TEMPERATURE AND GASSES

Chapter 13

TEMPERATURE SCALES

- There are 3 scales used to measure temperature. The Fahrenheit scale is used only in America, the Celsius scale is used in the rest of the world and the Kelvin scale is used only by scientist.
    - Fahrenheit - In this scale water freezes at 32° and boils at 212°, so there are 180 degrees between the two.
    - Celsius - For this scale water freezes at 0° and boils at 100° so there are 100 degrees between the two.
    - Kelvin - In this scale 0 is the lowest temperature possible, water freezes at 273 and boils at 373 degrees. A change of 1 degree is the same as in the Celsius scale.

CONVERTING BETWEEN SCALES

- Conversion between Fahrenheit and Celsius:

$$T_C = \frac{5}{9}(T_F - 32) \qquad T_F = \frac{9}{5}T_C + 32$$

- Conversion between Kelvin and Celsius:

$$T_C = T_K - 273.15 \qquad T_K = T_C + 273.15$$

EXAMPLE 13.1

- **Converting between Temperature Scales: Room Temperature:** "Room temperature" is generally defined to be 25°C. (a) What is room temperature in °F? (b) What is it in K?

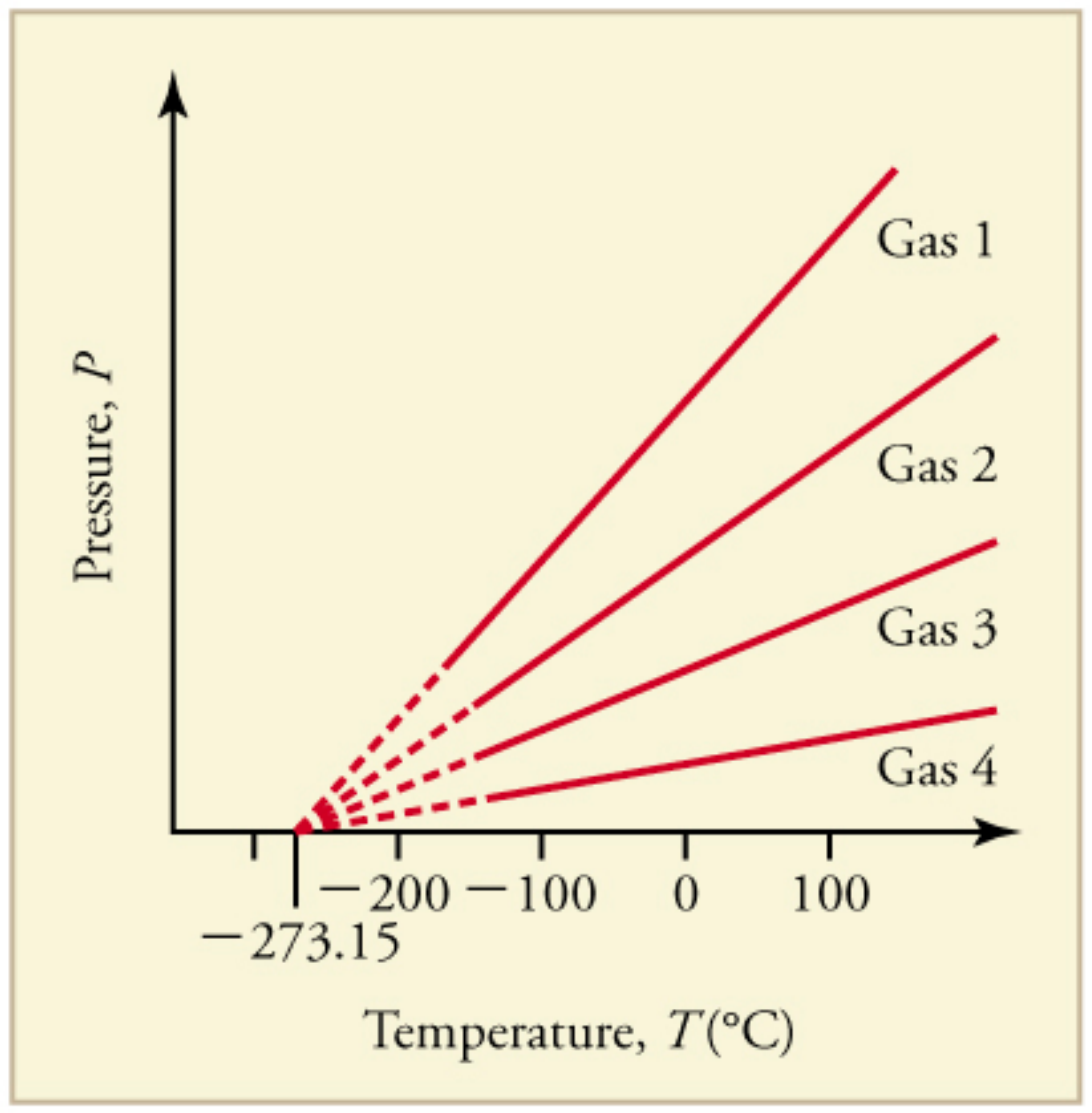
$T_C = 25$
$T_F = ?$
$T_K = ?$

$$T_F = \frac{9}{5}T_C + 32 \quad = \frac{9}{5}(25) + 32 = 77^\circ F$$

$$T_K = T_C + 273.15 \quad = 25 + 273.15 = 293K$$

ABSOLUTE ZERO

- Why do we think there is an absolute zero?
- Well if we take different gasses and cool them we find that their pressures decrease.
- If we extrapolate this trend all the gasses seem to reach zero pressure at the same temperature.
- Thus physicists theorized that this was the lowest temperature that could exist. -273.15°C or 0K.



THERMAL EXPANSION

- When substances are heated they expand. Solids largely follow a simple formula

$$\Delta L = \alpha L \Delta T$$

- where ΔL is the change in length, α is called the coefficient of linear expansion and is a number that depends on the substance, L is the length and ΔT is the change in temperature.

- Note because a degree in Celsius and Kelvin are the same amount, $\Delta T_C = \Delta T_K$.

EXAMPLE 13.3

