Gases

Properties of Gases

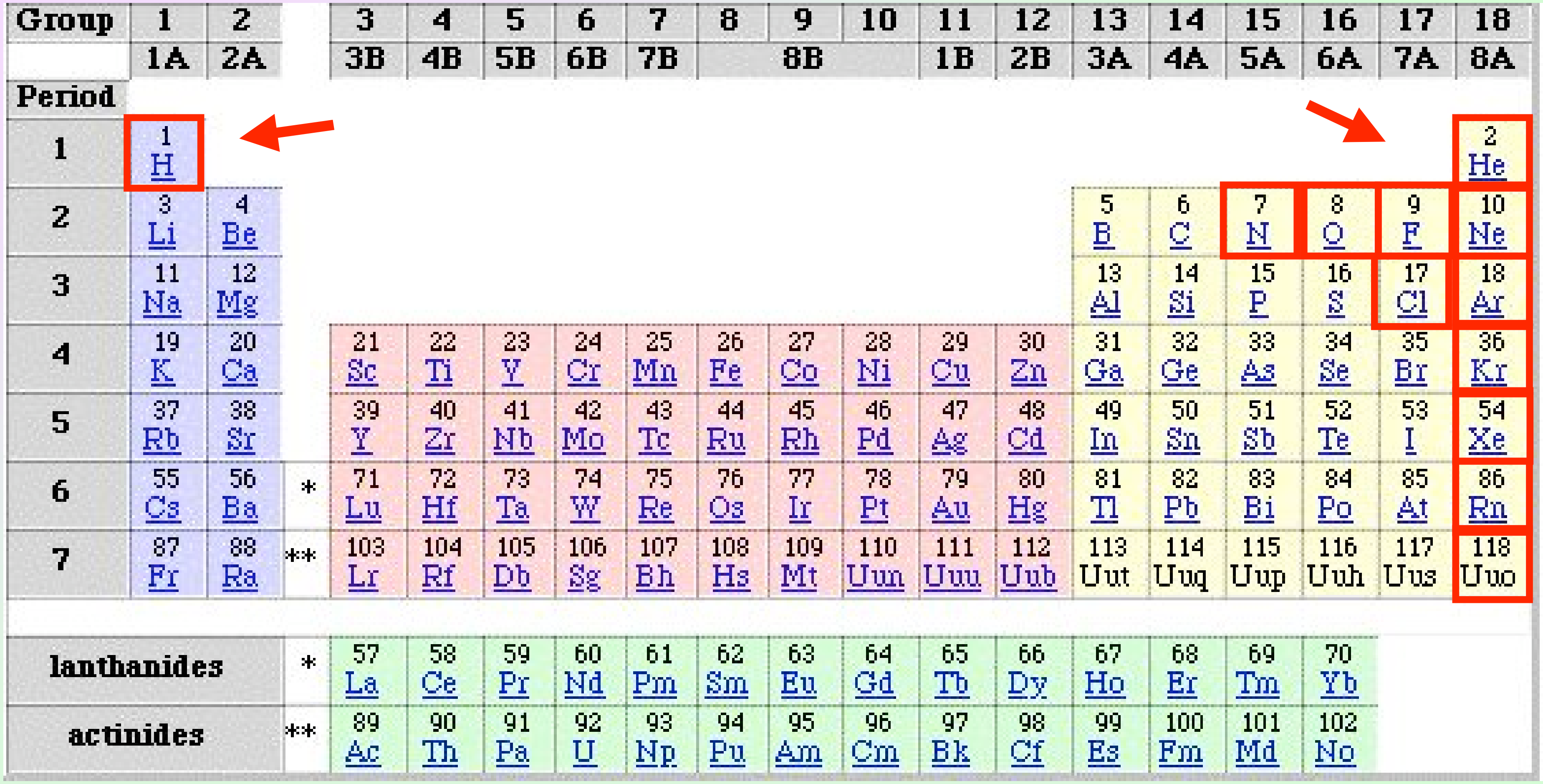
assume the volume and shape of their containers

most compressible of the states of matter

mix evenly and completely with other gases

much lower density than other forms of matter

Substances that Exist as Gases



Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1A	2A		3B	4B	5B	6B	7B	8B			1B	2B	3A	4A	5A	6A	7A	8A
Period																			
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
lanthanides			*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
actinides			**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Elements that exist as gases at 25˚C and 1 atm. The Noble gases (the Group 8A elements) are monatomic species; the other elements exist as diatomic molecules. Ozone (O_3) is also a gas.

Some substances found as gases at 1 atm and 25 °C

Elements

H_2, N_2, O_2, O_3, F_2, Cl_2
He, Ne, Ar, Kr, Xe, Rn

Compounds

HF, HCl, HBr, HI, CO, CO_2, NH_3, NO,
NO_2, N_2O, SO_2, H_2S, HCN

Pressure of a Gas

Pressure

The force exerted on an object divided by the surface area of the object;

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

Any gas confined to a container is found to exert a pressure on the container .

