THE UNIVERSITY OF UTAH

ATMOS 5130

Lecture 3

Physical Properties of Air

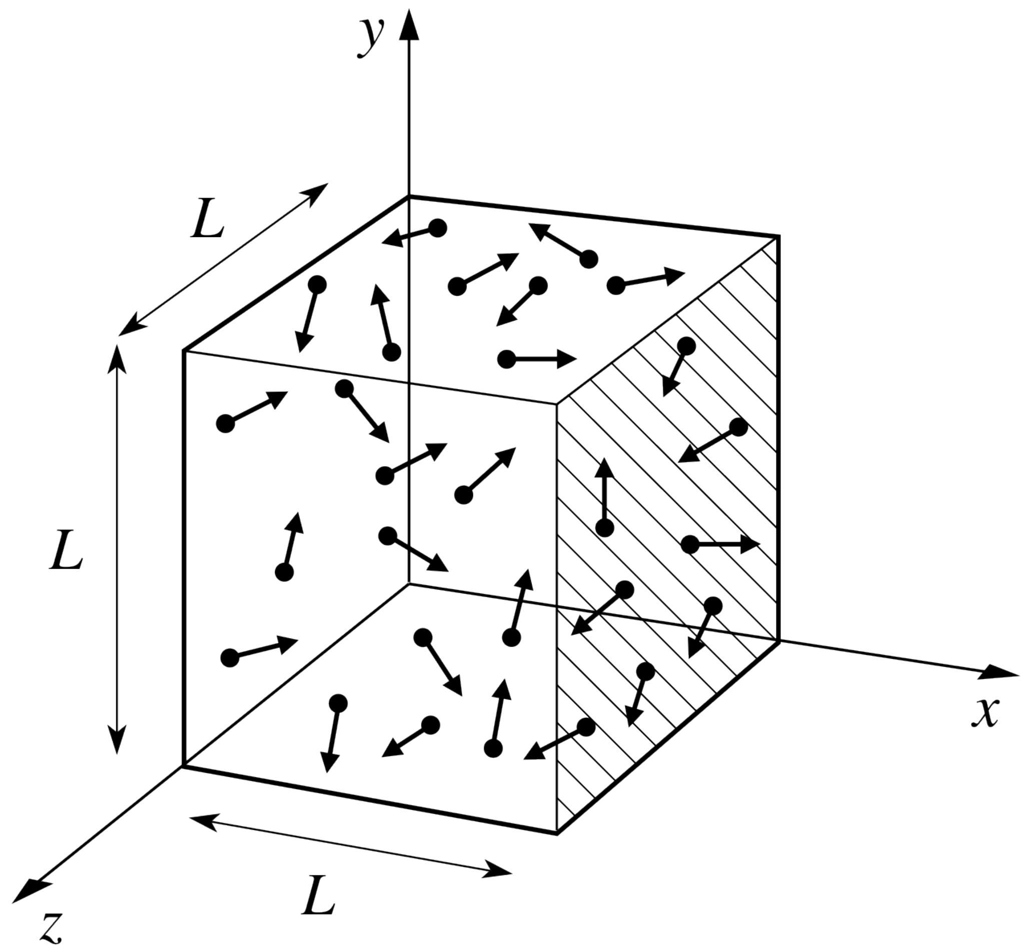
- Introduction to Kinetic Theory of Gases
- Boyle’s Law
- Charles’ Law
- Avogadro's Law
- Definition of a Mole and Molecular Weight
- Ideal Gas Law

Kinetic Theory of Gases

Study of the microscopic behavior of molecules and the interactions which lead to macroscopic relationships like the ideal gas law

Four basic postulates:

- **Gases are made up of molecules**
  - molecules as point masses that are perfect spheres.
  - Separation of molecules is large compared to molecular size
- **Molecules are in constant random motion**
  - With a distribution of speed that does not change.
- **The movement of molecules is governed by Newton's Laws:**
  - moves in a straight line at a steady velocity, not interacting with any of the other molecules except in a collision. Molecules exert equal and opposite forces on one another with collision.
- **Molecular collisions are perfectly elastic:**
  - Molecules do not lose any kinetic energy when they collide with one another.


y
L
L
x
z
L

CHAPTER 2: State vs. Process Variables

State Variables

Uniquely determined by the current state of the system

Properties of a system are at a point in time, not how it arrived at that state.

- Pressure
- Temperature
- Density

Process Variables

Associated with a process,

Exchange of energy between system and environment

e..g. heat energy (Q) added to air sample to bring it to current temp

CHAPTER 2: Extensive vs. Intensive Variables

Extensive Variables

Depends on the size of the sample or system

e.g. volume

Intensive Variables

Does not depend on the size of the sample or system

e.g. volume per mass

Chapter 3: Equation of State

For a homogeneous parcel of air, the state variables (intensive form) we will consider first are:

