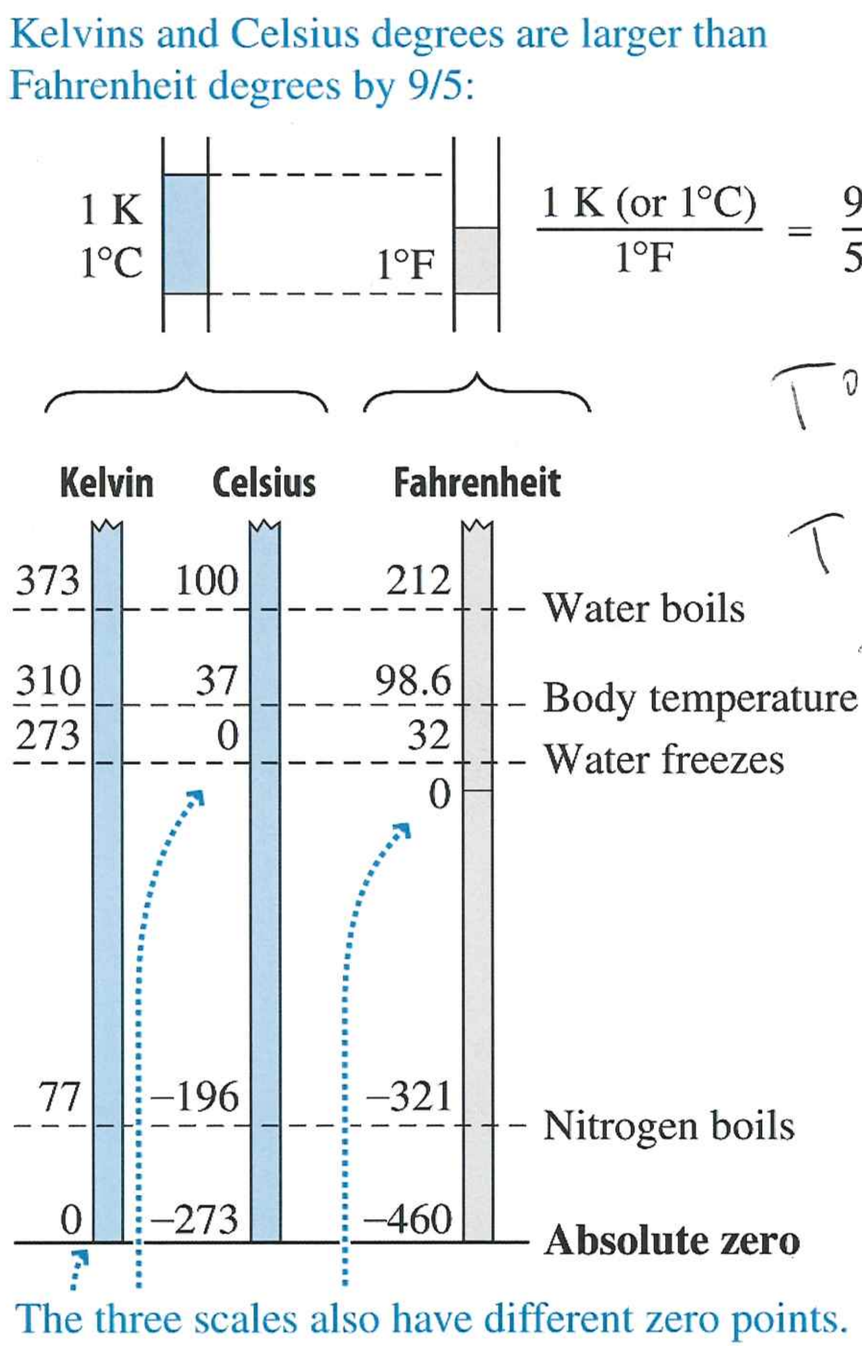
LECTURE 33

(Ch10: 3-4)

