

$$8-11. \quad \frac{n_2}{n_1} = \frac{g_2 e^{-E_2/kT}}{g_1 e^{-E_1/kT}} = \frac{g_2}{g_1} e^{-(E_2-E_1)/kT}$$

$$e^{(E_2-E_1)/kT} = \frac{g_2}{g_1} \times \frac{n_1}{n_2} = (E_2 - E_1)/kT = \ln \left(\frac{g_2}{g_1} \times \frac{n_1}{n_2} \right)$$

$$T = \frac{E_2 - E_1}{k \ln \left[\left(\frac{g_2}{g_1} \right) \left(\frac{n_1}{n_2} \right) \right]} = \frac{10.2 eV}{(8.67 \times 10^{-5} eV/K) \ln(4 \times 10^6)} = 7790 K$$

$$8-12. \quad \frac{n_2}{n_1} = \frac{g_2}{g_1} e^{-(E_2-E_1)/kT} = \frac{3}{1} e^{-\left[\frac{4 \times 10^{-3} eV}{(8.67 \times 10^{-5} eV/K)(300 K)} \right]} = 0.155$$

$$8-14. \quad c_v = 3R/M$$

$$(a) \text{ Al: } c_v = \frac{3(1.99 \text{ cal/mole}\cdot\text{K})}{27.0 \text{ g/mole}} = 0.221 \text{ cal/g}\cdot\text{K} \quad \{0.215 \text{ cal/g}\cdot\text{K}\}$$

$$(b) \text{ Cu: } c_v = \frac{3(1.99 \text{ cal/mole}\cdot\text{K})}{62.5 \text{ g/mole}} = 0.0955 \text{ cal/g}\cdot\text{K} \quad \{0.0920 \text{ cal/g}\cdot\text{K}\}$$

$$(c) \text{ Pb: } c_v = \frac{3(1.99 \text{ cal/mole}\cdot\text{K})}{207 \text{ g/mole}} = 0.0288 \text{ cal/g}\cdot\text{K} \quad \{0.0305 \text{ cal/g}\cdot\text{K}\}$$

The values for each element shown in brackets are taken from the *Handbook*

of Chemistry and Physics and apply at 25° C.

$$8-17. \text{ For hydrogen: } E_n = -\frac{mk^2e^4}{2\hbar^2} \frac{1}{n^2} = -\frac{13.605687}{n^2} eV \text{ using values of the constants}$$

accurate to six decimal places.

$$E_1 = -13.605687 eV$$

$$E_2 = -3.401422 eV \quad E_2 - E_1 = 10.204265 eV$$

$$E_3 = -1.511743 eV \quad E_3 - E_1 = 12.093944 eV$$

$$(a) \quad \frac{n_2}{n_1} = \frac{g_2}{g_1} e^{-(E_2-E_1)/kT} = \frac{8}{2} e^{-10.20427/0.02586} = 4e^{-395} = 4 \times 10^{-172} \approx 0$$

$$\frac{n_3}{n_1} = \frac{g_3}{g_1} e^{-(E_3 - E_1)/kT} = \frac{18}{2} e^{-12.09394/0.02586} = 9e^{-468} = 9 \times 10^{-203} \approx 0$$

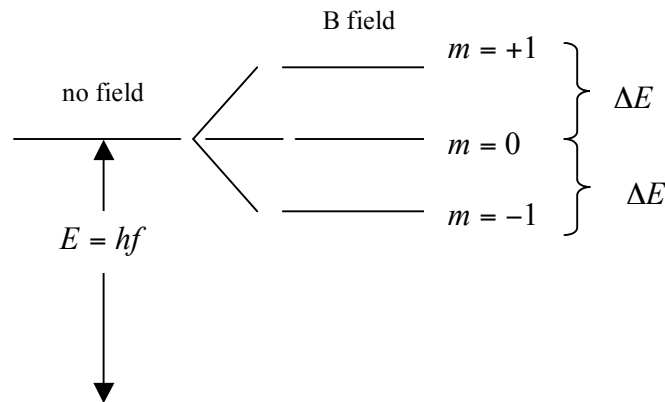
$$(b) \frac{n_2}{n_1} = 0.01 = 4e^{-10.20427/kT} \rightarrow e^{-10.20427/kT} = 0.0025$$

$$-10.20427/kT = \ln(0.0025) = -5.99146$$

$$T = \frac{10.20427 eV}{(5.99146)(8.61734 \times 10^{-5} eV/K)} = 19,760 K$$

$$(c) \frac{n_3}{n_1} = 9e^{-12.09394/(8.61734 \times 10^{-5})(19,760)} = 0.00742 = 0.7\%$$

8-18.