p = pressure

T = temperature

α = specific volume

ρ = density

$$\alpha \equiv \frac{1}{\rho}$$

Variable for all equations

V is the volume of gas

P is the pressure of gas

T is the temperature of gas

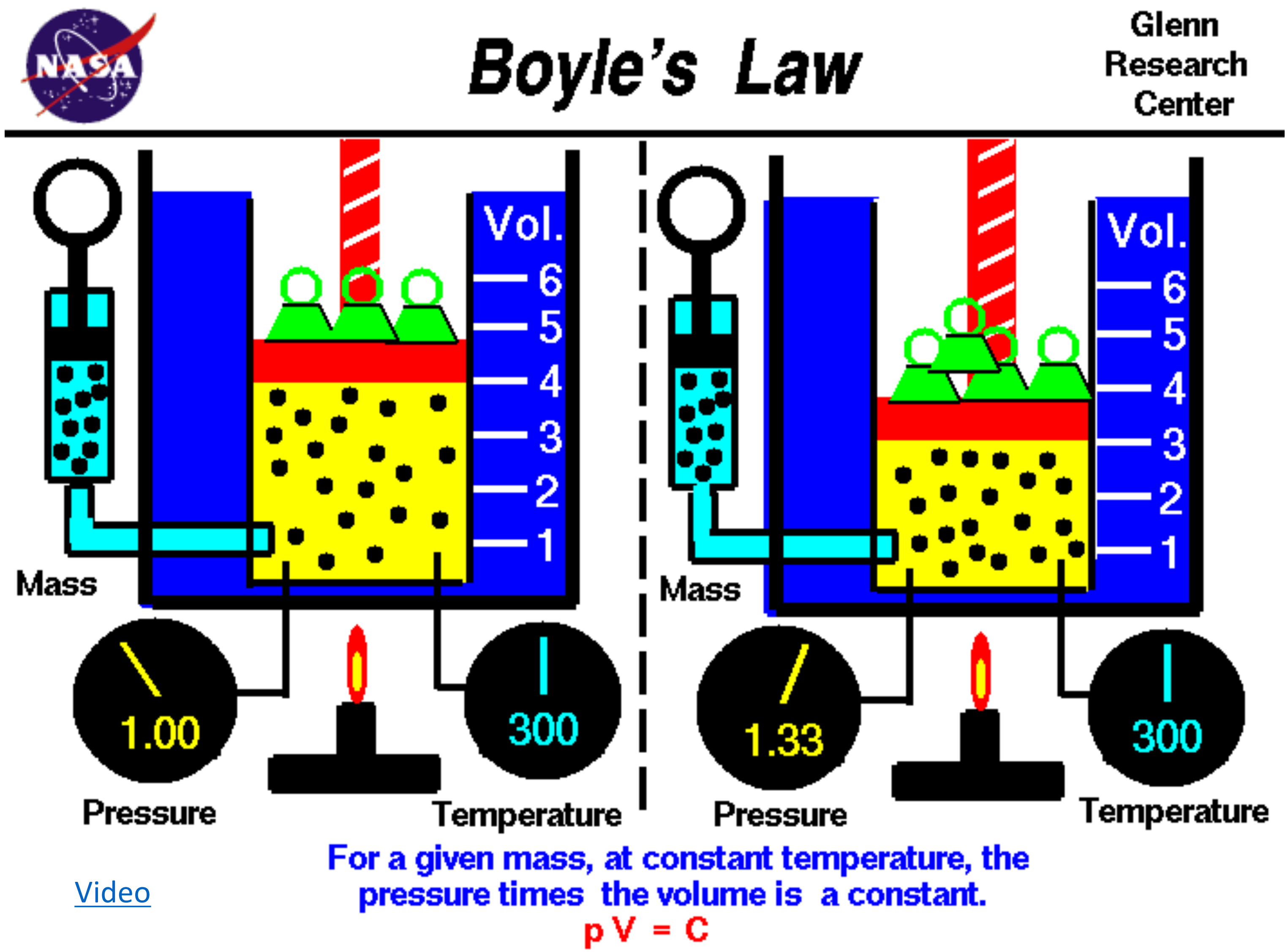
k is a constant

M = Mole

Boyle's Law

At constant temperature for a fixed mass, the absolute pressure and the volume of a gas are inversely proportional.

$$P \propto \frac{1}{V} \qquad\qquad PV = k$$



Boyle's Law
Glenn Research Center
Vol.
6
5
4
3
2
1
Mass
1.00
Pressure
300
Temperature
1.33
Pressure
300
Temperature
For a given mass, at constant temperature, the pressure times the volume is a constant.
p V = C

[Video]