Figure 12.2



$T°C = \frac{5}{9}(T°F - 32°)$

$T K = T°C + 273.15$

$T°F = \frac{9}{5} T°C + 32$

Topic Summary

- **Temperature and the Zeroth Law of Thermodynamics**
- **Thermometers and Temperature Scales**

$$T_C = T - 273.15 \qquad T_F = \frac{9}{5} T_C + 32$$

- **Thermal Expansion of Solids and Liquids**

$$\Delta L = \alpha L_0 \Delta T \qquad \Delta A = \gamma A_0 \Delta T \qquad \Delta V = \beta V_0 \Delta T$$

24. **Q|C** The Trans-Alaskan pipeline is 1 300 km long, reaching from Prudhoe Bay to the port of Valdez, and is subject to temperatures ranging from $-73^\circ C$ to $+35^\circ C$.

a. How much does the steel pipeline expand due to the difference in temperature?

b. How can one compensate for this expansion?

10.24 **(a)** The expansion of the pipeline will be $\Delta L = \alpha L_0(\Delta T)$, or

$$\Delta L = [11 \times 10^{-6}\ (^\circ C)^{-1}](1\ 300\ \text{km})[35^\circ C - (-73^\circ C)] = \boxed{1.5\ \text{km}}$$

(b) This is accommodated by accordion-like expansion joints placed in the pipeline at periodic intervals.

28. V The concrete sections of a certain superhighway are designed to have a length of 25.0 m. The sections are poured and cured at 10.0°C. What minimum spacing should the engineer leave between the sections to eliminate buckling if the concrete is to reach a temperature of 50.0°C?

10.28 Each slab will undergo an increase in length of $\Delta L = \alpha L_0(\Delta T)$, and the gap between successive slabs must be at least this wide to accommodate this expansion. Thus, the minimum gap size should be

$$\Delta L = \alpha_{\text{concrete}} L_0(T - T_0) = (12 \times 10^{-6}(°\text{C}^{-1}))(25.0\ \text{m})(50.0°\text{C} - 10.0°\text{C})$$

