DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS-2

TSOKOS LESSON 3-2
MODELING A GAS

Essential Idea:

- The properties of ideal gases allow scientists to make predictions of the behavior of real gases.

Nature Of Science:

- Collaboration: Scientists in the 19th century made valuable progress on the modern theories that form the basis of thermodynamics, making important links with other sciences, especially chemistry. The scientific method was in evidence with contrasting but complementary statements of some laws derived by different scientists. Empirical and theoretical thinking both have their place in science and this is evident in the comparison between the unattainable ideal gas and real gases.

Theory Of Knowledge:

- When does modeling of “ideal” situations become “good enough” to count as knowledge?

Understandings:

- Pressure
- Equation of state for an ideal gas
- Kinetic model of an ideal gas
- Mole, molar mass and the Avogadro constant
- Differences between real and ideal gases

Applications And Skills:

- Solving problems using the equation of state for an ideal gas and gas laws
- Sketching and interpreting changes of state of an ideal gas on pressure– volume, pressure–temperature and volume–temperature diagrams
- Investigating at least one gas law experimentally

Guidance:

- Students should be aware of the assumptions that underpin the molecular kinetic theory of ideal gases
- Gas laws are limited to constant volume, constant temperature, constant pressure and the ideal gas law
- Students should understand that a real gas approximates to an ideal gas at conditions of low pressure, moderate temperature and low density

Data Booklet Reference:

$$p = \frac{F}{A}$$

$$n = \frac{N}{N_A}$$

$$pV = nRT$$

$$\overline{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$$

Utilization:

- Transport of gases in liquid form or at high pressures/densities is common practice across the globe. Behaviour of real gases under extreme conditions needs to be carefully considered in these situations.
- Consideration of thermodynamic processes is essential to many areas of chemistry (see Chemistry sub-topic 1.3)
- Respiration processes (see Biology sub-topic D.6)

Aims:

- Aim 3: this is a good topic to make comparisons between empirical and theoretical thinking in science
- Aim 6: experiments could include (but are not limited to): verification of gas laws; calculation of the Avogadro constant; virtual investigation of gas law parameters not possible within a school laboratory setting

Video – Developing the Gas Laws

Avogadro (avocado) Constant

- "One mole of a substance contains the same number of molecules as in 12 grams of carbon-12."

$$N_A = 6.02x10^{23}\ molecules/mol$$

- "One mole of any substance is that quantity of the substance whose mass in grams is equal to the substance's molar mass, μ."

Avogadro (avocado) Constant

- The number of moles of a substance, ***n***, is equal to the number of molecules in the substance, ***N***, divided by the Avocado constant, ***N_A***

$$n = \frac{N}{N_A}$$

Avogadro (avocado) Constant

- The mass in grams, ***m*** , is equal to the number of moles, ***n***, times the molar mass, ***μ***.

$$m = n\mu$$

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Avogadro (avocado) Constant

- ***How many moles and atoms are there in 10 grams of plutonium (μ = 244)?***

Avogadro (avocado, acevedo) Constant

- ***How many moles and atoms are there in 10 grams of plutonium (μ = 244)?***

$$m = n\mu$$

$$n = \frac{m}{\mu}$$

$$n = \frac{10}{244} = 0.041 mol$$

$$n = \frac{N}{N_A}$$

$$N = (n)(N_A)$$

$$N = (0.041)(6.02x10^{23})$$

$$N = 2.5x10^{22} molecules$$

Moles of Gases

- Convenient to use moles (not the furry kind)
- Avogadro's Avocado number

$$N_A = 6.02x10^{23}\,\frac{molecules}{mol}$$

- Atomic Mass = Molar Mass = grams/mol

Moles of Gases

- The number of moles can be found by dividing the number of molecules, *N*, by the Avogadro's Avocado number