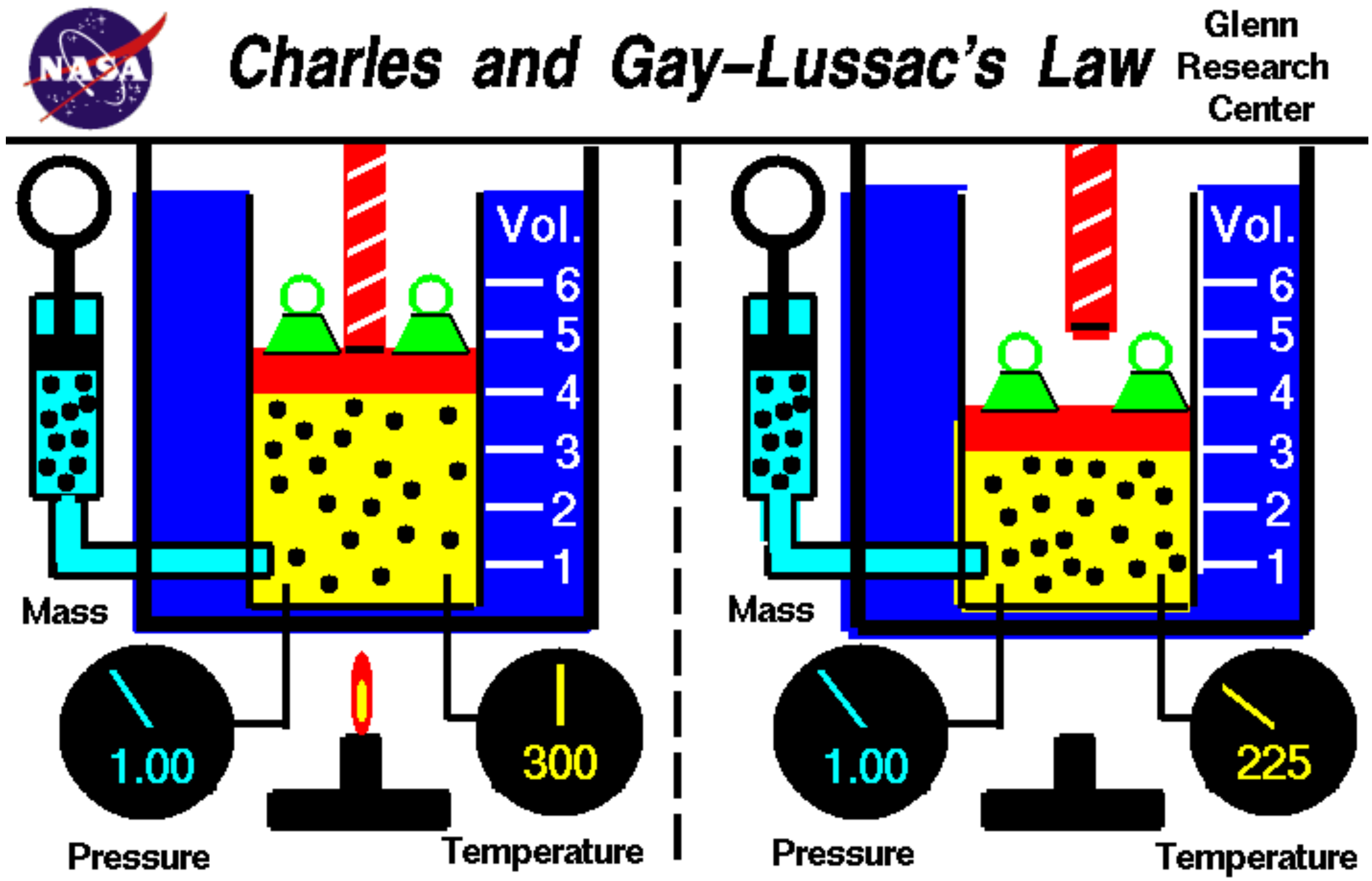
Charles and Gay-Lussac's Law

(also known as the law of volumes) is an experimental gas law that describes how gases tend to expand when heated.

$$V \propto T$$

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

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{or} \quad \frac{V_2}{V_1} = \frac{T_2}{T_1} \quad \text{or} \quad V_1 T_2 = V_2 T_1 .$$



For a given mass, at constant pressure, the volume is directly proportional to the temperature

$V = CT$

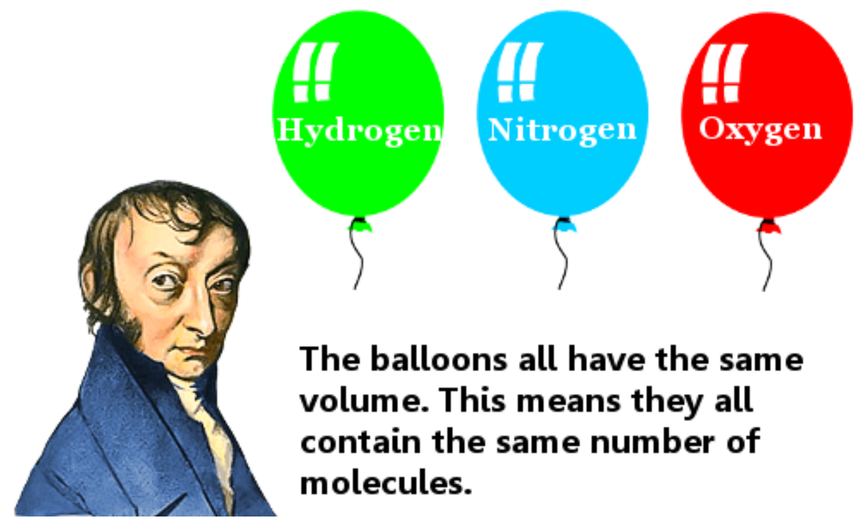
Video

Avogadro’s Law

Equal volumes of all gases, at the same temperature and pressure, have the same number of molecules.

$$V \propto n \qquad \frac{V}{n} = k$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

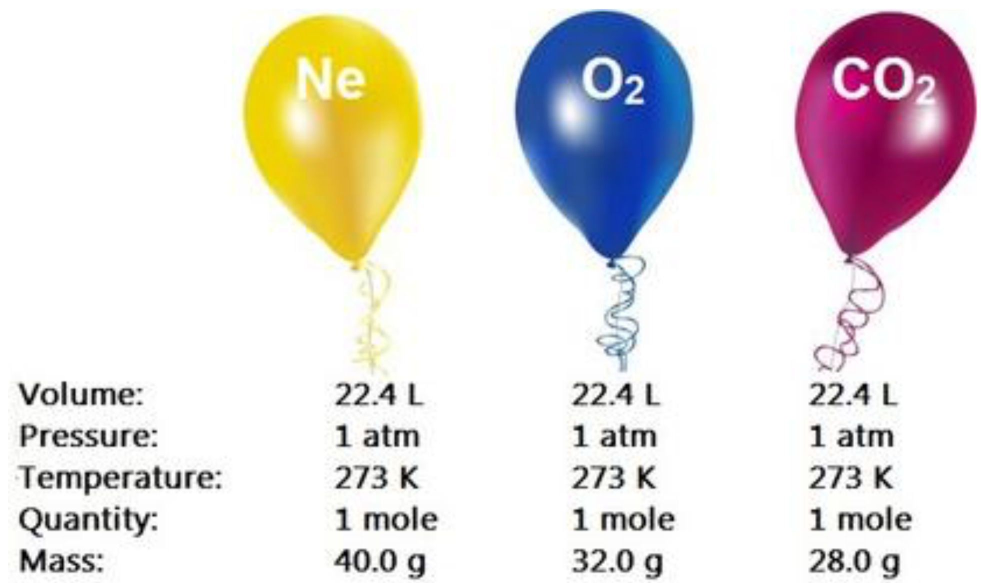


Definition of a mole (M)

Mole = $6.02214179 \times 10^{23}$,

One mole of an ideal gas at Standard Temperature and Pressure (STP) occupies 22.4 liters.