or $\Delta L = 1.2 \times 10^{-2}\ \text{m} = \boxed{1.2\ \text{cm}}$

The Unusual Behavior of Water

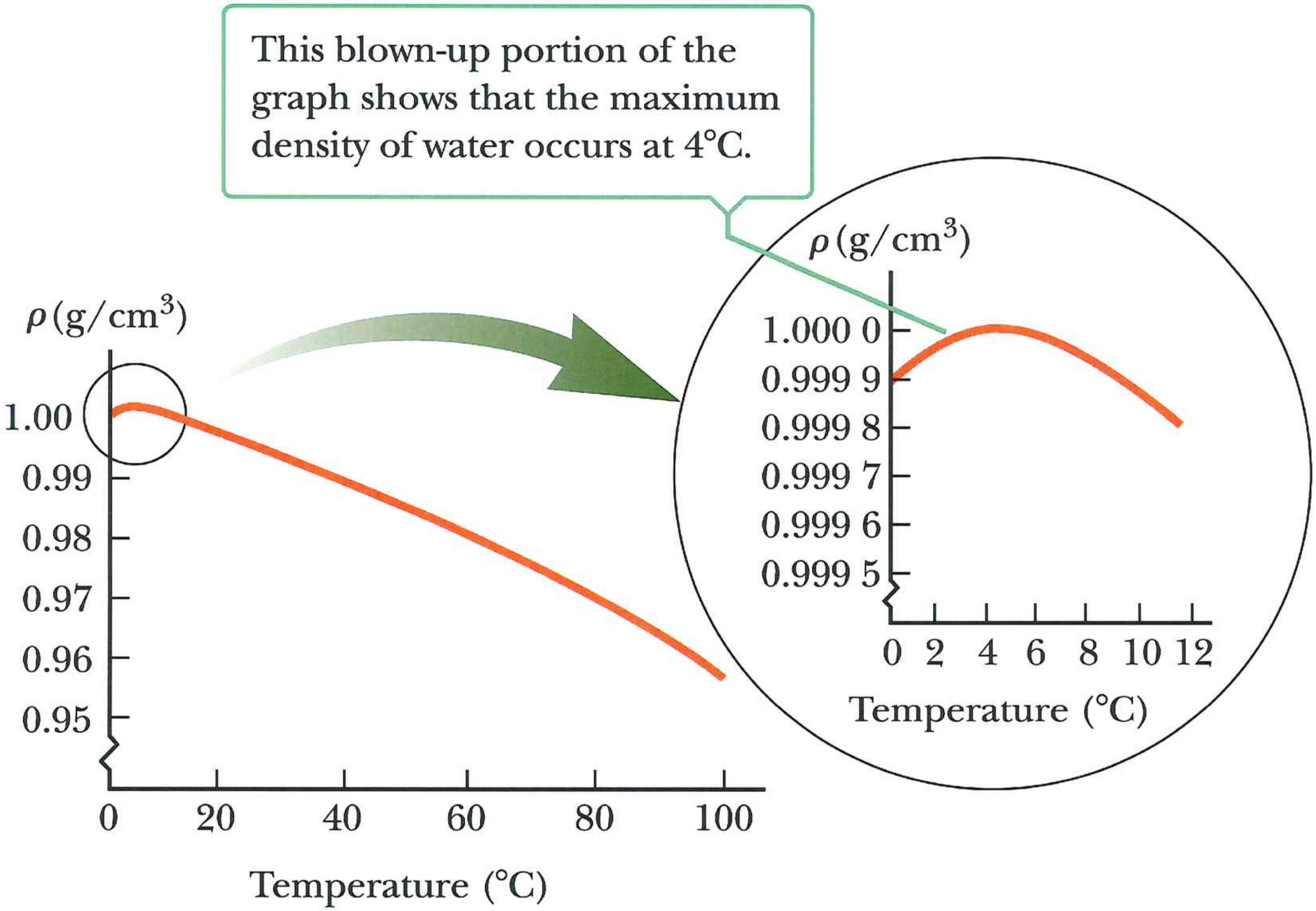
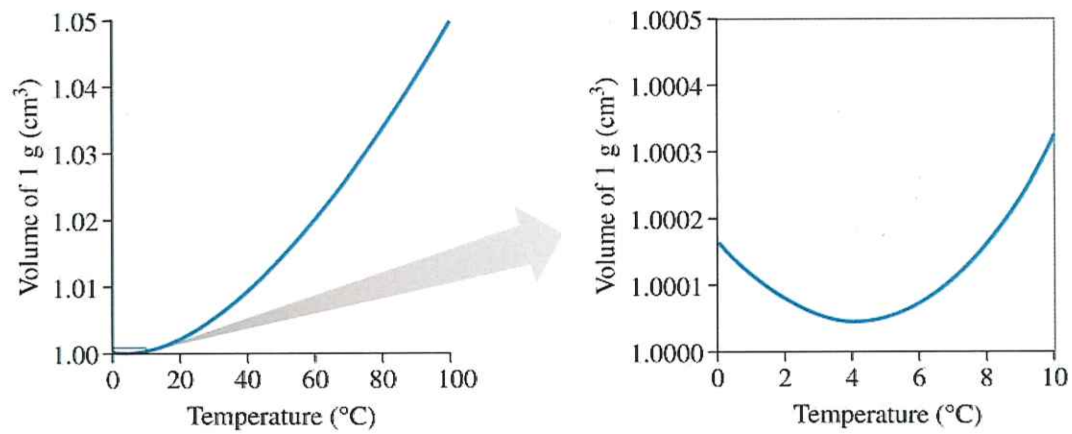


Figure 12.6

Thermal expansion of H_2O

Temperature (°C)	Volume of 1 g of water (cm³)	Density (g/cm³)
0	1.0002	0.9998
4	1.0000	1.0000
10	1.0003	0.9997
20	1.0018	0.9982
50	1.0121	0.9881
75	1.0258	0.9749
100	1.0434	0.9584

(a) Volume of 1 g of water as a function of temperature



(b) Large-scale graph of the volume of 1 g of water as a function of temperature

(c) Enlarged and rescaled detail of the lower-left end of the curve in (a)