SI Units of Pressure

customary units

1 standard atm = 760 mm Hg

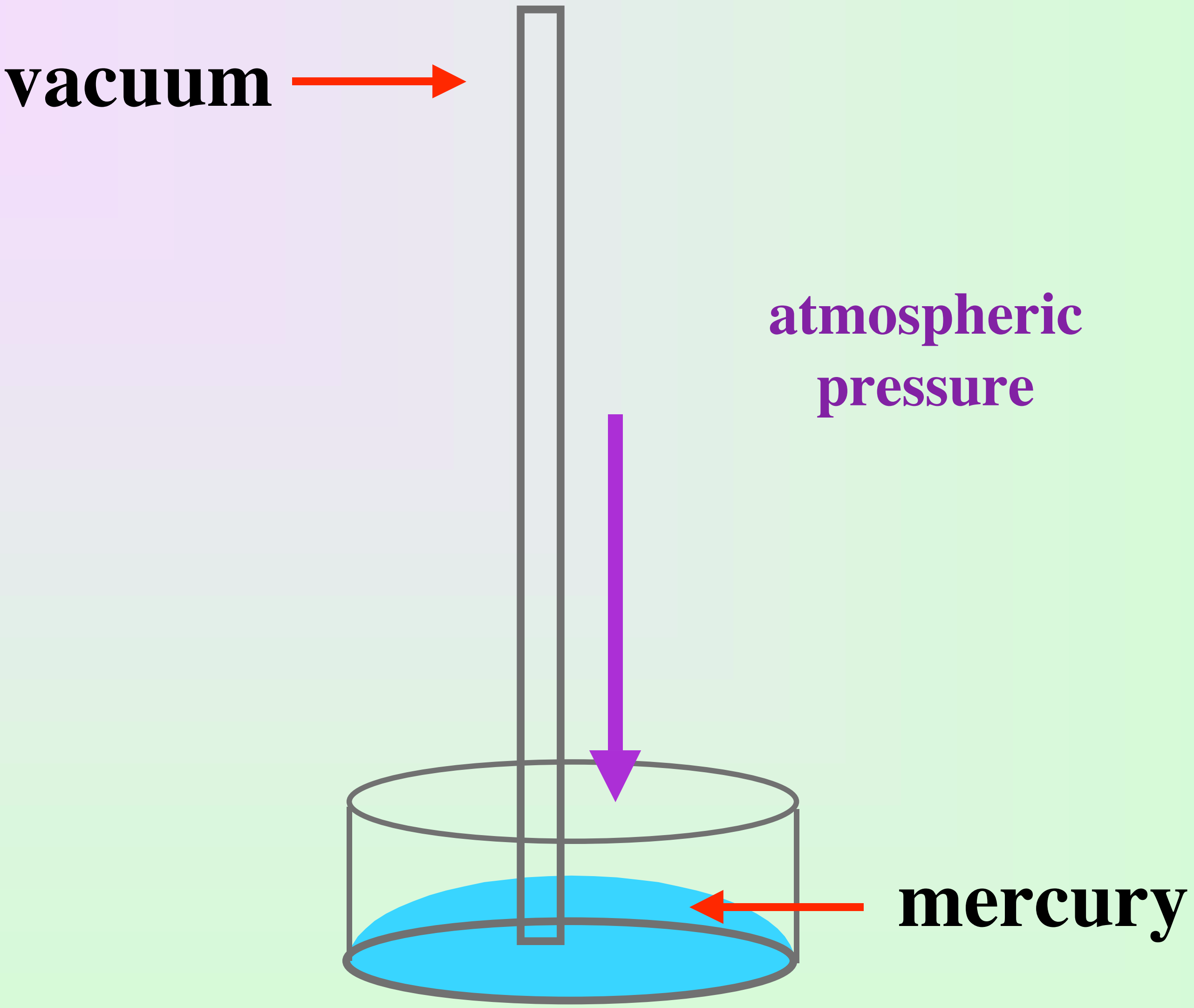
= 760 torr

SI units

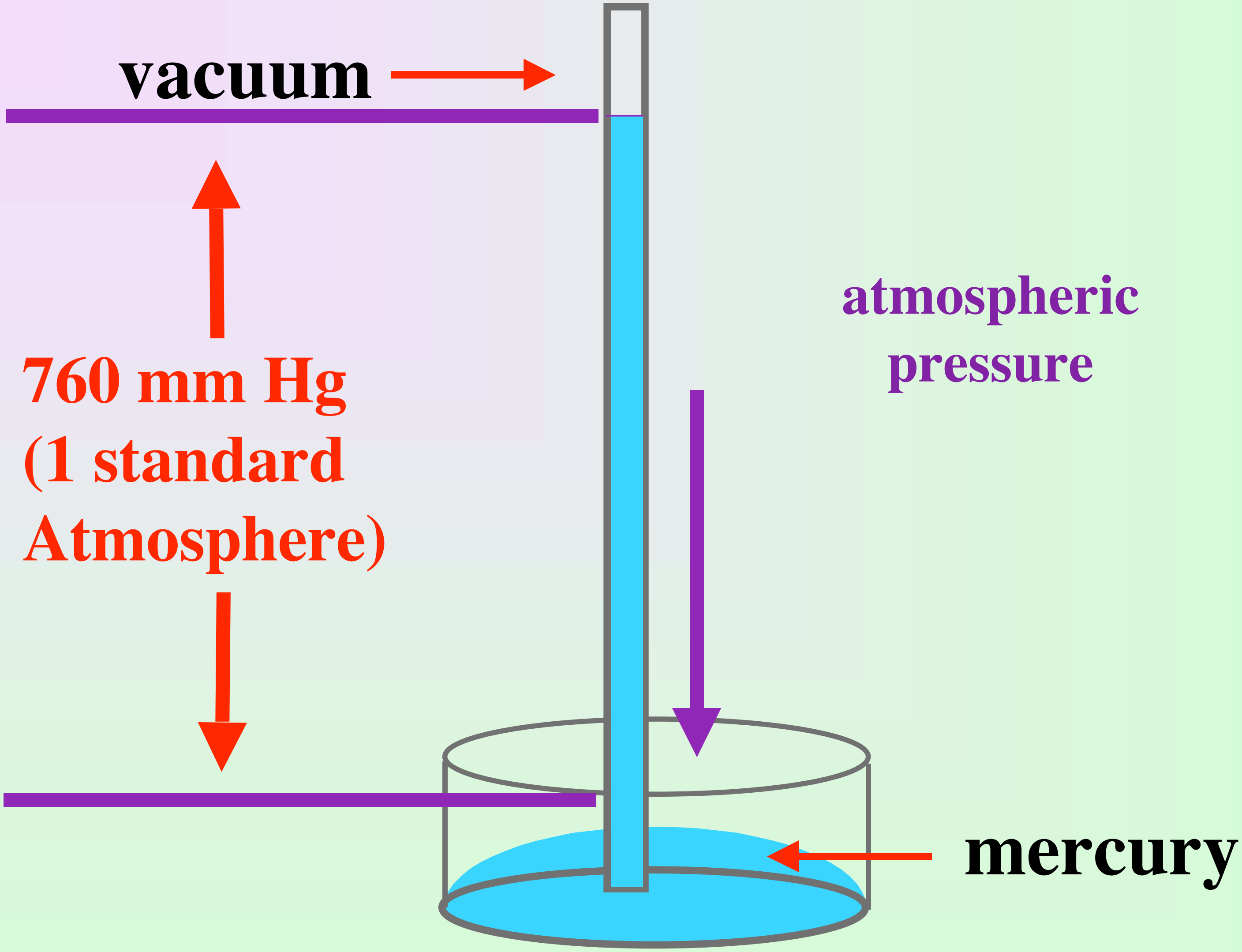
pressure = force/area

pressure = Newton/m^2 = Pascal

1 standard atmosphere = 101,325 Pa



A Torricellian Barometer



vacuum

760 mm Hg
(1 standard
Atmosphere)