Standard temperature: 0°C = 273.15 K
Standard pressure = 1 atm = 1013 hPa



Definition of a mole (M)

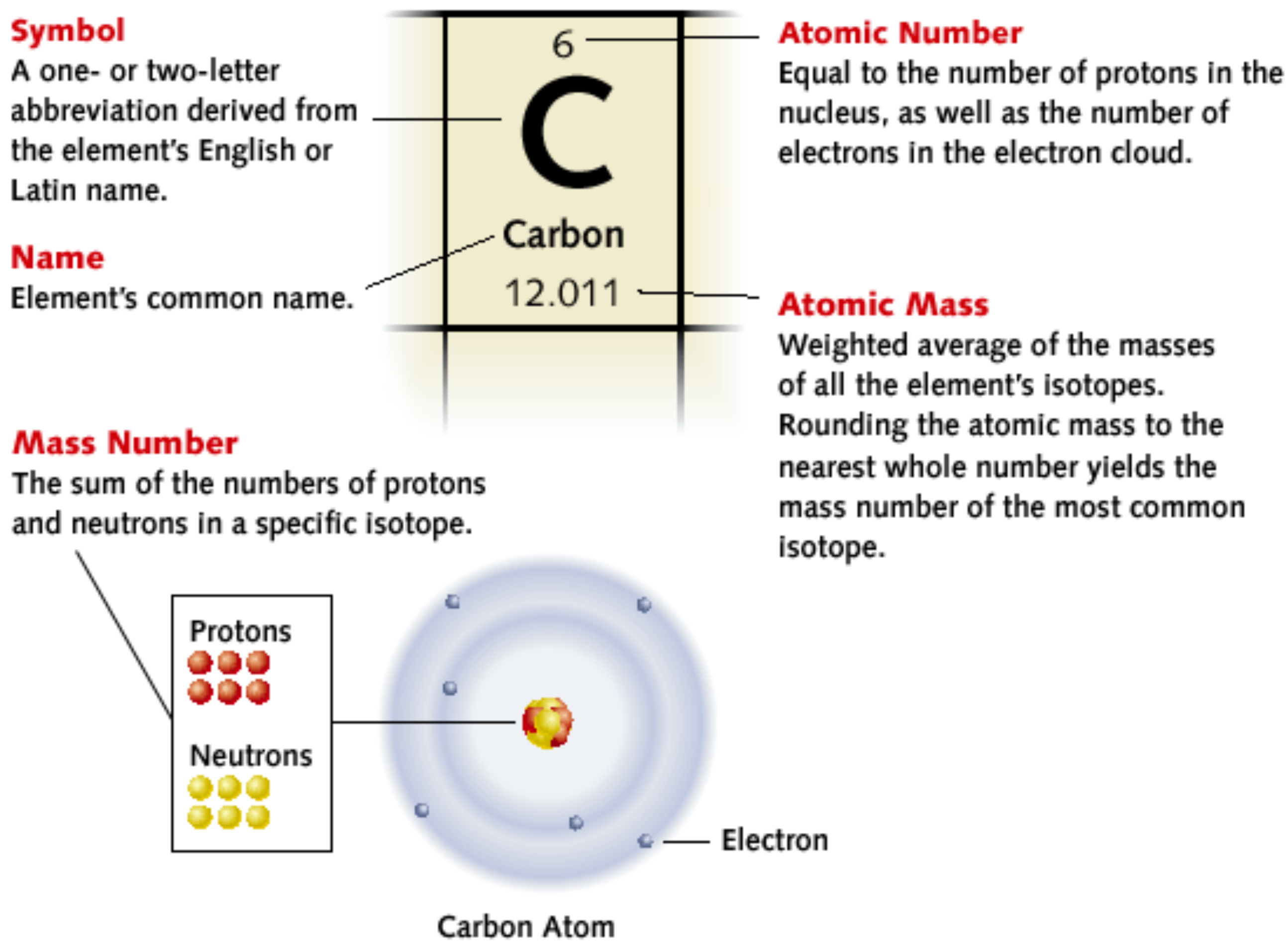
Mole = $6.02214179 \times 10^{23}$,

Number of atoms found in 12 grams of Carbon-12.

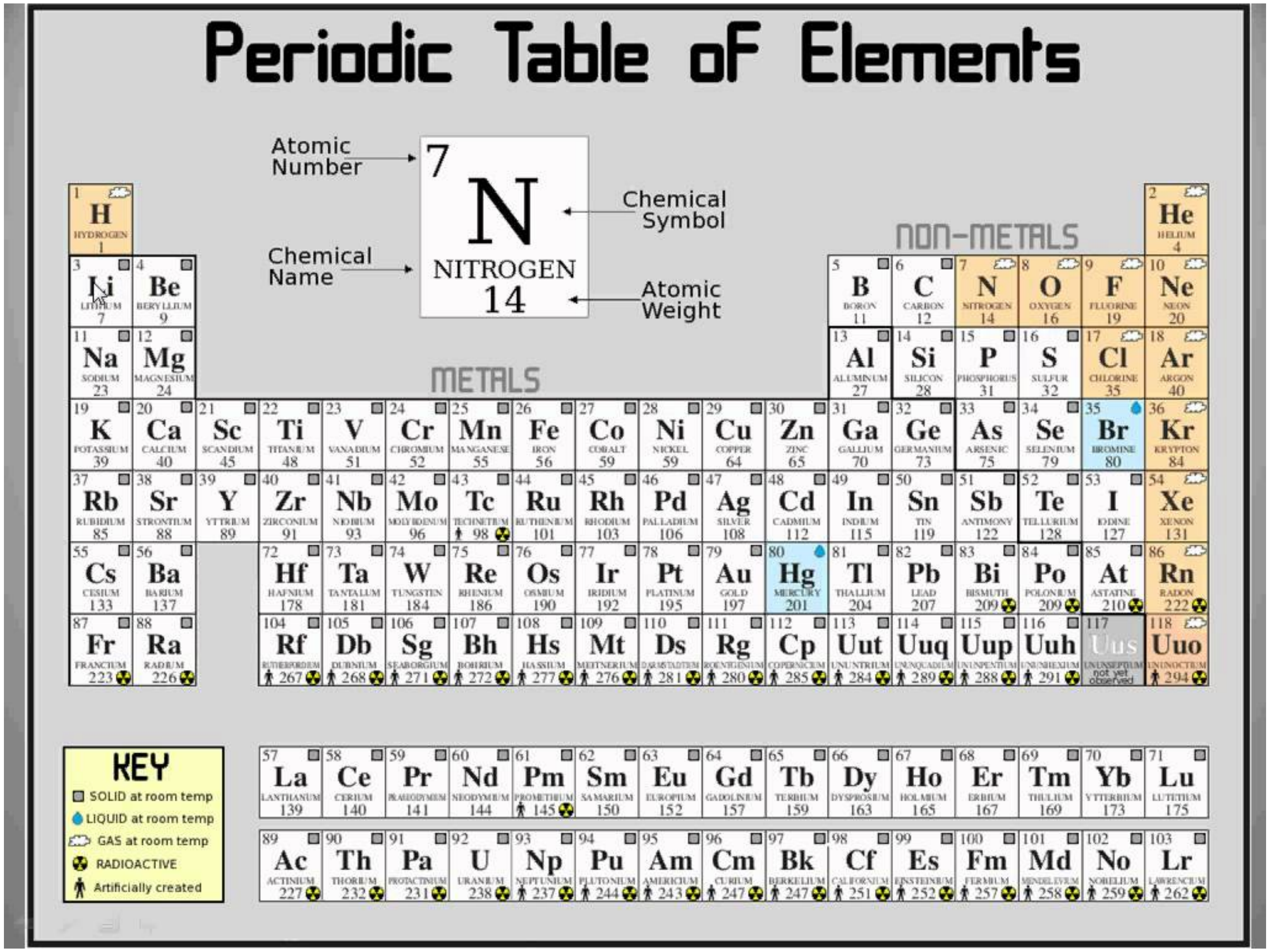
Carbon-12 was chosen arbitrarily to serve as the reference standard of the mole unit for the International System of Units (SI).