$\rho = \frac{m}{V}$; $V = \frac{m}{\rho}$; $m = const$

Hence, $V\downarrow = \frac{m}{\rho\uparrow}$; $V\uparrow = \frac{m}{\rho\downarrow}$

$1000 \frac{kg}{m^3} = \rho_{H_2O}$ $\rho_{ice} = 917 \frac{kg}{m^3}$

The Unusual Behavior of Water

Unnumbered Figure Page 268

Ideal gas

- **Particle density low enough that forces between molecules are negligible.**
- **Interactions are collisions between molecules and the container walls.**
- **Elastic collisions: gas doesn’t lose or gain energy.**
- **Most common gases at room temperature are nearly ideal.**

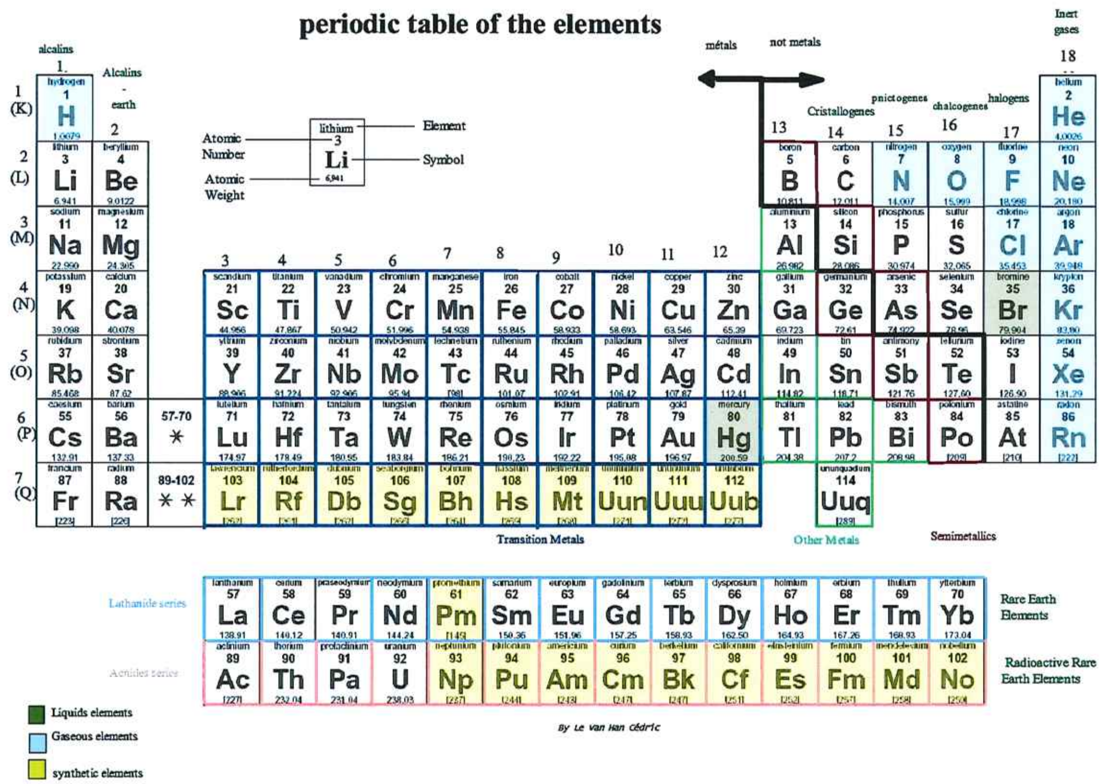
The Ideal Gas Law

Ideal gas: a collection of atoms or molecules that move randomly and exert no long-range forces on each other.

$$N_A = 6.02 \times 10^{23} \text{ particles/mole}$$

$$n = \frac{m}{\text{molar mass}}$$

The Ideal Gas Law



One mole (mol) of any substance is that amount of the substance that contains as many particles as there are atoms in 12 g of the isotope carbon-12.