- **Calculating Linear Thermal Expansion: The Golden Gate Bridge:** The main span of San Francisco's Golden Gate Bridge is 1275 m long at its coldest. The bridge is exposed to temperatures ranging from –15°C to 40°C. What is its change in length between these temperatures? Assume that the bridge is made entirely of steel.

L = 1275m

$\Delta T = 55°C$

$\Delta L = ?$

$$\Delta L = \alpha L \Delta T \quad = (12 \times 10^{-6}/°C)(1275m)(55°C) = 0.84m$$

$\alpha = 12 \times 10^{-6} / °C$?

IDEAL GAS LAW

- Gasses are the simplest state of matter and at higher temperatures to a good approximation can be considered as all behaving the same way.

- This universal ideal of a gas is appropriately called at ideal gas and it follows the ideal gas law, which is

$$PV = NkT$$

- where P is the pressure, V the volume, T the temperature, N the number of molecules in the gas and k a constant called Boltzmann's constant which has the value $k=1.38\times10^{-23}$ J/K.

EXAMPLE 13.6

- **Calculating Pressure Changes Due to Temperature Changes: Tire Pressure:** Suppose your bicycle tire is fully inflated, with an absolute pressure of 7.00×10^5Pa (a gauge pressure of just under 90.0 lb/in^2) at a temperature of 18.0°C. What is the pressure after its temperature has risen to 35.0°C? Assume that there are no appreciable leaks or changes in volume.

$P_1 = 7.00 \times 10^5$Pa

$T_1 = 18.0°C = 18+273 = 291K$

$T_2 = 35.0°C = 35 +273 = 308K$

$P_2 = ?$

$$PV = NkT \qquad \frac{P}{T} = \frac{Nk}{V} \qquad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = P_1 \frac{T_2}{T_1} = 7 \times 10^5 Pa \frac{308K}{291K} = 7.41 \times 10^5 Pa$$

EXAMPLE 13.7

- **Calculating the Number of Molecules in a Cubic Meter of Gas:** How many molecules are in a typical object, such as gas in a tire or water in a drink? We can use the ideal gas law to give us an idea of how large N typically is. Calculate the number of molecules in a cubic meter of gas at standard temperature and pressure (STP), which is defined to be 0°C and atmospheric pressure.

