Slide 1

Ideal Gas Law

Another fluid

Slide 2

Chemistry is all about…

MOLES! MOLES! MOLES!

(Nice job – class dismissed.)

Slide 3

Moles is central…

…but to have a middle, you need a beginning and an end.

Our most common calculation:

Grams to moles, moles to moles, moles to grams

This works when “weighing” is appropriate.

Slide 4

For solutions…???

Molarity to moles, moles to moles, moles to molarity

Slide 5

It's all about what's easiest:

If you have a pure solid or a pure liquid, just throw it on a balance!

If you have a solution, throw it in a graduated cylinder.

If you have a gas…you could mass it, but they are very light!

Slide 6

Gas laws

Getting MOLES! MOLES! MOLES! if your reactants and products are gases.

Slide 7

Solids, liquids and gases

There are 3 main states of matter:

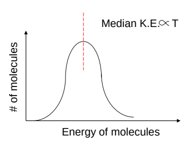
- Solids
- Liquids
- Gases

Each of the 3 have properties that are unique, but there is a gradual transition from one state of matter to the other.

Slide 8

Kinetic Model of Matter

Temperature, is a reflection of the role of molecular motions in systems



Slide 9

Kinetic Model of Matter

The difference between the different states of matter can also be related to the motions of the molecules:

- Solids – very little motion
- Liquids – free movement of molecules among each other
- Gases – free movement in mostly empty space

Slide 10

Kinetic Model of Matter

This difference in motion is a function of the relationship between the kinetic energy of the molecules and the forces of attraction of the molecules.

- Solids – not enough KE to break free of neighbors.
- Liquids – enough KE to be free, but still attracted to the girl next door.
- Gases – so much KE that you can't slow down to greet the neighbors.

Slide 11

Solids are different – more different

Liquids and gases are distinctly different, but they are much more like each other than either is like a solid.

Liquids and gases are both considered **fluids**.

Fluids flow!

Slide 12

Pressure

Fluids also have a new property we haven't discussed – **Pressure**.

Do you know what pressure is?

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Slide 13

Molecular Dynamics Picture

On the molecular scale, what is pressure? Where does the “force” come from?

It is the force of the molecules bumping into the walls of the container holding the gas.

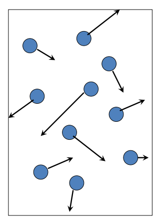
Slide 14

A picture paints a thousand words…

The molecules of a gas are in constant motion.

The molecules have random directions and a distribution of energies (think T).

The molecules collide with each other and the barriers of the vessel.

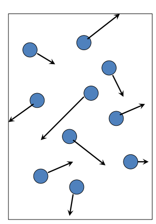


Slide 15

A picture paints a thousand words…

Every collision causes an exchange of energy.

The “average KE” (T) , however, stays the same.



Slide 16

Other properties of gases…

Besides pressure, what are the other physical properties of gases (or any matter):

- Mass
- Density
- Volume (length, width, height)
- Temperature
- # of moles (how many particles)
- Color, texture

Slide 17

Gases

Why do NASCAR teams under-inflate (low pressure) their tires in the pits?

Because the tires get very hot at 200 m.p.h. and the Pressure increases with Temperature!

$P \propto T$

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Gases

Why does a balloon inflate when you blow into it?

Because the Volume is proportional to how much stuff (moles) you put into it!

$V \propto n$ (Avogadro's Law)

Slide 19

Gases

What happens when you put a balloon in the freezer?

It shrinks! Volume is proportional to the Temperature.

$V \propto T$ (Charles' Law)

Slide 20

Gases

If you have a cylinder of helium, why is it that you can inflate a balloon that is much bigger than the cylinder?

Because the Volume is INVERSELY proportional to the Pressure!

$P \propto 1/V$ (Boyle's Law)

Slide 21

The 1st Clicker Question!!!

If I have Helium under 12 atm of pressure in a 10 L cylinder, how big would the balloon be at atmospheric pressure (1 atm)? (Assume all other conditions remain constant.)

A. 1.2 L
B. 120 L
C. 0.833 L
D. 83.3 L

Slide 22

Since P is proportional to 1/V, that means

PV = constant

What constant? More on that later, but it is constant.

$P_1V_1 = P_2V_2$

(12 atm) (10 L) = 1 atm * V_2

V_2 = 120 L!

Slide 23

What did I mean by “Assume all other conditions remain constant”?

Any condition that affects either the P or the V of the gas!

Slide 24

Relevant Gas variables

From my earlier examples:

$P \propto T$

$V \propto n$

$P \propto 1/V$

$V \propto T$

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Ideal Gas Law

Putting it all together:

$P \propto T$
$V \propto n$
$P \propto 1/V$
$V \propto T$

$PV \propto nT$
$PV = n R T$ where R is the "ideal gas constant"

Slide 26

PV = nRT

UNITS! UNITS! UNITS! (Still Joe's 1st Rule of Chemistry)

What should the units be?

It doesn't really matter – with one exception!

Slide 27

The Exception

Temperature!

We want the correct limiting behavior.

What happens if the temperature reaches absolute 0?

The molecules stop moving (KE=0), the temperature goes to zero and so the pressure should go to 0!

Slide 28

UNITS! UNITS! UNITS!

T = Kelvin
n = moles
V = ?
P = ?

Slide 29

UNITS! UNITS! UNITS!

What are the SI units?

Volume

m^3 – volume is cubic distance

Pressure

N/m^2 (Force/area)
$kg\ s^{-2}\ m^{-1}$ also called a "Pascal"

Slide 30

UNITS! UNITS! UNITS!

What are the common units?

Volume

Liter

Pressure

atm
mmHg

Slide 31

UNITS! UNITS! UNITS!