The Ideal Gas Law

What is the mass of Avogadro's number of carbon-12 atoms?

$$m = N_A(12\text{ u}) = 6.02\times10^{23}(12\text{ u})\left(\frac{1.6\times10^{-24}\text{ g}}{\text{u}}\right) = 12.0\text{ g}$$

$$m_{\text{atom}} = \frac{\text{molar mass}}{N_A}$$

$$m_{\text{He}} = \frac{4.00\text{ g/mol}}{6.02\times10^{23}\text{ atoms/mol}} = 6.64\times10^{-24}\text{ g/atom}$$

Chapter 10: The Ideal-Gas Law

Pressure, ***volume***, ***temperature***, and ***amount of gas*** are all related. Relationships between state variables are ***equations of state***.

Experiments done on dilute gases (a gas where interactions between molecules can be ignored) show that:

Boyle's law: For ***fixed temperature*** and amount of gas, pressure and volume are inversely proportional.

$$PV = \text{constant}, \quad \text{or} \quad P \propto \frac{1}{V}$$

Avogadro's law: For ***fixed temperature and pressure***, volume and quantity of gas are proportional. $V \propto n$ or $V \propto N$

Charles's law: If the amount of gas and ***pressure*** are fixed, volume is proportional to temperature. $V \propto T$

Gay-Lussac's Law: If the amount of gas and ***volume*** are fixed, pressure is proportional to temperature. $P \propto T$

Chapter 10: Molecular Picture of a Gas

- We will describe gases using state variables including volume **V**, pressure **P**, and temperature **T**; these characterize the gas's macroscopic state rather than its individual molecules.
- In addition to pressure, volume, and temperature, another state variable is the amount of gas:
  - We can describe gases using the number of molecules **N**, or the number of moles **n**.
  - One **mole (mol)** is Avogadro's number N_A of particles, where $N_A = 6.022\times10^{23}$.
  - Moles and Molecules (N and n) are related by: $\mathbf{N = N_A \times n}$
  - Mass m of an ideal gas is related to the molar mass $\mathbf{m_{molar}}$ and the number of moles by: $\mathbf{m = n \times m_{molar}}$.

Chapter 10: The Ideal-Gas Law

Combining everything, we get the **ideal-gas law**:

$$\boxed{PV = nRT}$$

The quantity ***R*** is the ***molar gas constant***.

$$R = 8.315\,\mathrm{J\cdot mol^{-1}\cdot K^{-1}}$$

Exercise:

Find the volume of 32 grams of O_2. Then, find the volume of 4 grams of He. *Known*: T = 0 °C, P = 1 atm.

Solving for one mole of gas, we get:

$$V = \frac{nRT}{P} = \frac{(1\,\mathrm{mol})(8.315\,\mathrm{J\cdot mol^{-1}\cdot K^{-1}})(273\,\mathrm{K})}{1.013\times 10^{5}\,\mathrm{Pa}} = 0.0224\,\mathrm{m^3}$$

Result at 0 °C (Mathematica on-line)

Result at 20 °C (Mathematica on-line)