atmospheric
pressure

mercury

A Torricellian Barometer

The Gas Laws

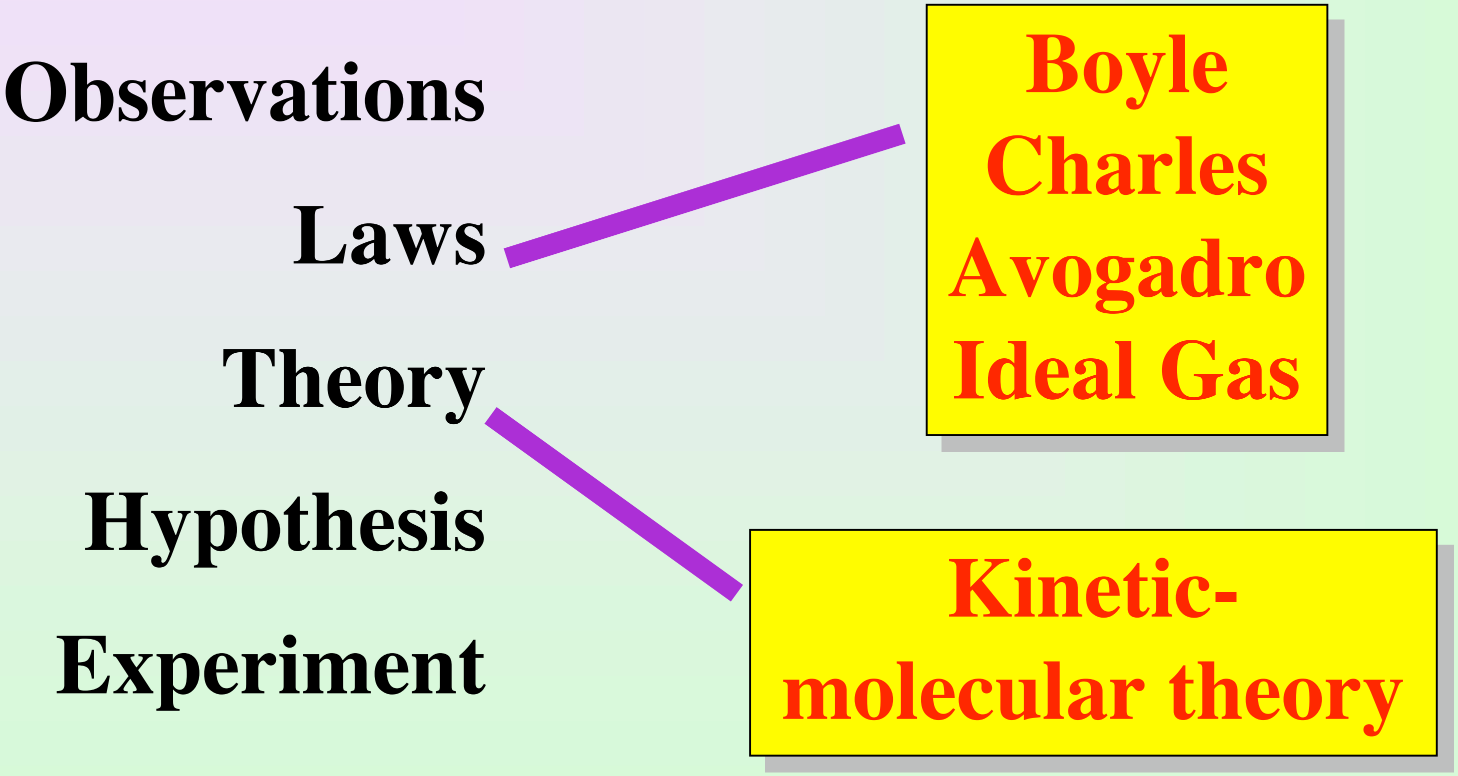
Boyle’s Law

Charles’ Law

Avogadro’s Law

The Ideal Gas Law

The Gas Laws and the Scientific Method



Observations

Laws

Theory

Hypothesis

Experiment

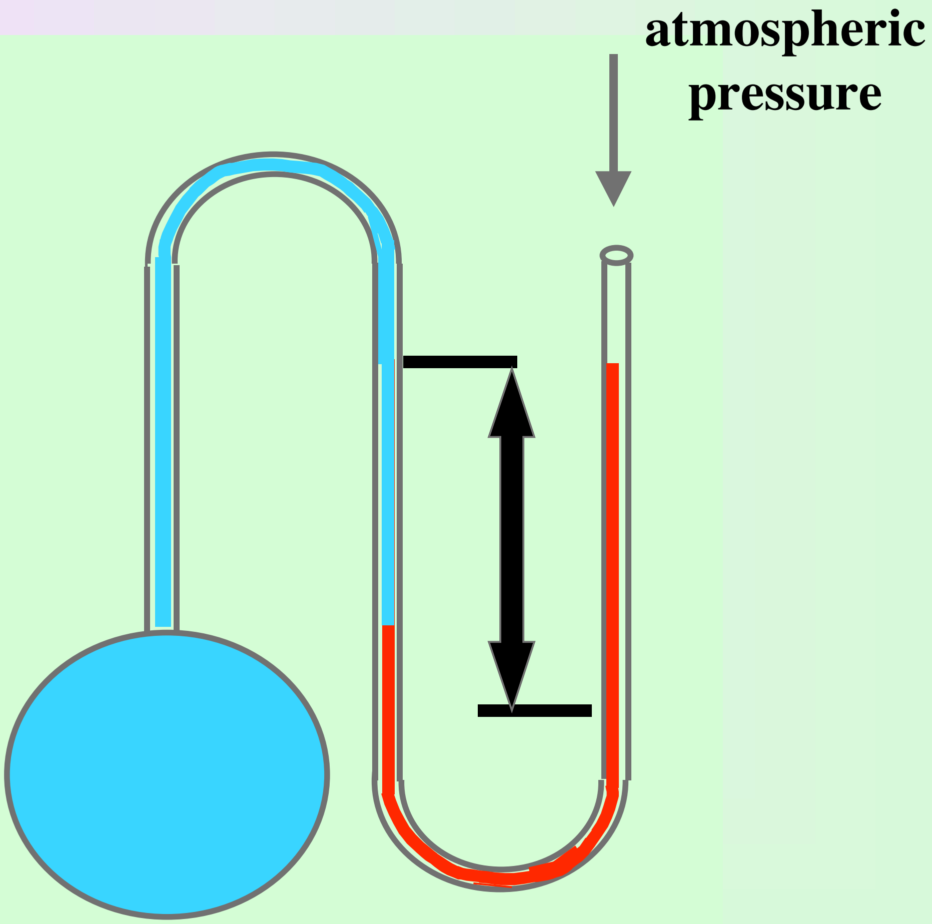
Boyle
Charles
Avogadro
Ideal Gas