Neglecting the spin, the $3p$ state is doubly degenerate: $\ell = 0, 1$ hence, there are two $m = 0$ levels equally populated.

$$E = hf = hc/\lambda = 1.8509 eV \quad (\lambda = 670.79 nm)$$

$$\Delta E = \frac{e\hbar B}{2m_e} = 2.315 \times 10^{-4} eV$$

(a) The fraction of atoms in each m -state relative to the ground state is: (Example 8-2)

$$\frac{n_{+1}}{n} = e^{-1.8511/0.02586} = e^{-71.58} = 10^{-31.09} = 8.18 \times 10^{-32}$$

$$\frac{n_0}{n} = 2 \times e^{-1.8509/0.02586} = 2e^{-71.57} = 2 \times 10^{-31.08} = 1.64 \times 10^{-31}$$

$$\frac{n_0}{n_{-1}} = e^{-1.8507/0.02586} = e^{-71.56} = 10^{-31.08} = 8.30 \times 10^{-32}$$

- (b) The brightest line with the B-field “on” will be the transition from the $m = 0$ level, the center line of the Zeeman spectrum. With that as the “standard”, the relative intensities will be: $8.30/16.4/8.18 \rightarrow 0.51/1.00/0.50$

8-21. Assuming the gases are ideal gases, the pressure is given by: $P = \frac{2}{3} \frac{N \langle E \rangle}{V}$ for classical, FD, and BE particles. P_{FD} will be highest due to the exclusion principle, which, in effect, limits the volume available to each particle so that each strikes the walls more frequently than the classical particles. On the other hand, P_{BE} will be lowest, because the particles tend to be in the same state, which in effect, is like classical particles with a mutual attraction, so they strike the walls less frequently.

$$8-23. \quad \lambda = \frac{h}{p} = \frac{h}{\sqrt{2m \langle E \rangle}} = \frac{h}{\sqrt{2m(3kT/2)}} = \frac{h}{(3mkT)^{1/2}}$$

The distance between molecules in an ideal gas $(V/N)^{1/3}$ is found from

$$PV = nRT = nRT(N_A/N_A) = NkT \rightarrow (V/N)^{1/3} = (kT/P)^{1/3}$$

and equating this to λ above, $(kT/P)^{1/3} = \frac{h}{(3mkT)^{1/2}}$

$$\frac{kT}{P} = \frac{h^3}{(3mkT)^{3/2}} \text{ and solving for } T, \text{ yields: } T^{5/2} = \frac{P}{k} \frac{h^3}{(3mk)^{3/2}}$$

$$T = \left[\frac{Ph^3}{k(3mk)^{3/2}} \right]^{2/5} = \left[\frac{(101kPa)(6.63 \times 10^{-34} J \cdot s)^3}{3(2 \times 1.67 \times 10^{-27} kg)(1.38 \times 10^{-23} J/K)^{3/2}} \right]^{2/5} = 4.4K$$

$$8-26. \quad T_C = \frac{h^2}{2mk} \left[\frac{N}{2\pi(2.315)V} \right]^{2/3} \quad (\text{Equation 8-48})$$

The density of liquid Ne is 1.207 g/cm^3 , so

$$\frac{N}{V} = \frac{(1.207 \text{ g/cm}^3)(6.022 \times 10^{23} \text{ molecules/mol})(10^6 \text{ cm}^3/\text{m}^3)}{20.18 \text{ g/mol}} = 3.601 \times 10^{28} / \text{m}^3$$

$$T = \frac{(6.626 \times 10^{-34} J \cdot s)^2}{2(20u \times 1.66 \times 10^{-27} \text{ kg/u})(.381 \times 10^{-23} J/K)} \left[\frac{3.601 \times 10^{28} \text{ m}^3}{2\pi(2.315)} \right]^{2/3} = 0.895K$$

Thus, T_C at which ^{20}Ne would become a superfluid is much lower than its freezing temperature of 24.5K.

$$8-28. \quad \langle E \rangle = \frac{hf}{e^{hf/kT} - 1} \quad (\text{Equation 8-60})$$

$$(a) \quad \text{For } T = 10hf/k; \quad hf = kT/10 \rightarrow \langle E \rangle = \frac{hf}{e^{1/10} - 1} = \frac{kT/10}{0.1051} = 0.951kT$$

$$(b) \quad \text{For } T = hf/k; \quad hf = kT \rightarrow \langle E \rangle = \frac{hf}{e^1 - 1} = \frac{kT}{1.718} = 0.582kT$$

$$(c) \quad \text{For } T = 0.1hf/k; \quad hf = 10kT \rightarrow \langle E \rangle = \frac{hf}{e^{10} - 1} = \frac{10kT}{2.20 \times 10^4} = 4.54 \times 10^{-4}kT$$

According to equipartition $\langle E \rangle = kT$ in each case.

$$8-29. \quad C_V = 3N_A k \left(\frac{hf}{kT} \right)^2 \frac{e^{hf/kT}}{(e^{hf/kT} - 1)^2} \quad \text{As } T \rightarrow \infty, \quad hf/kT \text{ gets small and}$$

$$e^{hf/kT} \approx 1 + hf/kT + \dots$$

$$C_V = 3N_A k \left(\frac{hf}{kT} \right)^2 \frac{(1 + hf/kT + \dots)}{(hf/kT)^2} \approx 3N_A k = 3N_A (R/N_A) = 3R$$

