{2\left(1.41\times10^{-26}\ \text{J/T}\right)} - 0.78\ \text{T} = 66\ \text{mT}\ .$$

34. Due to spin degeneracy ($m_s = \pm 1/2$), each state can accommodate two electrons. Thus, in the energy-level diagram shown, two electrons can be placed in the ground state with energy $E_1 = 4(h^2/8mL^2)$, six can occupy the "triple state" with $E_2 = 6(h^2/8mL^2)$, and so forth. With 11 electrons, the lowest energy configuration consists of two electrons with $E_1 = 4(h^2/8mL^2)$, six electrons with $E_2 = 6(h^2/8mL^2)$, and three electrons with $E_3 = 7(h^2/8mL^2)$. Thus, we find the ground-state energy of the 11-electron system to be

$$\begin{aligned} E_{\text{ground}} &= 2E_1 + 6E_2 + 3E_3 = 2\left(\frac{4h^2}{8mL^2}\right) + 6\left(\frac{6h^2}{8mL^2}\right) + 3\left(\frac{7h^2}{8mL^2}\right) \\ &= \left[(2)(4) + (6)(6) + (3)(7)\right]\left(\frac{h^2}{8mL^2}\right) = 65\left(\frac{h^2}{8mL^2}\right). \end{aligned}$$

The first excited state of the 11-electron system consists of two electrons with $E_1 = 4(h^2/8mL^2)$, five electrons with $E_2 = 6(h^2/8mL^2)$, and four electrons with $E_3 = 7(h^2/8mL^2)$. Thus, its energy is

$$\begin{aligned} E_{\text{1st excited}} &= 2E_1 + 5E_2 + 4E_3 = 2\left(\frac{4h^2}{8mL^2}\right) + 5\left(\frac{6h^2}{8mL^2}\right) + 4\left(\frac{7h^2}{8mL^2}\right) \\ &= \left[(2)(4) + (5)(6) + (4)(7)\right]\left(\frac{h^2}{8mL^2}\right) = 66\left(\frac{h^2}{8mL^2}\right). \end{aligned}$$

Thus, the multiple of $h^2/8mL^2$ is 66.

45. Let the power of the laser beam be P and the energy of each photon emitted be E. Then, the rate of photon emission is

$$R = \frac{P}{E} = \frac{P}{hc/\lambda} = \frac{P\lambda}{hc} = \frac{\left(15.6\times10^{-3}\ \mathrm{W}\right)\left(632.8\times10^{-9}\ \mathrm{m}\right)}{\left(6.63\times10^{-34}\ \mathrm{J\cdot s}\right)\left(2.998\times10^{8}\ \mathrm{m/s}\right)} = 5.0\times10^{16}\ \mathrm{s}^{-1}.$$