The number of units in a mole also bears the name Avogadro’s number, or Avogadro’s constant.

Molecular Weight = mass of one mole of substance



Exploring Earth funded by NSF


Periodic Table of Elements
Atomic Number
Chemical Symbol
Chemical Name
Atomic Weight
7 N NITROGEN 14
NON-METALS
METALS
1 H HYDROGEN 1
2 He HELIUM 4
3 Li LITHIUM 7
4 Be BERYLLIUM 9
5 B BORON 11
6 C CARBON 12
7 N NITROGEN 14
8 O OXYGEN 16
9 F FLUORINE 19
10 Ne NEON 20
11 Na SODIUM 23
12 Mg MAGNESIUM 24
13 Al ALUMINUM 27
14 Si SILICON 28
15 P PHOSPHORUS 31
16 S SULFUR 32
17 Cl CHLORINE 35
18 Ar ARGON 40
19 K POTASSIUM 39
20 Ca CALCIUM 40
21 Sc SCANDIUM 45
22 Ti TITANIUM 48
23 V VANADIUM 51
24 Cr CHROMIUM 52
25 Mn MANGANESE 55
26 Fe IRON 56
27 Co COBALT 59
28 Ni NICKEL 59
29 Cu COPPER 64
30 Zn ZINC 65
31 Ga GALLIUM 70
32 Ge GERMANIUM 73
33 As ARSENIC 75
34 Se SELENIUM 79
35 Br BROMINE 80
36 Kr KRYPTON 84
37 Rb RUBIDIUM 85
38 Sr STRONTIUM 88
39 Y YTTRIUM 89
40 Zr ZIRCONIUM 91
41 Nb NIOBIUM 93
42 Mo MOLYBDENUM 96
43 Tc TECHNETIUM 98
44 Ru RUTHENIUM 101
45 Rh RHODIUM 103
46 Pd PALLADIUM 106
47 Ag SILVER 108
48 Cd CADMIUM 112
49 In INDIUM 115
50 Sn TIN 119
51 Sb ANTIMONY 122
52 Te TELLURIUM 128
53 I IODINE 127
54 Xe XENON 131
55 Cs CESIUM 133
56 Ba BARIUM 137
72 Hf HAFNIUM 178
73 Ta TANTALUM 181
74 W TUNGSTEN 184
75 Re RHENIUM 186
76 Os OSMIUM 190
77 Ir IRIDIUM 192
78 Pt PLATINUM 195
79 Au GOLD 197
80 Hg MERCURY 201
81 Tl THALLIUM 204
82 Pb LEAD 207
83 Bi BISMUTH 209
84 Po POLONIUM 209
85 At ASTATINE 210
86 Rn RADON 222
87 Fr FRANCIUM 223
88 Ra RADIUM 226
104 Rf 267
105 Db DUBNIUM 268
106 Sg SEABORGIUM 271
107 Bh BOHRIUM 272
108 Hs HASSIUM 277
109 Mt 276
110 Ds 281
111 Rg 280
112 Cp 285
113 Uut UNUNTRIUM 284
114 Uuq 289
115 Uup 288
116 Uuh 291
117 Uus not yet observed
118 Uuo 294
57 La LANTHANUM 139
58 Ce CERIUM 140
59 Pr 141
60 Nd 144
61 Pm PROMETHIUM 145
62 Sm SAMARIUM 150
63 Eu EUROPIUM 152
64 Gd 157
65 Tb TERBIUM 159
66 Dy 163
67 Ho HOLMIUM 165
68 Er ERBIUM 167
69 Tm THULIUM 169
70 Yb YTTERBIUM 173
71 Lu LUTETIUM 175
89 Ac ACTINIUM 227
90 Th THORIUM 232
91 Pa 231
92 U URANIUM 238
93 Np NEPTUNIUM 237
94 Pu PLUTONIUM 244
95 Am AMERICIUM 243
96 Cm CURIUM 247
97 Bk BERKELIUM 247
98 Cf 251
99 Es 252
100 Fm FERMIUM 257
101 Md 258
102 No NOBELIUM 259
103 Lr 262
KEY
SOLID at room temp
LIQUID at room temp
GAS at room temp
RADIOACTIVE
Artificially created

Element	Atomic Weight (g/mol)
Ba	137.327
C	12.0107
Ca	40.078
Cr	51.9961
H	1.00794
Mg	24.3050
N	14.0067
Na	22.989770
O	15.9994
P	30.973761

Use the data from the periodic table to answer the following questions.

Calculate the molecular weight of $Ca_3\,(PO_4)_2$ [Calcium Phosphate]

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Use the data from the periodic table to answer the following questions.