The Ideal Gas Law

$$PV = nRT$$

$$R = 8.31\ \text{J/mol}\cdot\text{K}$$

$$R = 0.0821\ \text{L}\cdot\text{atm/mol}\cdot\text{K}$$

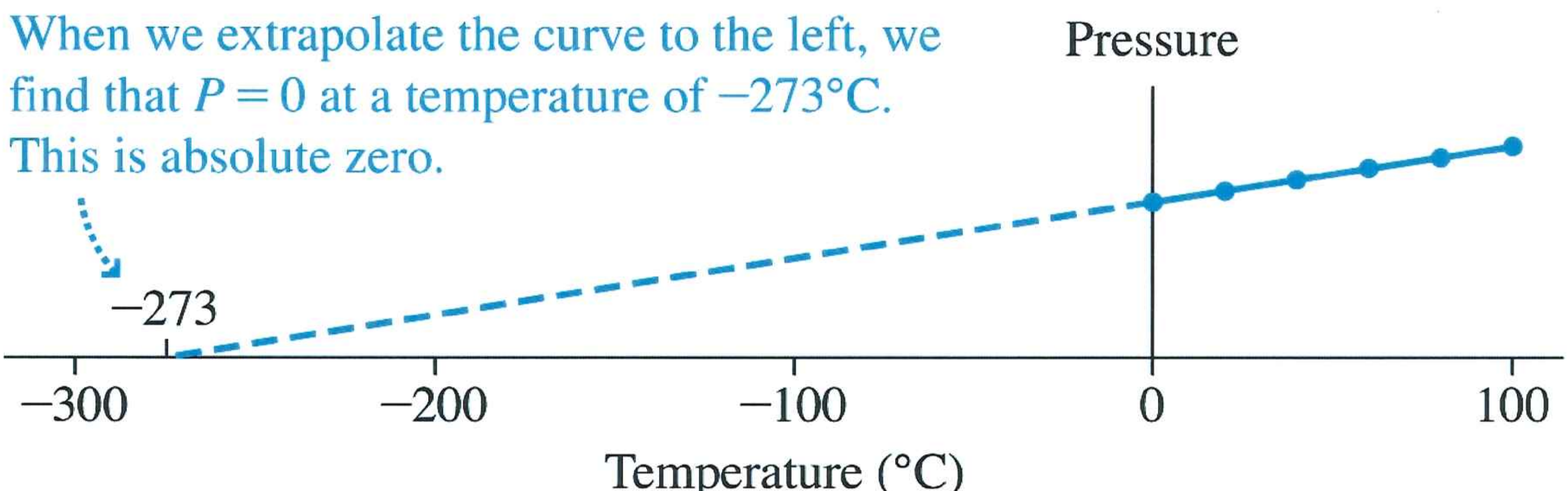
Volume occupied by 1 mol of any ideal gas at atmospheric pressure and at 0°C is 22.4 L.

Chapter 10: The Ideal-Gas Law

Gay-Lussac's ***constant-volume gas theromometer***.

$$PV = nRT$$

If the volume is kept constant, then we can measure the decrease in pressure with the decrease in temperature.



Extrapolating our measurement until the pressure becomes 0, we find the absolute 0 temperature.

This could be done just the same with the volume and constant pressure.

Ideal gas is in a closed metal cylinder. If its pressure is 1000 Pa initially, and its temperature is 293 K, what is its pressure after its temperature is raised to 333 K ?

Equation of state (atomic) for ideal gas: $p.V = n.R.T$

So for the initial state: $p_1 .V_1 = N.k_B .T_1$ Note: $V_1 = V_2$

And for the final state: $P_2 .V_2 = N.k_B .T_2$

Therefore, $(p_1) / (p_2) = T_1 / T_2$

and isolating $p_2 = (p_1 \times T_2) / T_1$

$p_2 = (1000 \text{ [Pa] } \times 333 \text{ [K] }) / (293 \text{ [K] })$

$p_2 = 1137$ Pa

36. V Gas is contained in an 8.00-L vessel at a temperature of 20.0°C and a pressure of 9.00 atm.

a. Determine the number of moles of gas in the vessel.

b. How many molecules are in the vessel?

10.36 **(a)** The volume of the gas is $V = 8.00\ \text{L} = 8.00 \times 10^3\ \text{cm}^3 = 8.00 \times 10^{-3}\ \text{m}^3$, and the absolute temperature is $T = (20.0 + 273)\ \text{K} = 293\ \text{K}$. The ideal gas law then gives the number of moles present as

$$n = \frac{PV}{RT} = \frac{\left[9.00\ \text{atm}\left(1.013\times10^5\ \text{Pa/1 atm}\right)\right]\left(8.00\times10^{-3}\ \text{m}^3\right)}{\left(8.31\ \text{J/mol}\cdot\text{K}\right)\left(293\text{K}\right)} = \boxed{3.00\ \text{mol}}$$

(b) The number of molecules present in the container is

$$N = n\cdot N_A = (3.00\ \text{mol})(6.02\times10^{23}\ \text{molecules/mol}) = \boxed{1.81\times10^{24}\ \text{molecules}}$$

38. The density of helium gas at $0°C$ is $\rho_0 = 0.179\ \text{kg/m}^3$. The temperature is then raised to $T = 100°C$, but the pressure is kept constant. Assuming the helium is an ideal gas, calculate the new density ρ_f of the gas.

