9-21. $E_{0r} = \dfrac{\hbar^2}{2I}$ (Equation 9-14) where $I = \dfrac{1}{2} m r_0^2$ for a symmetric molecule.

$$E_{0r} = \frac{\hbar^2}{m r_0^2} = \frac{(\hbar c)^2}{m c^2 r_0^2} = \frac{(197.3 eV \bullet nm)^2}{(16uc)^2 (931.5 \times 10^6 eV / uc^2)(0.121 nm)^2} = 1.78 \times 10^{-4} eV$$

9-22. For Co: $f = 6.42 \times 10^{13} Hz$ (See Example 9-6)

$E_V = (v + 1/2) hf$ (Equation 9-20)

(a) $E_1 - E_0 = 3hf/2 - hf/2 = hf$

$$= (4.14 \times 10^{-15} eV \bullet s)(6.42 \times 10^{13} Hz)$$

$$= 0.27 eV$$

(b) $\dfrac{n_1}{n_0} = e^{-(E_1 - E_0)/kT}$ (from Equation 8-2)

$$0.01 = e^{-(0.27)/(8.62 \times 10^{-5})T}$$

$$\ln(0.01) = -(0.27 eV) / (8.62 \times 10^{-5} eV / K) T$$

$$T = \frac{-(0.27 eV)}{\ln(0.01)(8.62 \times 10^{-5} eV / K)}$$

$$T = 680 K$$

9-23. For LiH: $f = 4.22\times10^{13}\,Hz$ (from Table 9-7)

(a) $E_V = (v+1/2)hf = E_0 = hf/2 = (4.14\times10^{-15}\,eV\bullet s)(4.22\times10^{13}\,Hz)/2$

$E_0 = 0.087\,eV$

(b) $\mu = \dfrac{m_1 m_2}{m_1 + m_2}$ (Equation 9-17)

$$\mu = \frac{(7.0160u)(1.0078u)}{(7.0160u)+(1.0078u)} = 0.8812u$$

(c) $f = \dfrac{1}{2\pi}\sqrt{\dfrac{K}{\mu}}$ (Equation 9-21)

$$K = (2\pi f)^2\,\mu = (2\pi)^2(4.22\times10^{13}\,Hz)(0.8812)(1.66\times10^{-27}\,kg/u)$$

$K = 117\,N/m$

(d) $E_n = n^2h^2/8mr_0^2 \rightarrow r_0^2 = n^2h^2/8mE_n$

$r_0 \approx h/(8mE_0)^{1/2}$

$$r_0 \approx \frac{6.63\times10^{-34}\,J\bullet s}{\left[8(0.8812u)(1.66\times10^{-27}\,kg/u)(0.087eV)(1.60\times10^{-19}\,J/eV)\right]^{1/2}}$$

$r_0 \approx 5.19\times10^{-11}\,m = 0.052\,nm$

9-25. (a) $\mu = \dfrac{m_1 m_2}{m_1 + m_2} = \dfrac{(39.1u)(35.45u)}{39.1u + 35.45u} = 18.6u$

(b) $E_{0r} = \dfrac{\hbar^2}{2I}$ (Equation 9-14) $I = \mu r_0^2$

$$E_{0r} = \frac{\hbar^2}{2\mu r_0^2} = \frac{(\hbar c)^2}{2\mu c^2 r_0^2} \rightarrow r_0^2 = \frac{(\hbar c)^2}{2\mu c^2 E_V}$$

$$\therefore r_0 = \frac{\hbar c}{(2\mu c^2 E_V)^{1/2}} = \frac{197.3eV\bullet nm}{\left[2(10.6uc^2)(931.5\times10^6\,eV/uc^2)(1.43\times10^{-5}\,eV)\right]^{1/2}}$$

$r_0 = 0.280\,nm$

9-27. 1. $f = \frac{1}{2\pi}\sqrt{\frac{K}{\mu}}$ (Equation 9-21) Solving for the force constant, $K = (2\pi f)^2 \mu$

2. The reduced mass μ of the NO molecule is

$$\mu = \frac{m_N m_O}{m_N + m_O} = \frac{(14.01\,u)(16.00\,u)}{14.01\,u + 16.00\,u} = 7.47\,u$$

3. $K = (2\pi \times 5.63 \times 10^{13}\ \text{Hz})^2 \times 7.47\,u \times 1.66 \times 10^{-27}\ \text{kg/u} = 1.55 \times 10^3\ \text{N/m}$

(Note: This is equivalent to about 8.8 lbs/ft, the force constant of a moderately strong spring.)

9-29. $\Delta E = hf$ where $f = 1.05 \times 10^{13}\,Hz$ for Li. Approximating the potential (near the bottom) with a square well, $\Delta E(2 \to 1) = (2^2 - 1)\left(\frac{\pi^2}{2}\right)\frac{\hbar^2}{mr_0^2} = hf$

For Li_2: $r_0^2 = \frac{3\pi^2}{2}\frac{\hbar}{2\pi}\frac{1}{f\mu} = \frac{3\pi}{4}\frac{\hbar}{f\mu}$

$$r = \left[\left(\frac{3\pi}{4}\right)\frac{1.055 \times 10^{-34}\,J \bullet s}{(1.05 \times 10^{13}\,Hz)(6.939u)(1.66 \times 10^{-27}\,kg/u)}\right]^{1/2}$$

$$= 4.53 \times 10^{-11}\,m = 0.045\,nm$$