$$n = \frac{N}{N_A}$$

- Also found by dividing the mass of the gas in grams by the Atomic / Molar Mass

$$n = \frac{m(g)}{\mu(g/mol)}$$

Kinetic Theory of Gases

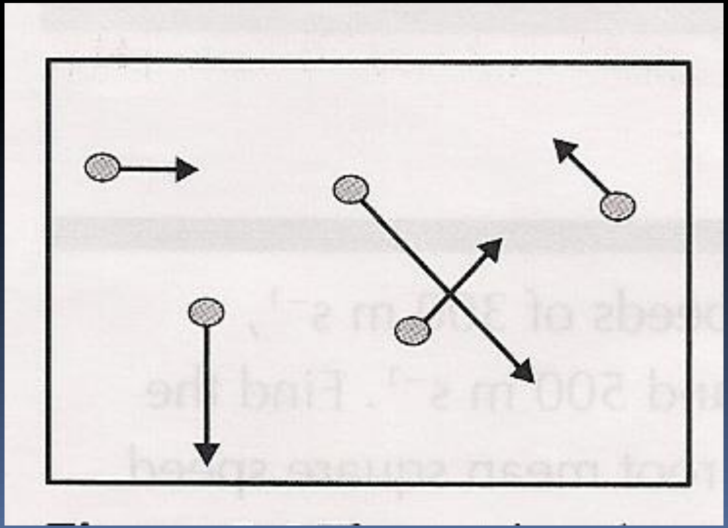
- Explained through a simple mechanical model
- Several basic assumptions must be made

Kinetic Theory of Gases

- Basic Assumptions:
  - Gas consists of a large number of molecules
  - Molecules move with a range of speeds
  - Volume of individual molecules is negligible compared to volume of the container
  - Collisions between the molecules and between molecules and the container are <u>elastic</u>
  - Molecules exert no forces on each other or on the container except when in contact (i.e., no intermolecular forces)

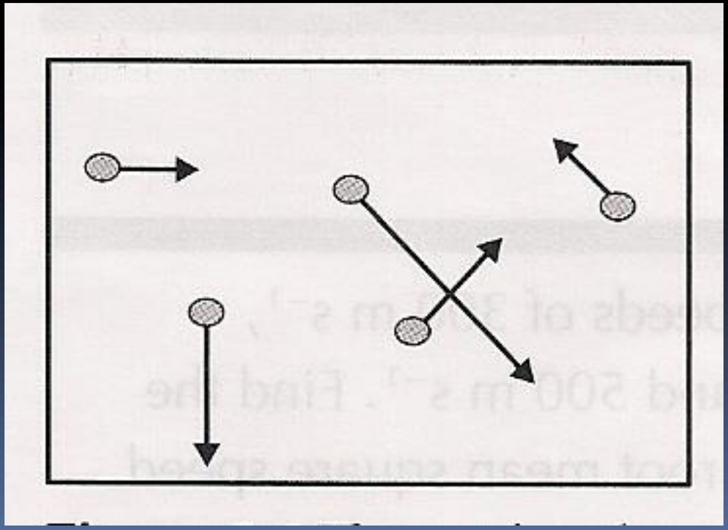
Kinetic Theory of Gases

- Basic Assumptions:
  - Duration of collisions (impulse) is small compared to time between collisions
  - Molecules follow the laws of Newtonian mechanics



Kinetic Theory of Gases

- Basic Assumptions:
  - ***That's why they call it an 'Ideal' Gas***



Kinetic Theory of Gases

- Boltzmann Equation:

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

$$\overline{v^2} = \frac{\left(v_1{}^2 + v_2{}^2 + \ldots + v_n{}^2\right)}{n}$$

  - The v^2 term is the average of the squares of the speeds of the molecules of the gas
    - This is called the ***root mean square (rms)*** speed
    - Not the average speed, but close enough that the terms are used interchangeably

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  - ***k*** is the Bolzmann constant and is equal to 1.38 x 10^{-23} J/K
    - It is a ratio of the gas constant ***R*** to the Avogadro (avocado) number
    - ***Note that temperature in this equation must be in Kelvin***

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- The importance of this equation is that it shows how absolute temperature is directly proportional to the average kinetic energy of the molecules of a gas