10.38 The mass of the gas in the balloon does not change as the temperature increases. Thus,

$$\frac{\rho_f}{\rho_i} = \frac{(m/V_f)}{(m/V_i)} = \frac{V_i}{V_f} \quad \text{or} \quad \rho_f = \rho_i\left(\frac{V_i}{V_f}\right)$$

From the ideal gas law with both n and P constant, we find $V_i/V_f = T_i/T_f$, and now have

$$\rho_f = \rho_i\left(\frac{T_i}{T_f}\right) = \left(0.179\ \text{kg/m}^3\right)\left(\frac{273\ \text{K}}{373\ \text{K}}\right) = \boxed{0.131\ \text{kg/m}^3}$$

39. An air bubble has a volume of 1.50 cm^3 when it is released by a submarine 1.00×10^2 m below the surface of a lake. What is the volume of the bubble when it reaches the surface? Assume the temperature and the number of air molecules in the bubble remain constant during its ascent.

10.39 The pressure 100 m below the surface is found, using $P_1 = P_{atm} + \rho gh$, to be

$$P_1 = 1.013 \times 10^5 \text{ Pa} + (10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(100 \text{ m}) = 1.08 \times 10^6 \text{ Pa}$$

The ideal gas law, with both n and T constant, gives the volume at the surface as

$$V_2 = \left(\frac{P_1}{P_2}\right)V_1 = \left(\frac{P_1}{P_{atm}}\right)V = \left(\frac{1.08 \times 10^6 \text{ Pa}}{1.013 \times 10^5 \text{ Pa}}\right)(1.50 \text{ cm}^3) = \boxed{160 \text{ cm}^3}$$

34. T An automobile tire is inflated with air originally at $10.0°C$ and normal atmospheric pressure. During the process, the air is compressed to 28.0% of its original volume and the temperature is increased to $40.0°C$.

a. What is the tire pressure in pascals?

b. After the car is driven at high speed, the tire's air temperature rises to $85.0°C$ and the tire's interior volume increases by 2.00%. What is the new tire pressure (absolute) in pascals?

10.34 **(a)** With $P_0 = 1.00$ atm, $T_0 = 10.0°C = 283$ K, $T_1 = 40.0°C = 313$ K, and $V_1 = 0.280V_0$, we find

$$\frac{P_1V_1}{P_0V_0} = \frac{n_1RT_1}{n_0RT_0} \Rightarrow P_1 = \left(\frac{V_0}{V_1}\right)\left(\frac{T_1}{T_0}\right)P_0 = \left(\frac{1}{0.280}\right)\left(\frac{313\text{ K}}{283\text{ K}}\right)(1.00\text{ atm}) = \boxed{3.95\text{ atm}}$$

and $P_1 = (3.95\text{ atm})(1.013 \times 10^5\text{ Pa/1 atm}) = 4.00 \times 10^5\text{ Pa} = \boxed{400\text{ kPa}}$.

(b) If now, conditions inside the tire change so that $V_f = 1.02V_1$ and $T_f = 85.0°C = 358$ K, we form a new ratio to find

$$\frac{P_fV_f}{P_1V_1} = \frac{n_fRT_f}{n_1RT_1} \Rightarrow P_f = \left(\frac{V_1}{V_f}\right)\left(\frac{T_f}{T_1}\right)P_1 = \left(\frac{1}{1.02}\right)\left(\frac{358\text{ K}}{313\text{ K}}\right)(3.95\text{ atm}) = \boxed{4.43\text{ atm}}$$

and $P_f = (4.43\text{ atm})\left(\frac{1.013\times10^5\text{ Pa}}{1\text{ atm}}\right) = 4.49\times10^5\text{ Pa} = \boxed{449\text{ kPa}}$