

Gases

- Petrucci, Harwood and Herring: Chapter 6

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Gases 1

- We will be looking at Macroscopic and Microscopic properties:
 - Macroscopic
 - Properties of bulk gases
 - Observable
 - Pressure, volume, mass, temperature...
 - Microscopic
 - Properties at the molecular level
 - Not readily observable
 - Mass of molecules, molecular speed, energy, collision frequency

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Gases 2

Macroscopic Properties

- Our aim is to look at the relationship between the macroscopic properties of a gas and end up with the gas laws

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Gases 3

Pressure

- To contain a gas you must have a container capable of exerting a force on it (e.g. the walls of a balloon).
- This implies that the the gas is exerting a balancing force
- Normally we talk about the pressure (force/area) rather than force

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Gases 4

Measuring Pressure

- The simplest way to measure gas pressure is to have it balance a liquid pressure.
- Therefore we need to quantify the liquid pressure

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Gases 5

- Consider a cylinder of liquid with area A and height h
- The force exerted at the bottom of the cylinder is its weight

$$F = m \cdot g$$

- The pressure exerted is

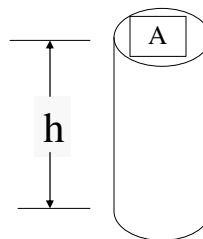
$$P = F/A = m \cdot g/A$$

- The density of the liquid is

$$d = m/V \quad \text{and} \quad m = d \cdot V \quad \text{but} \quad V = A \cdot h$$

- So

$$P = m \cdot g/A = g \cdot V \cdot d/A = g \cdot A \cdot h \cdot d/A = g \cdot h \cdot d$$



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Gases 6

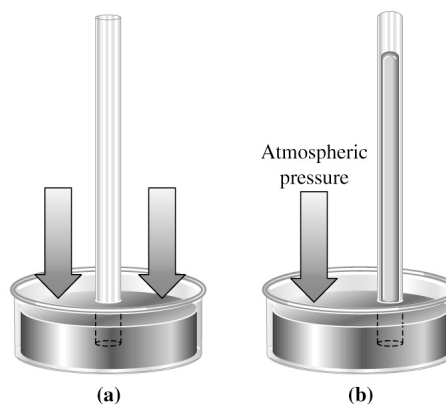
Barometer

To measure Atmospheric Pressure

On the left the tube is open

On the right the tube is closed and a liquid column is supported by the atmospheric pressure:

Air pressure equals the liquid pressure



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Barometer (continued)

So for a barometer

$P = g \cdot h \cdot d$ $P = \text{atmospheric pressure}$
 $h = \text{height of liquid column}$
 $d = \text{density of the liquid}$

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Atmospheric Pressure

- By definition the average pressure at sea level will support a column of 760 mm of mercury. (760 torr)
- What is this in SI units?

$$P = g \cdot h \cdot d$$

$$g = 9.81 \text{ m} \cdot \text{s}^{-2}, h = 0.76 \text{ m},$$

$$d_{\text{Hg}} = 13.6 \text{ g} \cdot \text{cm}^{-3} = 13.6 \text{ kg} \cdot \text{L}^{-1} = 13.6 \times 10^3 \text{ kg} \cdot \text{m}^{-3}$$

$$P = 9.81 \times 0.76 \times 13.6 \times 10^3 = 1.013 \times 10^5 \text{ Pa (N} \cdot \text{m}^{-2}\text{)}$$

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If we made a barometer out of water, what would be the height of the water column if the pressure is 745 torr?