$V = 1\ m^3$

$T = 0°C = 273K$

$P = 1.01 \times 10^5\ Pa$

$N = ?$

$$PV = NkT$$

$$N = \frac{PV}{kT} = \frac{(1.01 \times 10^5 Pa)(1m^3)}{(1.38 \times 10^{-23} J/K)(273K)} = 2.68 \times 10^{25} molecules$$

UNDERSTANDING THE IDEAL GAS LAW

- The ideal part of the Ideal Gas Law is that the molecules only interact by collisions and that those collisions are elastic.
- Under these assumptions we can write down what is going on in a gas just using the physics we have learned.
- Let's imagine a gas in a box. Every time a molecule hits a wall it will transfer some momentum to the wall. This change in momentum, or force, causes the pressure on the wall.

UNDERSTANDING THE IDEAL GAS LAW

When a molecule hits the wall the component of the velocity in the direction of the wall will transfer momentum. Let's call this the x direction. Since the collision is elastic if this is v_x before the collision it must be $-v_x$ after.

$$\Delta p = mv_x - m(-v_x) = 2mv_x$$

This molecule will hit the wall, bounce across the box, hit the other side and then come back to hit the wall again. The time it will take to do this is if the length of the box is L is

$$\Delta t = \frac{2L}{v_x} \qquad \text{so} \qquad F = \frac{\Delta p}{\Delta t} = \frac{2mv_x}{\frac{2L}{v_x}} = \frac{mv_x^2}{L}$$

This is for just one molecule. If there are N molecules then each one will hit the wall with a different speed. But we can talk about the average square speed of a molecule, then

$$F = \frac{mN\bar{v_x^2}}{L}$$

UNDERSTANDING THE IDEAL GAS LAW

$$F = \frac{mN\bar{v_x^2}}{L}$$

since there is nothing special about the x-direction we know

$$\bar{v^2} = \bar{v_x^2} + \bar{v_y^2} + \bar{v_z^2} \quad \text{and} \quad \bar{v_x^2} = \bar{v_y^2} = \bar{v_z^2} \quad \text{so} \quad \bar{v_x^2} = \frac{1}{3}\bar{v^2}$$

and we can write the force as

$$F = \frac{mN\bar{v^2}}{3L}$$

the pressure on the wall can then be written as

$$P = \frac{F}{A} = \frac{2}{3}\frac{N}{LA}\frac{1}{2}m\bar{v^2}$$

THERMAL ENERGY

$$P = \frac{F}{A} = \frac{2}{3}\frac{N}{LA}\frac{1}{2}m\bar{v^2}$$

$$PV = N\frac{2}{3}(\frac{1}{2}m\bar{v^2})$$

Notice that 1/2mv^2 is the mean kinetic energy per particle, so if

$$PV = NkT$$ then $$kT = \frac{2}{3}(\frac{1}{2}m\bar{v^2})$$ and $$\overline{KE} = \frac{3}{2}kT$$

So not only do we derive the ideal gas law using mechanics, but we find that temperature must be related to the total kinetic energy of the gas.

In a gas the average speed molecules are moving is zero, since velocity is a vector and then are moving in every direction. More interesting is the root mean square (or rms) speed of the molecules, which is directly related to the temperature of the gas.

$$v_{rms} = \sqrt{\bar{v^2}} = \sqrt{\frac{3kT}{m}}$$

EXAMPLE 13.10

- **Calculating Kinetic Energy and Speed of a Gas Molecule** (a) What is the average kinetic energy of a gas molecule at 20.0°C (room temperature)? (b) Find the rms speed of a nitrogen molecule (N_2) at this temperature.

T = 20.0°C = 293K

$$\overline{KE} = \frac{3}{2}kT \quad = 1.5(1.38 \times 10^{-23} J/K)(293K) = 6.07 \times 10^{-21} J$$

$$m = 2(14)amu \quad = 2(14)(1.67 \times 10^{-27} kg) = 4.65 \times 10^{-26} kg$$

$$v_{rms} = \sqrt{\frac{3kT}{m}}$$

$$= \sqrt{\frac{3(1.38 \times 10^{-23} J/K)(273K)}{4.65 \times 10^{-26} kg}} = 511 m/s$$

HOME WORK

- Chap 13 - 5, 6, 9, 12, 29, 31, 39, 42