Kinetic-molecular theory

Boyle’s Law

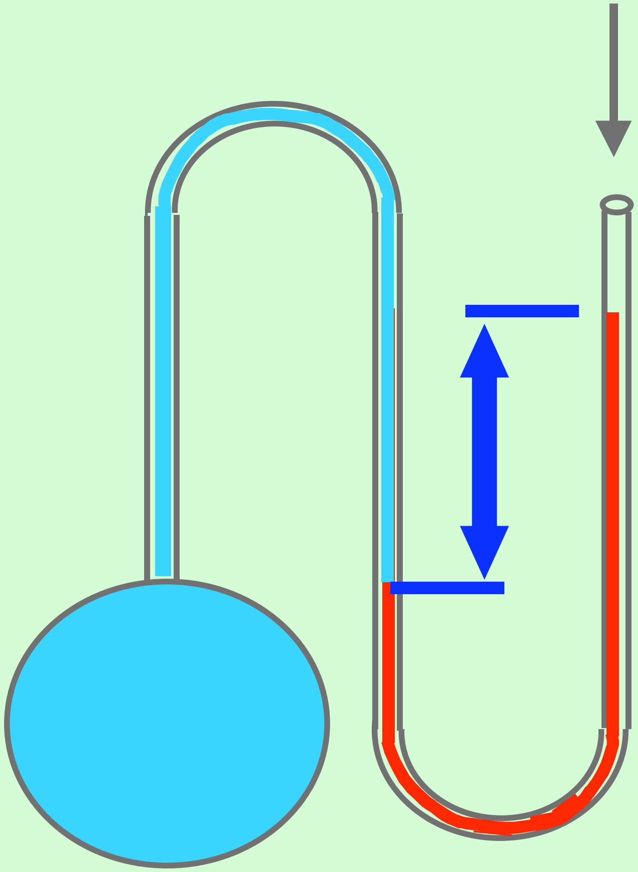
Robert Boyle 1626 – 1691

Manometer



$$P_{gas} = P_{atm} - h_{Hg}$$

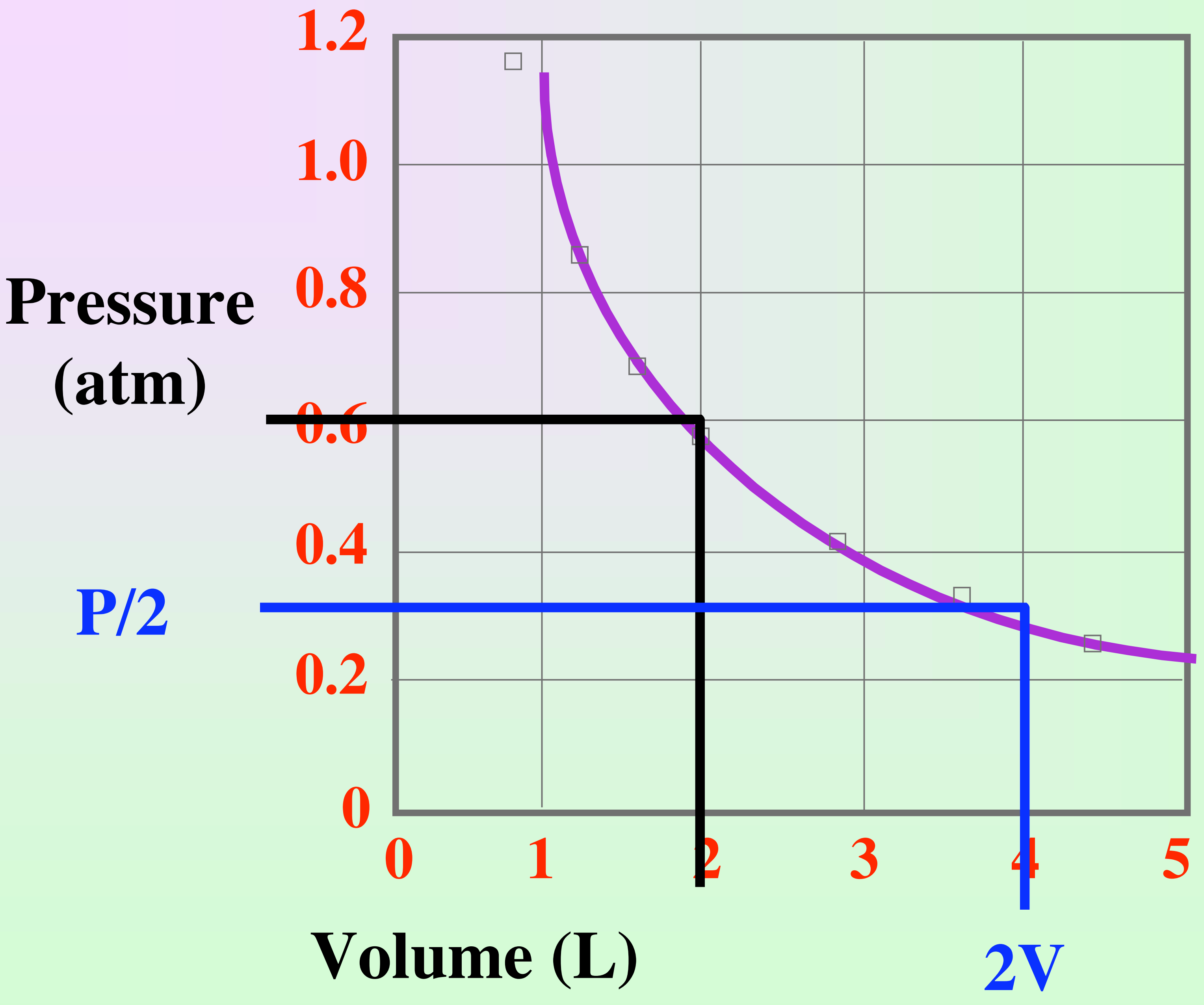
Manometer



$$P_{gas} = P_{atm} + h_{Hg}$$

Boyle's Data

Pressure (mm Hg)	Volume (arbitrary units)
724	1.50
869	1.33
951	1.22
998	1.16
1230	0.94
1893	0.61
2250	0.51


