

33. (a) Since energy is conserved, the energy E of the photon is given by $E = E_i - E_f$, where E_i is the initial energy of the hydrogen atom and E_f is the final energy. The electron energy is given by $(-13.6 \text{ eV})/n^2$, where n is the principal quantum number. Thus,

$$E = E_3 - E_1 = \frac{-13.6 \text{ eV}}{(3)^2} - \frac{-13.6 \text{ eV}}{(1)^2} = 12.1 \text{ eV} .$$

(b) The photon momentum is given by

$$p = \frac{E}{c} = \frac{(12.1 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})}{3.00 \times 10^8 \text{ m/s}} = 6.45 \times 10^{-27} \text{ kg} \cdot \text{m/s} .$$

(c) Using $hc = 1240 \text{ eV} \cdot \text{nm}$, the wavelength is $\lambda = \frac{hc}{E} = \frac{1240 \text{ eV} \cdot \text{nm}}{12.1 \text{ eV}} = 102 \text{ nm}$.

40. (a) The calculation is shown in Sample Problem — “Light emission from a hydrogen atom.” The difference in the values obtained in parts (a) and (b) of that Sample Problem is $122 \text{ nm} - 91.4 \text{ nm} \approx 31 \text{ nm}$.

(b) We use Eq. 39-1. For the Lyman series,

$$\Delta f = \frac{2.998 \times 10^8 \text{ m/s}}{91.4 \times 10^{-9} \text{ m}} - \frac{2.998 \times 10^8 \text{ m/s}}{122 \times 10^{-9} \text{ m}} = 8.2 \times 10^{14} \text{ Hz} .$$

(c) Fig. 39-18 shows that the width of the Balmer series is $656.3 \text{ nm} - 364.6 \text{ nm} \approx 292 \text{ nm} \approx 0.29 \mu\text{m}$.

(d) The series limit can be obtained from the $\infty \rightarrow 2$ transition:

$$\Delta f = \frac{2.998 \times 10^8 \text{ m/s}}{364.6 \times 10^{-9} \text{ m}} - \frac{2.998 \times 10^8 \text{ m/s}}{656.3 \times 10^{-9} \text{ m}} = 3.65 \times 10^{14} \text{ Hz} \approx 3.7 \times 10^{14} \text{ Hz} .$$

42. Conservation of linear momentum of the atom-photon system requires that

$$p_{\text{recoil}} = p_{\text{photon}} \Rightarrow m_p v_{\text{recoil}} = \frac{hf}{c}$$

where we use Eq. 39-7 for the photon and use the classical momentum formula for the atom (since we expect its speed to be much less than c). Thus, from Eq. 39-6 and Table 37-3,

$$v_{\text{recoil}} = \frac{\Delta E}{m_p c} = \frac{E_4 - E_1}{(m_p c^2)/c} = \frac{(-13.6 \text{ eV})(4^{-2} - 1^{-2})}{(938 \times 10^6 \text{ eV})/(2.998 \times 10^8 \text{ m/s})} = 4.1 \text{ m/s} .$$