Molecular Explanation of Pressure

- Pressure in a gas is a result of collisions of the molecules with the walls of the container
- Each collision results in a momentum change in the molecule
- The wall must exert a force on the molecule to effect this change in momentum
- Newton's third law says that the molecule must then exert an equal and opposite force on the wall of the container

Molecular Explanation of Pressure

- Pressure then is the total force created by all colliding molecules divided by the surface area of the container
- ***Pressure results from collisions of molecules with the container, NOT from collisions with each other***
  - Elastic collisions between molecules result in individual changes in velocity and energy, but momentum and kinetic energy are conserved

Molecular Explanation of Pressure

- The two factors that affect pressure are speed of the molecules and frequency of the collisions

$$P \propto (speed)(frequency)$$

- When the gas is heated, speed increases and collision frequency increases as a result
- When gas is heated isothermally, speed stays the same but collision frequency increases due to less separation distance

Molecular Explanation of Pressure

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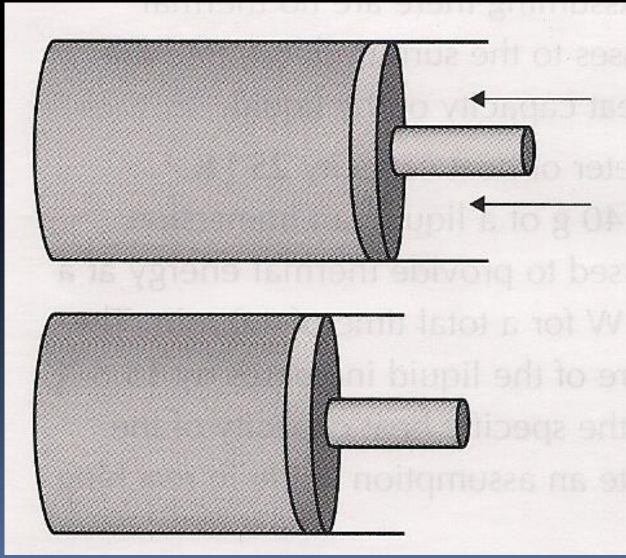
$$P \propto (speed)(frequency)$$

So what do you think will happen if a gas is compressed rapidly with a piston?

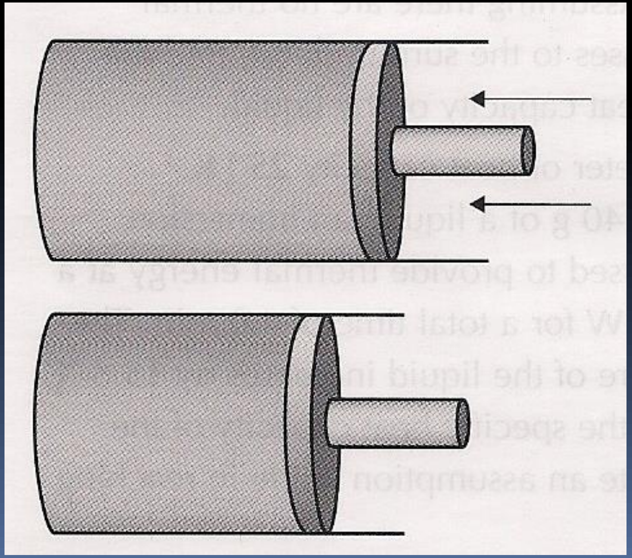


Molecular Explanation of Pressure

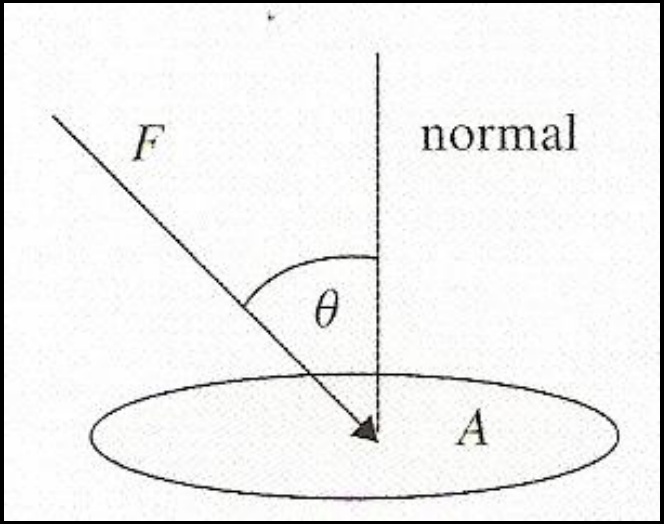
- The two factors that affect pressure are speed of the molecules and frequency of the collisions

$$P \propto (speed)(frequency)$$

What if a gas is compressed extremely slowly with the piston?