The rule of Dulong and Petit.

$$8-31. \quad C_V = 3R \left(\frac{hf}{kT} \right)^2 \frac{e^{hf/kT}}{(e^{hf/kT} - 1)^2} \quad (\text{Equation 8-62})$$

At the Einstein temperature $T_E = hf/k$,

$$C_V = 3R(1)^2 \frac{e^1}{(e^1 - 1)^2} = 3R(0.9207) = 3(8.31 \text{ J/K} \cdot \text{mol})(0.9207)$$

$$= 22.95 \text{ J/K} \cdot \text{mol} = 5.48 \text{ cal/K} \cdot \text{mol}$$

8-35. Approximating the nuclear potential with an infinite square well and ignoring the Coulomb repulsion of the protons, the energy levels for both protons and neutrons are given by $E_n = (n^2 h^2)/(8mL^2)$ and six levels will be occupied in ^{22}Ne , five levels with 10 protons and six levels with 12 neutrons.

$$E_F (\text{protons}) = \frac{(5)^2 (1240 \text{ MeV} \cdot \text{fm})^2}{8(1.0078u \times 931.5 \text{ MeV} / u)(3.15 \text{ fm})^2} = 516 \text{ MeV}$$

$$E_F (\text{neutrons}) = \frac{(6)^2 (1240 \text{ MeV} \cdot \text{fm})^2}{8(1.0087u \times 931.5 \text{ MeV} / u)(3.15 \text{ fm})^2} = 742 \text{ MeV}$$

$$\langle E \rangle (\text{protons}) = (3/5)E_F = 310 \text{ MeV}$$

$$\langle E \rangle (\text{neutrons}) = (3/5)E_F = 445 \text{ MeV}$$

As we will discover in Chapter 11, these estimates are nearly an order of magnitude too

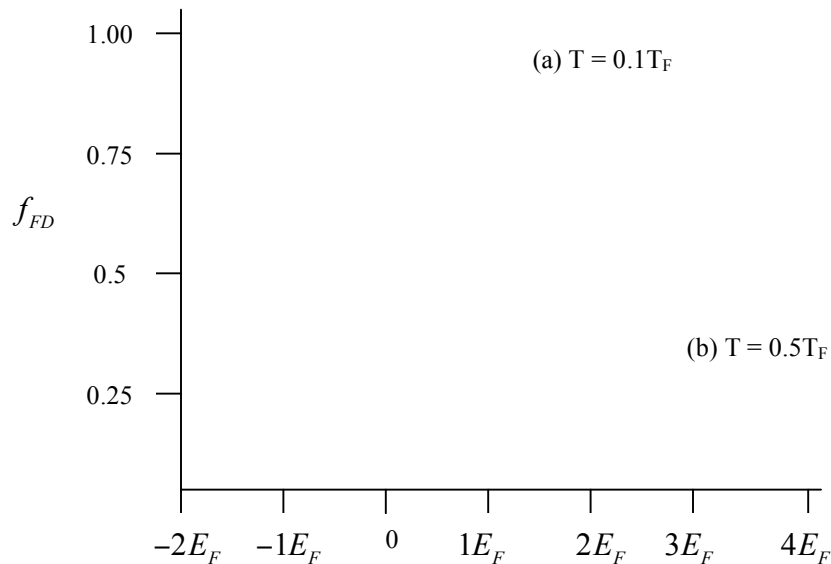
large. The number of particles is not a large sample.

8-36. $E_1 = h^2 / 8mL^2$. All 10 bosons can be in this level, so $E_1 (\text{total}) = 10h^2 / 8mL^2$.

8-37. (a) $f_{FD}(E) = \frac{1}{e^{(E-E_F)/kT} + 1}$ (Equation 8-68)

$$= \frac{1}{e^{(E-E_F)/0.1E_F} + 1} = \frac{1}{e^{10(E-E_F)/E_F} + 1}$$

(b) $f_{FD}(E) = \frac{1}{e^{(E-E_F)/0.5E_F} + 1} = \frac{1}{e^{2(E-E_F)/E_F} + 1}$



8-38. $\frac{N_o}{N} \approx 1 - \left(\frac{T}{T_c}\right)^{3/2}$ (Equation 8-52)

(a) $\frac{N_o}{N} \approx 1 - \left(\frac{T_c/2}{T_c}\right)^{3/2} = 1 - \left(\frac{1}{2}\right)^{3/2} = 0.646$

(b) $\frac{N_o}{N} \approx 1 - \left(\frac{T_c/4}{T_c}\right)^{3/2} = 1 - \left(\frac{1}{4}\right)^{3/2} = 0.875$