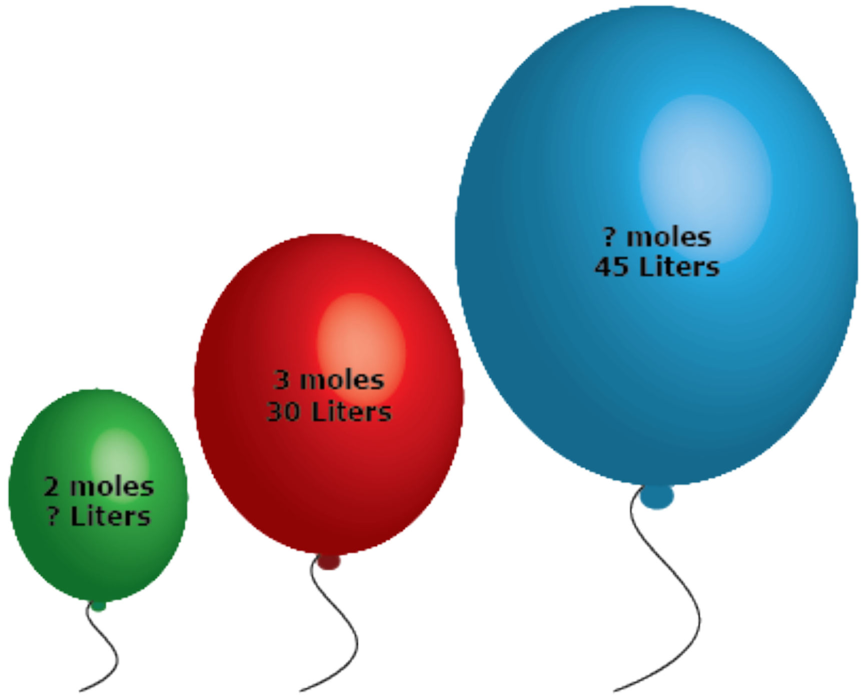
Calculate the molecular weight of $Ca_3 (PO_4)_2$ [Calcium Phosphate]

Answer:

The molecular weight =

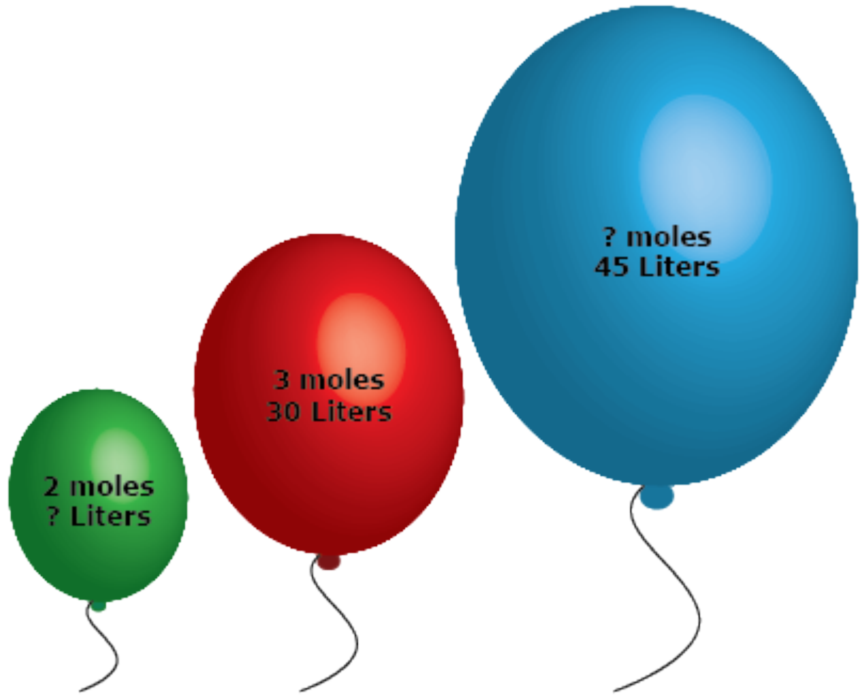
3(40.078) + 2(30.973761) + 8(15.9994) =

120.23 + 61.947522 + 127.9952 = **310.18 g/mol.**



Question: Three balloons are filled with different amounts of an ideal gas. One balloon is filled with 3 moles of the ideal gas, filling the balloon to 30 L.

a) One balloon contains 2 moles of gas. What is the volume of the balloon?
b) One balloon encloses a volume of 45 L. How many moles of gas are in the balloon?



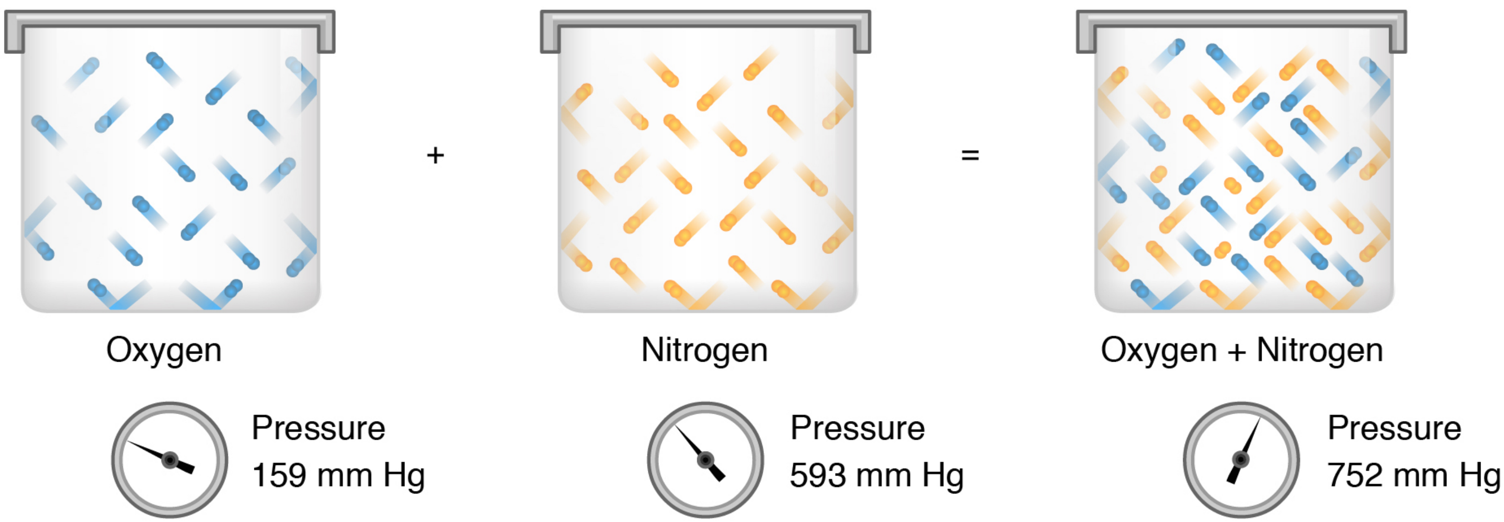
Question: Three balloons are filled with different amounts of an ideal gas. One balloon is filled with 3 moles of the ideal gas, filling the balloon to 30 L.