Pressure



- Force per unit area
- Only the force ***normal*** to the area
- Unit is the Pascal (Pa) or Nm^{-2}
- Atmospheric pressure is 1.013×10^5 Pa

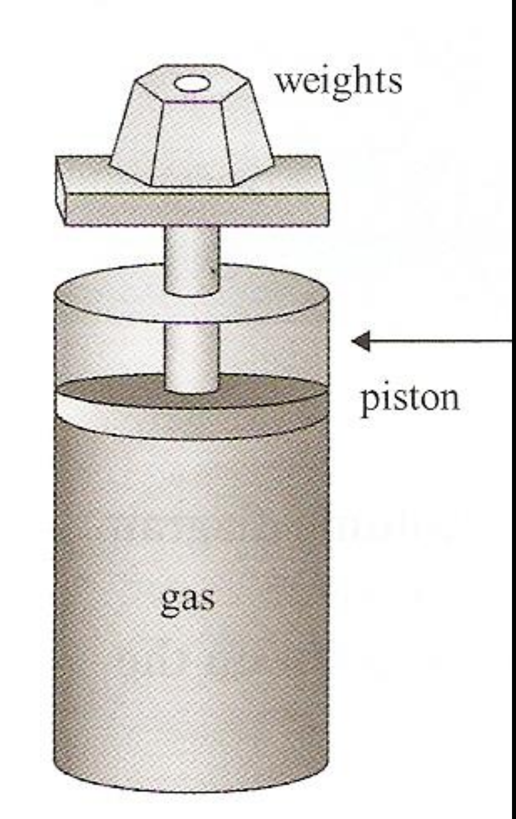
$$P = \frac{F\cos\theta}{A}$$

Boyle-Mariotte Law

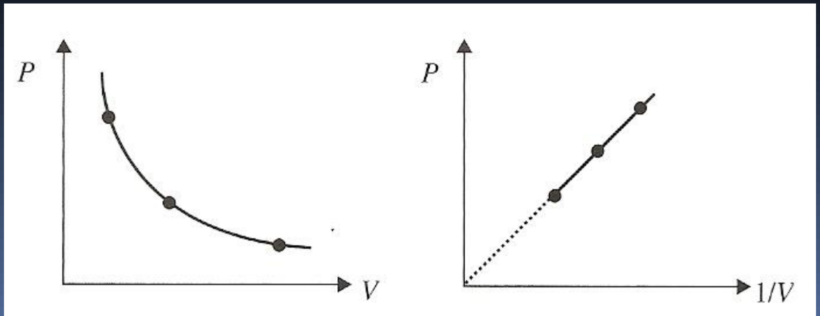
- ***<u>At constant temperature</u>*** and with a constant quantity of gas, pressure is inversely proportional to volume