1.2
1.0
0.8
0.6
0.4
0.2
0
Pressure (atm)
P/2
0
1
2
3
4
5
Volume (L)
2V

Boyle's Data

Pressure (mm Hg)	**Volume** (arbitrary units)	**PV**
724	1.50	1090
869	1.33	1160
951	1.22	1160
998	1.16	1160
1230	0.94	1200
1893	0.61	1200
2250	0.51	1100

Boyle's Law

at constant temperature, the volume of a constant amount of gas is inversely proportional to the pressure

constant *n*, constant *T*

$$PV = k$$

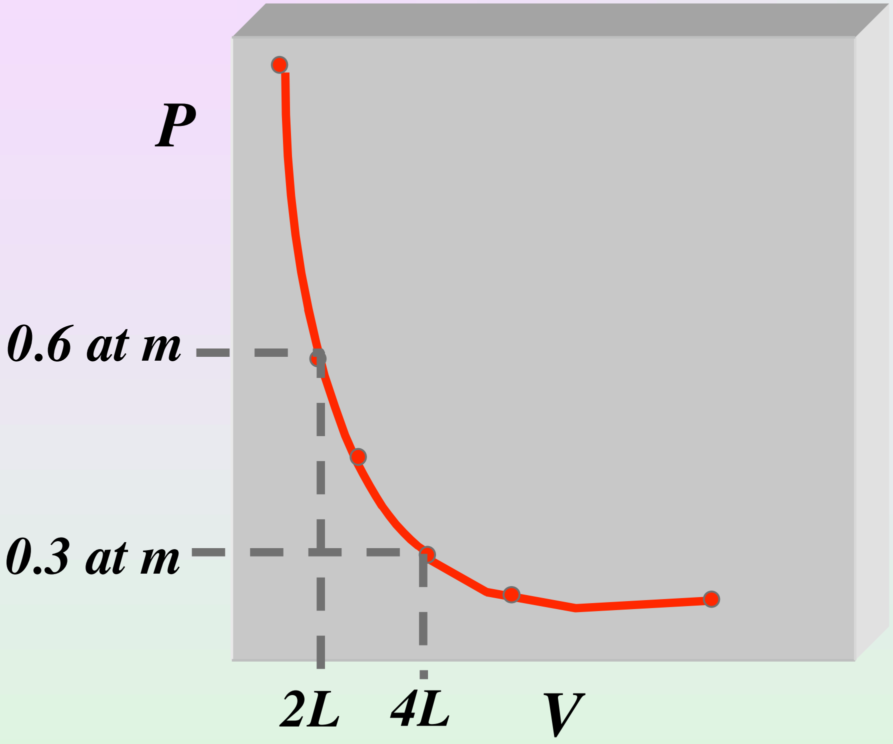
$$P = k\frac{1}{V}$$

Plot of P versus V is a hyperbola

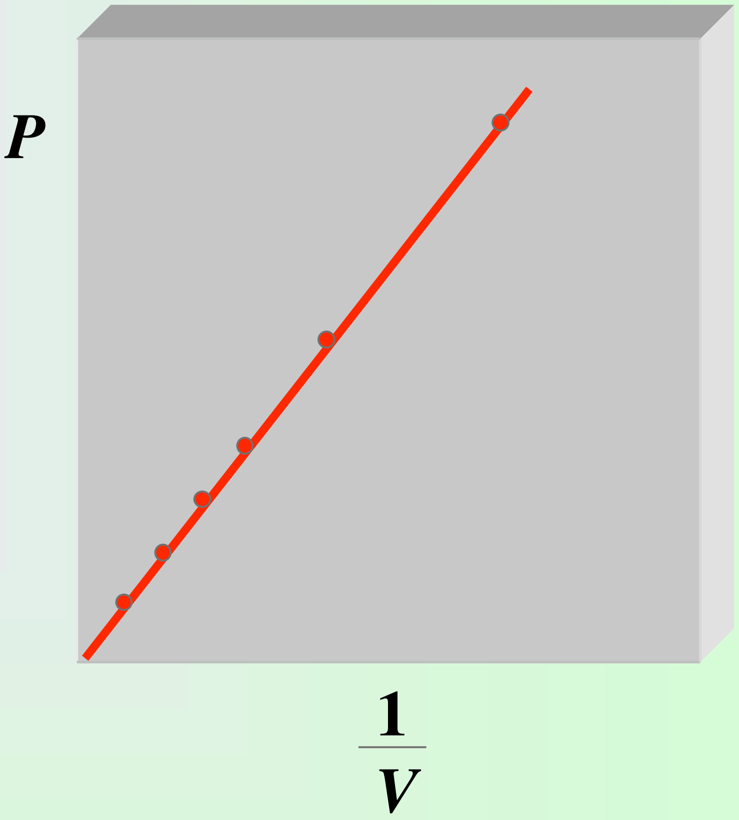
$PV = k$

$P = (1/V\ )\ k$

is of the form y = mx + b, which is the equation for a straight line



(a)



(b)