a) One balloon contains 2 moles of gas. What is the volume of the balloon? **20 L**
b) One balloon encloses a volume of 45 L. How many moles of gas are in the balloon? **4.5 moles**

Dalton's Law of Partial Pressures

Total pressure exerted by a mixture of gases is equal to the sum of the partial pressure that would be exerted by each constituent alone if it filled the entire volume at the temperature of the mixture.

$$p = \sum_{i=1}^{k} p_i$$



Gas Constants

Average Translational Kinetic Energy of a molecule in an ideal gas is:

$KE_{avg} = (3/2)\ k_BT$ PER MOLECULE

$Ke_{avg} = (3/2)\ RT$ PER MOLE

$$R = N_Ak_B$$

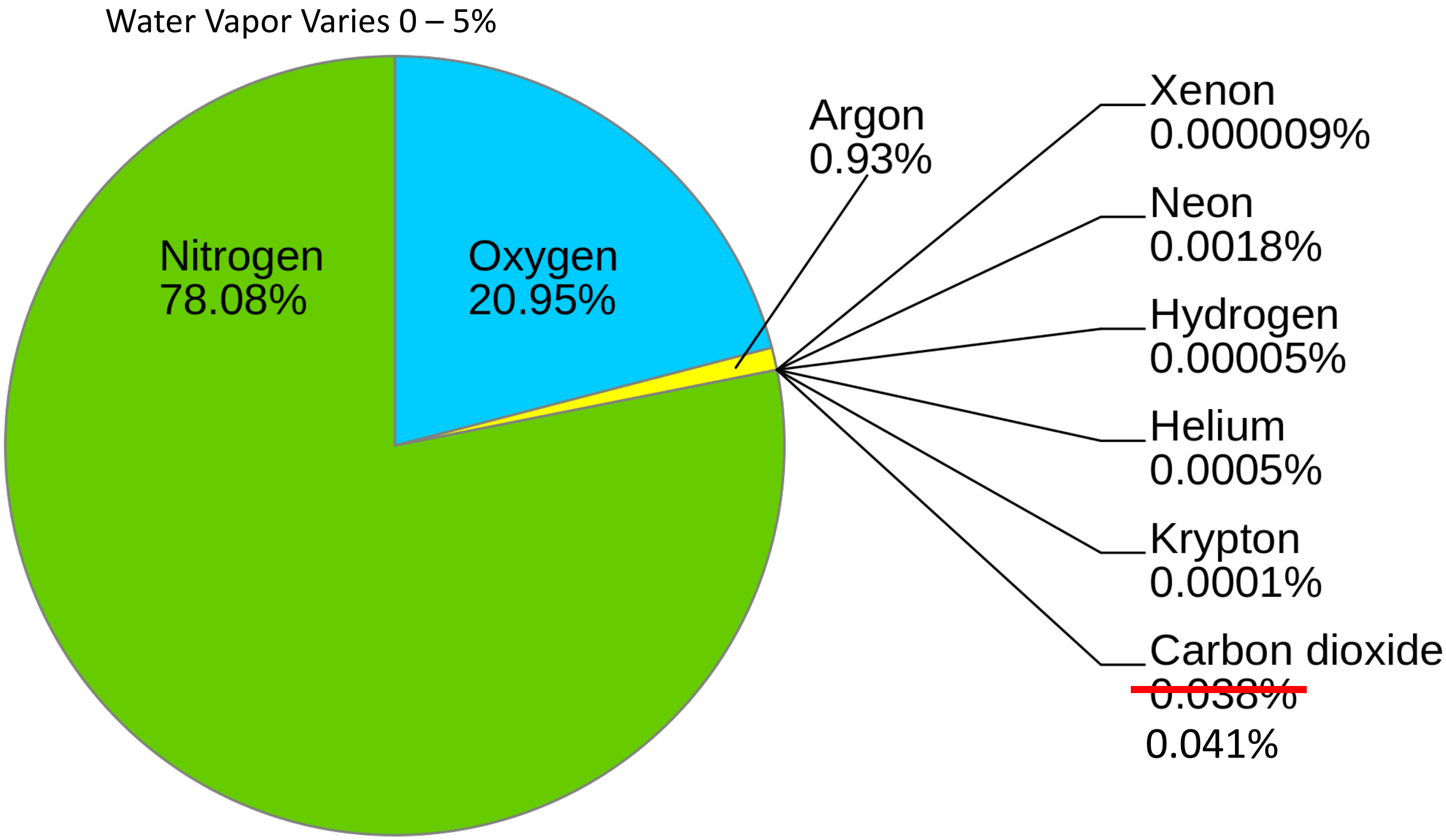
Where
N_A = Avogadro Constant
k_B = Boltzmann constant

k_B = Boltzmann constant = 1.38066×10^{-23} J/K

Universal Gas Constant
R = 8.3145 J/mol K

In our textbook, the universal gas constant is written as R^*

Composition of a DRY Atmosphere: Troposphere



Gas Constants for Dry Air

Universal Gas Constant
R = 8.3145 J/mol K

In our textbook, the universal gas constant is written as R^*

Mass of dry air:

$m_d \approx$ Nitrogen (N_2) + Oxygen (O_2) + Argon (Ar) + Carbon Dioxide (CO_2)

$m_d \approx (0.7808 \, * \, 28) + (.2095 \, * \, 32) + (.00093 \, * \, 40) + (0.000405 \, * \, 44) = 28.96$

$$R_d = \frac{R^*}{m_d} = 8314.472 \, (\frac{J}{kmol} * K)/28.9655(\text{kg/kmol}) = 287.047 \text{ J/(kg*K)}$$

<u>NOW can be used with Intensive Variables</u>

Ideal Gas Law

$PV = nR^{*}T$

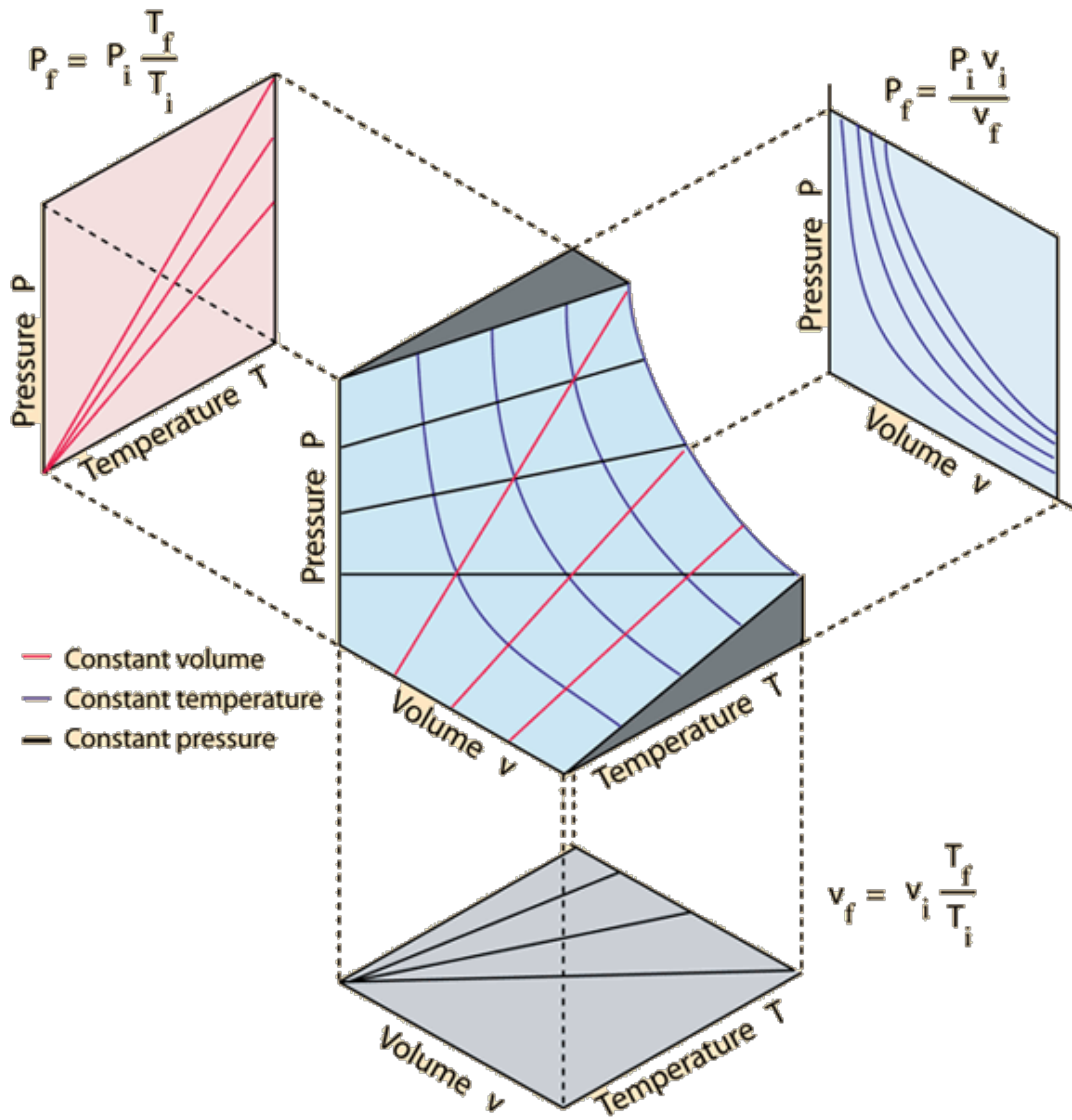
where:

P is the pressure of the gas,
V is the volume of the gas,
n is the amount of substance of gas (also known as number of moles),
R is the ideal, or universal, gas constant, equal to the product of the Boltzmann constant and the Avogadro constant,
T is the absolute temperature of the gas.

Ideal Gas Law – Meteorologist

$$p = \rho R d T$$

R = Gas constant for dry air
p = pressure
ρ = density



Boyle's Law

Charles' Law

CLASS Presentation

- Form group of 2 students
- Present ~20 minute presentation (~ 10 minute each person)
- Focus on topics found within “In Practice” section of your textbook.
- Your research should go beyond the textbook.
- Be Creative!   Props

Examples of material to present

- Hygrometer
- Wind Chill
- Radiosonde
- Skew-T diagram
- Psychrometer
- Heat Index
- Aneroid Barometer
- Altimeter
- Subsidence inversion

Suggestions for effective display

- **Keep it simple!** Fancy designs or color shifts make important material hard to read. Less is more.
- Use at least a 24-point font so everyone in the room can read your material.
- Try to limit the material to eight lines per slide, and keep the number of words to a minimum. **Keep it simple**.
- Limit the tables to four rows/columns for readability. Sacrifice content for legibility. Large tables can be displayed more effectively as a graph.
- Use easily read fonts.
- Don't fill up the slide - the peripheral material may not make it onto the display screen.
- **Identify the journal when you give references.**
- Finally, always preview your presentation. You will look foolish if symbols that looked OK in a WORD document didn't translate into anything readable in POWERPOINT.

Start with: PV = nRT

Show derivation to: $p = \rho RT$