$$PV = constant$$

$$P_1V_1 = P_2V_2$$



- The graph of pressure versus volume is a hyperbola, aka an isothermal curve

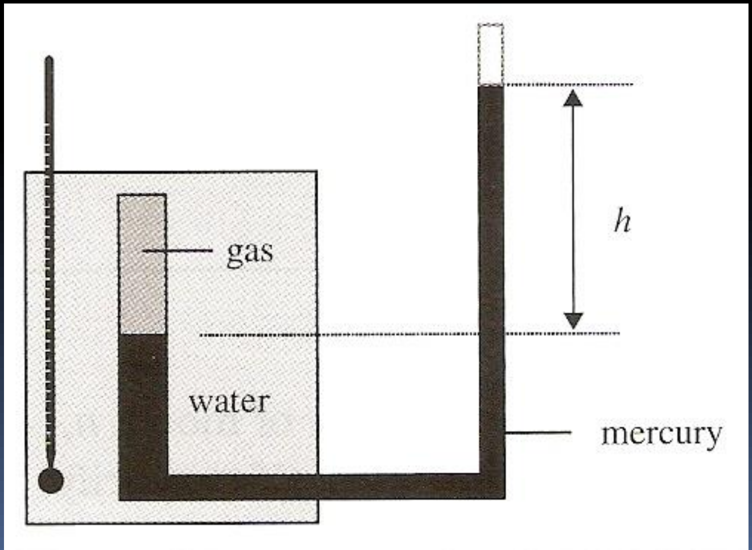


Volume-Temperature Law

- When the temperature is expressed in ***Kelvin*** and ***pressure is kept constant***, volume and temperature are proportional to each other

$$\frac{V}{T} = constant$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$



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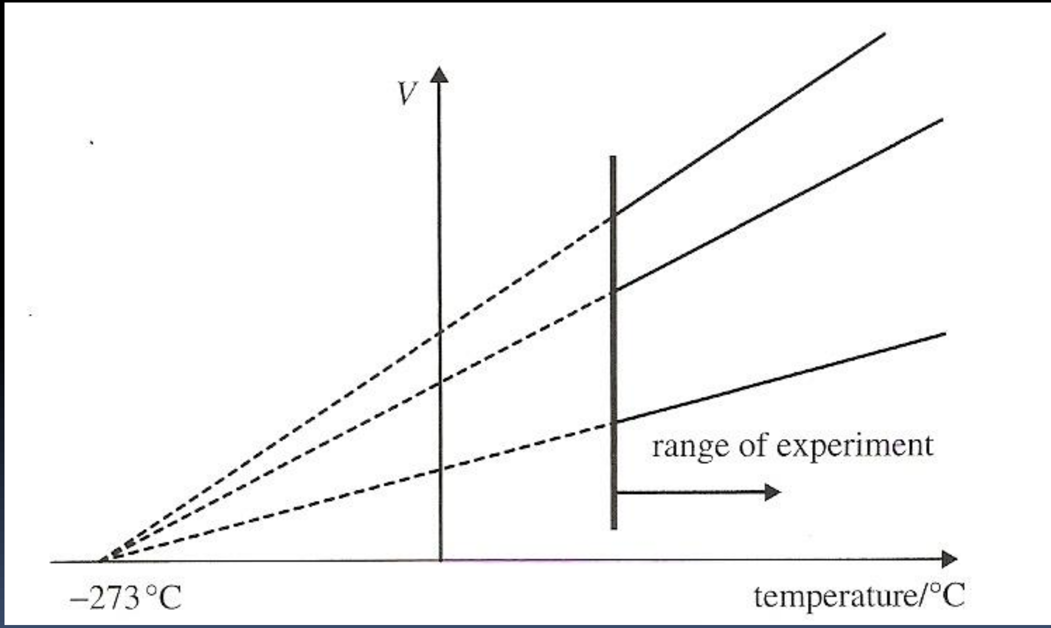