Charles's Law

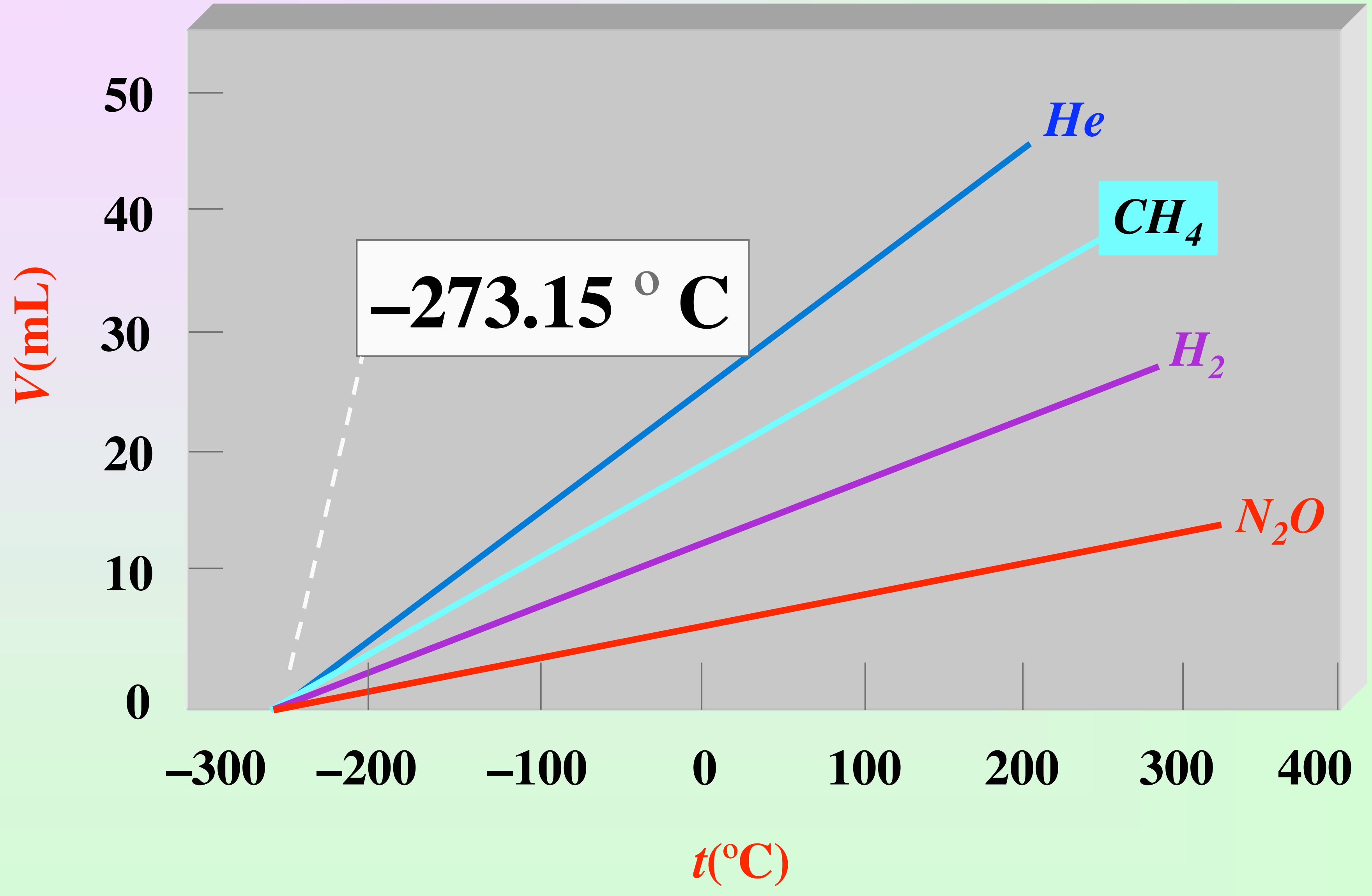
Jacques Charles 1746 – 1823

Charles's Law

at constant pressure, the volume of a constant amount of gas is directly proportional to the absolute temperature

constant *n*, constant *P*

$$V = kT$$



V(mL)
50
40
30
20
10
0
He
CH_4
–273.15 °C
H_2
N_2O
–300
–200
–100
0
100
200
300
400
t(°C)

Celsius scale		Kelvin scale
5727° C	Temperature at the surface of the sun	6000 K
1064° C	Melting point of gold	1337 K
100° C	Boiling point of water	373.15 K
37° C	Body temperature	310 K
0° C	Melting point of ice	273.15 K
–196° C	Boiling point of N_2	77K
–268.95° C	Boiling point of He	4.2 K
–273.15° C	Lowest temperature (absolute zero)	0 K

Avogadro's Law

Amadeo Avogadro (1776 – 1856)

Avogadro’s Law

at constant temperature and pressure, the volume of a gas is directly proportional to the number moles

constant T, constant P

$$V = kn$$

equal volumes of different gases contain equal numbers of molecules

The Ideal-Gas Equation

The Ideal Gas Law

$$PV = n\mathrm{R}T$$

constant n, constant T (Boyle's Law)

constant n, constant P (Charles' Law)

constant P, constant T (Avogadro's Law)

The Ideal-Gas Law

$PV = nRT$

P is pressure in atmospheres
V is volume in liters
n is number of moles
T is absolute temperature in Kelvins
R is called the gas constant

An ideal gas is a hypothetical gas whose pressure-volume-temperature behavior can be completely accounted for by the ideal-gas equation.