The problem calls for the relationship between P and h

$$P = g \cdot h \cdot d$$

$$P = \frac{745}{760} \times 1.013 \times 10^5 \text{ Pa}$$

$$d = 1.00 \text{ g cm}^{-3} = 1.00 \times 10^3 \text{ kg m}^{-3}$$

$$g = 9.81 \text{ m s}^{-2}$$

$$P = g \cdot h \cdot d$$

$$\frac{745}{760} \times 1.013 \times 10^5 = 9.81 \times h \times 1.00 \times 10^3 \quad \therefore h = 10.1 \text{ m}$$

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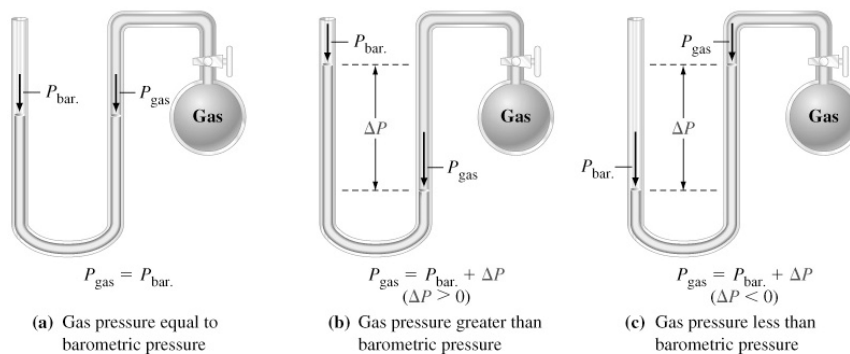
Measuring Gas Pressures

Gas pressures can be measured with a manometer. This is similar to a barometer but measures pressure differences using a liquid.

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When one side of the manometer is open to the atmosphere



$$\Delta P = g \cdot h \cdot d$$

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Gases 12

Gas Laws

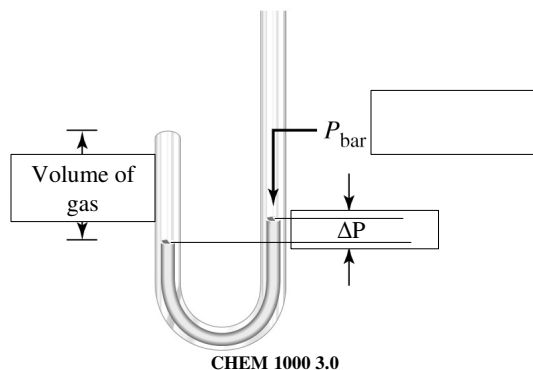
- The aim is to determine the relationship between the gas observables (pressure, volume, mass, temperature).
- These were determined experimentally

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Boyle's Law

- Boyle (~1622) kept the mass of gas and the temperature constant and studied the relationship between pressure and volume



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Boyle's Law

- Boyle found that pressure and volume were inversely proportional. (double the pressure and the volume goes to one half).
- This is usually expressed as

$$P.V = \text{constant}$$

or

$$P_1 V_1 = P_2 V_2$$

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Charles's Law

- Charles (1787) and Gay-Lussac (1822) kept the mass of gas and the pressure constant and studied the relationship between temperature and volume

They found $\frac{V_{(100^\circ C)}}{V_{(0^\circ C)}} = 1.375$

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Charles's Law

- Further experiments showed that volume and temperature were linearly related and that the temperature intercept (when volume is zero) was at -273.15°C .
- This temperature is now defined as absolute zero and the Kelvin temperature scale given by

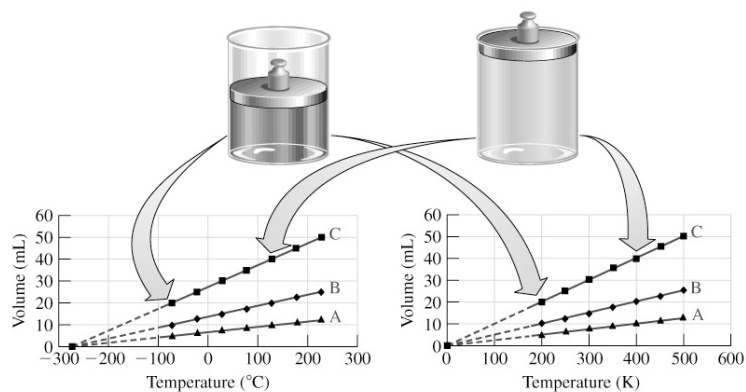
$$T(\text{K}) = t(^{\circ}\text{C}) + 273.15$$

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Charles's Law

- Graphically:



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Charles's Law/Combined Gas Law

Charles's Law can be expressed as $\frac{V}{T} = \text{constant}$

Combining Boyle's Law and Charles's Law

$P \cdot V = \text{constant}$ and $\frac{V}{T} = \text{constant}$

gives

$$\frac{P \cdot V}{T} = \text{constant} \quad \text{or} \quad \frac{P_1 \cdot V_1}{T_1} = \frac{P_2 \cdot V_2}{T_2}$$

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Avogadro's Law

- From Gay-Lussac's experiment on reacting gases Avogadro concluded
"Equal volumes of different gases, at the same temperature and pressure, contain equal numbers of molecules"
- Extending this to a consideration of adding volumes of gases- one concludes that gas volume is proportional to number of molecules and subsequently to number of moles.

$$V \propto n \text{ or } V/n = \text{constant}$$

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Gas Law

Given that :

$P.V = \text{constant}$ (Boyle's Law)

$\frac{V}{T} = \text{constant}$ (Charles's Law)

$\frac{V}{n} = \text{constant}$ (Avogadro's Law)

leads to

$\frac{P.V}{n.T} = \text{constant}$

Usually written **$PV = nRT$**
(Where R is a constant)

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Ideal Gas Law

- The ideal gas law can be written in terms of moles or molecules

$$PV = nRT$$

n=number of moles R= Gas constant

$$PV = NkT$$

N=number of molecules k= Boltzmann's constant

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Ideal Gas Law

- Values of the constants
 - $R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$ ($\text{Pa m}^3 \text{ K}^{-1} \text{ mol}^{-1}$, $\text{kPa L K}^{-1} \text{ mol}^{-1}$)
 $R = 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}$
 - $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$ (really $\text{J K}^{-1} \text{ molecule}^{-1}$ but molecule is just a number)

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Other useful forms of the ideal gas law

$$PV = \frac{m}{M} RT \quad m = \text{mass of gas}$$

$M = \text{molar mass (molecular weight)}$

$$d_{\text{gas}} = \frac{m}{V} = \frac{PM}{RT}$$

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Dalton's Law

- In a gas mixture each component fills the container and exerts the pressure it would if the other gases were not present.
- Alternatively, each component acts as if it were alone in the container

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Dalton's Law

- Thus for any component i
$$P_i V = n_i RT$$

We call P_i the partial pressure of component i
- The total pressure is given by the sum of the partial pressures

$$P = P_1 + P_2 + P_3 + \dots$$

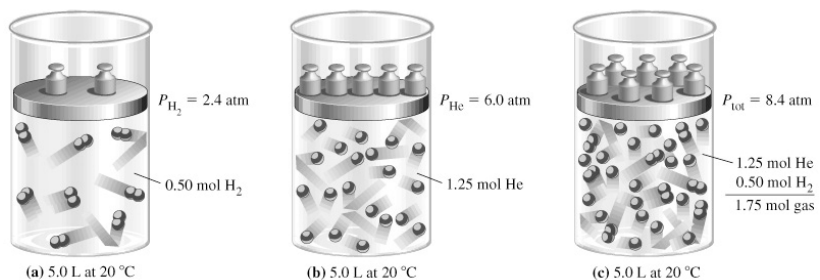
- Also note that the mole fraction in the gas phase

$$\chi_i = \frac{n_i}{n} = \frac{P_i}{P}$$

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Dalton's Law

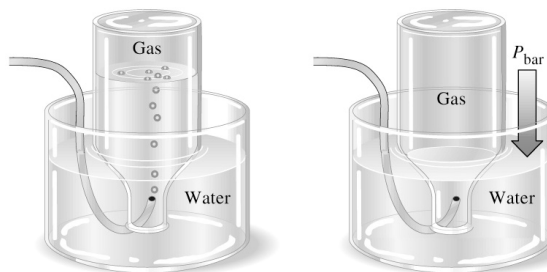


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Dalton's Law

- A common use of Dalton's Law is when gases are collected over water



$$P_{\text{sample}} + P_{\text{water}} = P_{\text{bar}}$$

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