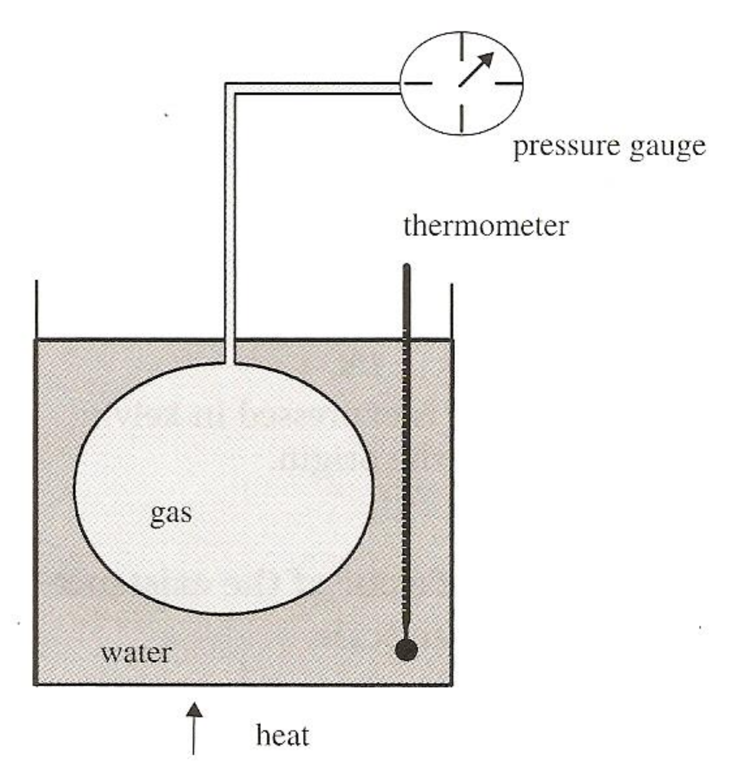
Graph of different quantities of the same gas or same gas at different pressures

Pressure-Temperature Law

- When the temperature is expressed in ***Kelvin*** and ***volume is kept constant***, pressure and temperature are proportional to each other

$$\frac{P}{T} = cons\tan t$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$



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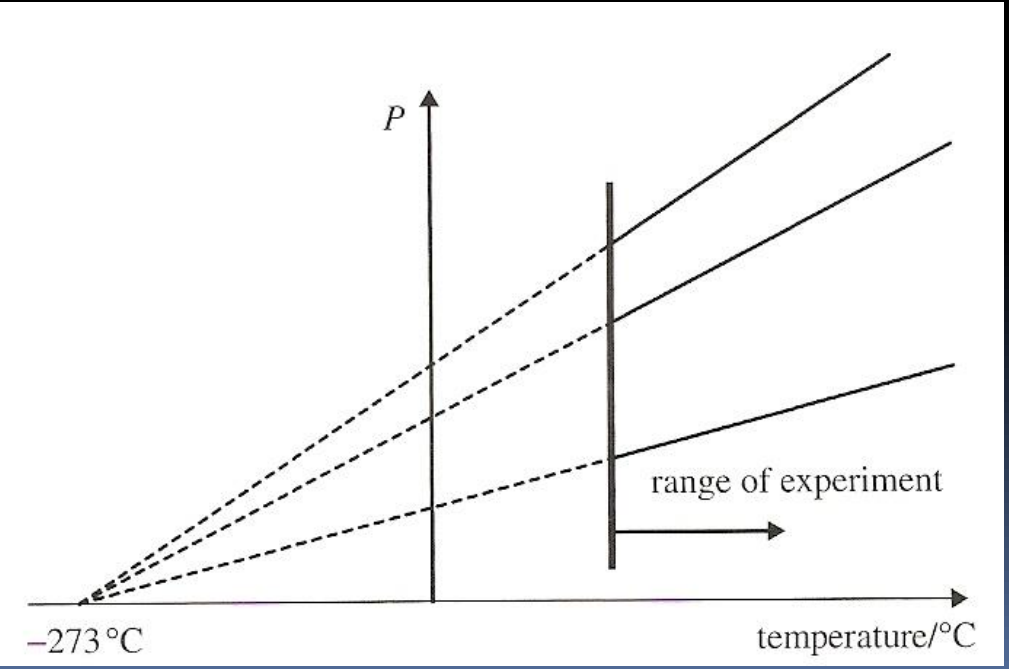

Equation of State

$$\frac{PV}{T} = constant$$

$$\frac{PV}{T} = (n)(constant)$$

$$R = 8.31 JK^{-1}mol^{-1}$$

$$PV = nRT$$

Ideal Gas Law

- An ideal gas will obey this law at all temperatures, pressures and volumes.
- Real gases obey this law only for a certain range of temperatures, pressures and volumes.

$$PV = nRT$$

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

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Essential Idea:

- The properties of ideal gases allow scientists to make predictions of the behavior of real gases.

QUESTIONS

Homework

#13-32

Stopped here 1/13/15