Standard temperature and pressure

$PV = nRT$

standard conditions defined

$P = 1$ atm

$T = 0^{\circ}\mathrm{C}$ (273 K)

STP

Standard Molar Volume

The volume occupied by 1 mole of a gas at STP is 22.414 L

The Gas Constant R

The volume occupied by 1 mole of a gas at STP is 22.414 L

$$PV = nRT$$

$$R = \frac{PV}{nT}$$

$$R = \frac{(1\ \mathrm{atm})\ (22.414\ \mathrm{L})}{(1\ \mathrm{mol})\ (273.15\ \mathrm{K})}$$

$R = 0.082057$ (L atm/mol K)

Example

What is the volume occupied by 49.8 g of HCl at STP?

$$49.8\text{ g} \times \frac{1\text{mol}}{36.46\text{ g}} = 1.366\text{ mol}$$

$P = 1$ atm

$T = 273$ K

$$\boxed{V = \frac{nRT}{P}}$$

$$\frac{(1.366\text{ mol})\ (0.0821\text{ L atm/mol K})\ (273\text{K})}{1\text{ atm}}$$

V = 30.6 L

Example

What is the volume occupied by 49.8 g of HCl at STP? (alternative solution)

P = 1 atm

T = 273 K

$$n = \frac{49.8\ g}{36.46\ g/mol} = 1.366\ mol$$

$$V = \frac{22.4\ \text{L}}{1\ \text{mol}}\ \text{x}\ \ 1.366\ \text{mol}$$

V = 30.6 L

Example

A compound has the empirical formula BH_3. At 27 ° C, 74.3 mL of the gas exerted a pressure of 1.12 atm. If the mass of the gas was 0.0934 g, what is its molecular formula?

$$PV = nRT \qquad n = \frac{PV}{RT}$$

Example (cont.)

A compound has the empirical formula BH_3. At 27 ° C, 74.3 mL of the gas exerted a pressure of 1.12 atm. If the mass of the gas was 0.0934 g, what is its molecular formula?

$$n = 0.00338 \text{ mol}$$

$$\frac{0.0934 \text{ g}}{0.00338 \text{ mol}} = 27.6 \text{ g/mol}$$

$$\boxed{B_2H_6}$$

BH_3 = 13.8 g / empirical formula

The ideal gas law is often used to calculate the changes that will occur when the conditions of a gas are changed

$$PV = nRT$$

If nRT are constant

$$P = \left(nRT\right)\frac{1}{V}$$

$$PV = \left(nRT\right) = P_2V_2$$

$$PV = nRT$$

If nRP are constant

$$V = \left(\frac{nR}{P}\right)T$$

$$\frac{V}{T} = \left(\frac{nR}{P}\right) = \frac{V_2}{T_2}$$

The ideal gas law is often used to calculate the changes that will occur when the conditions of a gas are changed

$$PV = nRT$$

If PRT are constant

$$V = \left(\frac{RT}{P}\right) n$$

$$\frac{V}{n} = \left(\frac{RT}{P}\right) = \frac{V_2}{n_2}$$

$$PV = nRT$$

If nRV are constant

$$P = \left(\frac{nR}{V}\right) T$$

$$\frac{P}{T} = \left(\frac{nR}{V}\right) = \frac{P_2}{T_2}$$

Example

A sample of oxygen gas initially at 0.97 atm is cooled from 21 °C to -68 °C at constant volume. What is its final pressure.

PV = nRT

$$\frac{P}{T} = \left(\frac{nR}{V}\right) = \frac{P_2}{T_2}$$

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

Example

A sample of oxygen gas initially at 0.97 atm is cooled from 21 °C to -68 °C at constant volume. What is its final pressure.

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

$$\frac{(0.97\ \text{atm})}{292\ \text{K}} = \frac{P_2}{205\ \text{K}}$$

$P_2 = 0.68$ atm

Density Calculations

Example

What is the density of UF_6 gas at 62 $^{\circ}$ C and 779mmHg ?

$$\frac{n}{V} = \frac{P}{RT}$$

$$\frac{n}{V} = \frac{\dfrac{779\text{mmHg}}{760\text{mmHg/atm}}}{(0.0821\ \text{L atm/mol K})\ (335\ \text{K})}$$

$$= \frac{0.0373\ \text{mol}}{\text{L}} \times \frac{352.03\text{g}}{1\ \text{mol}} = 13.1\text{g/L}$$

A common unit for gasses

Example

Cyanogen ,empirical formula CN, is a gas with a density of 2.335 g/L at 0°C and 1 atm. What is its molecular formula?

$$n = \frac{PV}{RT}$$

$$n = \frac{(1\text{atm})\ (1\text{ L})}{(0.0821\ \text{L atm/mol K})\ (273\text{K})}$$

$$= 0.0446\ \text{mol}$$

$$\frac{2.335\text{g}}{0.0446\ \text{mol}} = \frac{52\ \text{g/mol Cyanogen}}{26\text{g /mol (CN)}} = 2$$

$$C_2N_2$$