T = Kelvin
N = moles
V = liter
P = atm

Let "R" be your guide

Slide 32

R has units!

There are a couple different R values that are frequently used.

$R = 0.082058 \frac{L\ atm}{mol\ K}$ - common for gas dynamics

$R = 8.314 \frac{J}{mol\ K}$ - more common for thermo

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PV=nRT

PV = n R T

$R = 0.082058 \frac{L\ atm}{mol\ K}$

To get everything to cancel:
P = atm n = mol
V = L T = K

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It's the IDEAL gas law – when is a gas IDEAL

What makes an ideal gas, ideal?

1. The volume of the molecules is negligible << the empty space
2. The molecules don't interact with each other – there is no attraction or repulsion between them.

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Sample Problem

A balloon is filled with 1.0 gram of hydrogen at STP, what is its volume?

P = 1 atm, T = 298 K @ thermodynamic STP

P = 1 atm, T = 273 K @ gaseous STP

$1.0\ g\ H_2 * \frac{1\ mol\ H_2}{2.016\ g\ H_2} = 0.496\ mol$

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Sample Problem

A balloon is filled with 1 gram of hydrogen at STP, what is its volume?

P V = nRT

1 atm V = (0.496 mol) * (0.082058 Latm/mol K) * 273 K

V =11.1 L

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Clicker Question

A 1 L glass flask is filled with He gas at STP. The temperature was increased to 100ºC, what is the pressure in the flask?

A. 1 atm
B. 0.366 atm
C. 1.366 atm
D. 100 atm
E. 0.732 atm

Slide 38

Clicker Question

A 1 L glass flask is filled with He gas at STP. The temperature was increased to 100ºC, what is the pressure in the flask?

P = 1 atm T = 273 K V = 1 L n=?

P = ? T = 100 C = 373 K V = 1L n =?

Two ways to go!

Slide 39

Clicker Question

A 1 L glass flask is filled with He gas at STP. The temperature was increased to 100ºC, what is the pressure in the flask?

P = 1 atm T = 273 K V = 1 L n=?

P = ? T = 100 C = 373 K V = 1L n =?

Find n

PV = nRT

1 atm * 1 L = n (0.082056 Latm/mol K) (273 K)

n = 0.0446 mol

Slide 40

Clicker Question

A 1 L glass flask is filled with He gas at STP. The temperature was increased to 100ºC, what is the pressure in the flask?

P = 1 atm T = 273 K V = 1 L n=0.0446 mol
P = ? T = 373 K V = 1L n =0.0446 mol

Use the n to find P
PV = nRT
P * 1 L = (0.0446 mol) (0.082056 Latm/mol K) (373 K)
P = 1.366 atm

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Second Way – throw out what's constant

A 1 L glass flask is filled with He gas at STP. The temperature was increased to 100ºC, what is the pressure in the flask?

P = 1 atm T = 273 K V = 1 L n = ?
P = ? T = 373 K V = 1L n = ?

Collect the variables
PV = nRT
P/T = nR/V (n is constant, V is constant, R is constant)
$P_1/T_1 = P_2/T_2$
1 atm/273 K = P_2/373 K
P_2 = 1.366 atm

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Sample Problem #2

A 1.00 L balloon is filled with helium gas at STP. If the balloon is put into a freezer at 5º C, what is its volume?

PV = nRT

You could just use the Ideal Gas Law to calculate the new volume. (You need to calculate n first, but that's easy enough)

Slide 43

Sample Problem #2

A 1.00 L balloon is filled with helium gas at STP. If the balloon is put into a freezer at 5º C, what is its volume?

PV = nRT

1 atm * 1 L = n (0.082058 Latm/mol K) * 273 K
n = 0.0446 mol
1 atm * V = (0.0446 mol) (0.082058 Latm/mol K)*278 K
V = 1.02 L

There is, however, an easier way!

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Sample Problem #2

A 1 L balloon is filled with helium gas at thermodynamic STP. If the balloon is put into a freezer at 5º C, what is its volume?

The pressure and the number of moles of gas remain constant throughout the experiment, so…

PV = nRT

$\frac{V}{T} = \frac{nR}{P}$

Everything on the right remains constant.

$\frac{V_f}{T_f} = \text{constant} = \frac{V_i}{T_i}$

Slide 45

Sample Problem #2

A 1 L balloon is filled with helium gas at thermodynamic STP. If the balloon is put into a freezer at 5º C, what is its volume?

$\frac{V_f}{T_f} = \frac{V_i}{T_i}$

$\frac{V_f}{278\ K} = \frac{1\ L}{273\ K}$

$V_f = 1.02\ L$

Slide 46

Clicker Question #2

28.8 g of dry ice (frozen CO_2) I allowed to sublime (go from solid to gas) inside of a large balloon. What will be the volume of the balloon at a temperature of 22ºC and 742 mmHg?

A. 1.2 L

B. 714 L

C. 0.021 L

D. 16 L

Slide 47

Clicker Question #2

28.8 g of dry ice (frozen CO_2) I allowed to sublime (go from solid to gas) inside of a large balloon. What will be the volume of the balloon at a temperature of 22ºC and 742 mmHg?

PV = nRT

V= nRT/P

$$28.8\text{ g } CO_2 * \frac{1\text{ mol } CO_2}{44.01\text{ g } CO_2} = 0.654\text{ mol } CO_2$$

T = 22 C + 273.15 = 295 K

$$P = 742\text{ mm Hg} * \frac{1\text{ atm}}{760\text{ mm Hg}} = 0.976\text{ atm}$$

$$V = \frac{(0.654\text{ mol}) * 0.082058\text{ L atm/mol K} * 295\text{ K}}{0.976\text{ atm}}$$

V = 16.2 L