Properties of Gases

- PRESSURE: Units and Measurement
- Avogadro’s Law
- Charles’ Law
- Boyle’s Law
- Ideal Gas Law
- Dalton’s Law
PRESSURE
Units and Measurement

Pressure = Force/Area

**SI Units**
- Force = mass x acceleration
- Force = kg-m/s² = Newton
- Pressure = Newton/m² = Pascal

**Customary Units**
- Pressure = atmospheres, torr, mmHg

Relate SI to customary
- 1.013 X 10⁵ Pascal = 1 Atm = 760 torr
PRESSURE
Mercury Barometer

760 mm Hg for standard atmosphere
Avogadro’s Hypothesis

Equal volumes of gases contain the same number of molecules at constant T,P

22.414 L of any gas contains $6.022 \times 10^{23}$ atoms (or molecules) at STP
Charles’ Law

Definition of Temperature

\[ V = V_0 - V_0 \alpha t \]
Boyle’s Law
Ideal Gas Law

\[ PV = nRT \]

- **Charles**: \( V \) vs. \( T \) at constant \( n, P \)
- **Boyle**: \( P \) vs. \( V \) at constant \( n, T \)
- **Avogadro**: effect of changing \( n \)
- **Compressibility Factor**: \( \frac{PV}{RT} = 1 \)
- **Molecular weight from density**:
  
  \[ n = \text{moles} = \frac{g}{M}; \; d = \text{density} = \frac{g}{V} \]
  
  \[ PV = \left(\frac{g}{M}\right)RT \]
  
  \[ M = \left(\frac{g}{V}\right)(RT/P) \]
Dalton’s Law
Partial Pressures

\[ P_T = p_A + p_B + p_C \]

\[ = X_A P_T + X_B P_T + X_C P_T \]

where \( X_A + X_B + X_C = 1 \)
Air Bag Chemistry
Air Bag Chemistry

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.
Automotive Airbags -
What Now?

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Air Bag Chemistry

On ignition: \(2 \text{NaN}_3 \Rightarrow 2\text{Na} + 3\text{N}_2\)

Secondary reactions:
\[
10 \text{Na} + 2 \text{KNO}_3 \Rightarrow \text{K}_2\text{O} + 5 \text{Na}_2\text{O} + \text{N}_2 \\
\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{SiO}_2 \Rightarrow \text{K}_2\text{Na}_2\text{SiO}_4
\]
Kinetic-Molecular Theory for Gaseous Behavior

Relates the easily observable P-V-T properties of gases to less easily recognizable properties such as numbers of particles and their speeds.

Kinetic-molecular theory is based on a simple theoretical model of a gas as a collection of colliding particles.
Kinetic-Molecular Theory for Gaseous Behavior

Key Assumptions and Features:

• Particles are widely separated and negligibly small
  \[ d(\text{N}_2, g) = 0.00125 \text{ g/L (273°C)} \]
  \[ d(\text{N}_2, \text{liq}) = 0.808 \text{ g/mL (-195.8°C)} \]

• No attractive or repulsive forces. Therefore, gases behave independently and expand spontaneously.

• Constant motion and elastic collisions account for diffusion and the time-independence of pressure.

• Mechanical work measured as K.E. = \( \frac{1}{2}mv^2 \)

• Increasing T increases KE and increases P
Kinetic-Molecular Theory for Gaseous Behavior

- $P_T$ is a function of two factors:
  - # of impacts/unit area/unit time
  - change in momentum ($\Delta mv$) on impact
Kinetic-Molecular Theory for Gaseous Behavior

- # of Impacts
  - Directly proportional to N, the number of molecules contained
  - Inversely proportional to V, the volume of the container
  - Directly proportional to v, the velocity of the molecules

NET RESULT: # of impacts $\propto (N)(1/V)(v)$
Kinetic-Molecular Theory for Gaseous Behavior

- Change in momentum $\Delta mv$
  - Directly proportional to $m$ with heavier molecules causing a greater effect
  - Directly proportional to $v$ with faster molecules causing a greater effect

NET RESULT: $\Delta mv \propto (m)(v)$
Kinetic-Molecular Theory for Gaseous Behavior

**# of Impacts**

NET RESULT: \# of impacts \( \alpha (N)(1/V)(v) \)

**Change in momentum \( \Delta mv \)**

NET RESULT: \( \Delta mv \ \alpha (m)(v) \)

\[
P_T \alpha [\# \text{of impacts}][\text{Change in momentum}]
\]

\[
P_T \alpha [(N)(1/V)(v)][(m)(v)] = (N/V)(mv^2)
\]

\[
P_T \alpha (n/V)(T)
\]

\[
P_T = nRT/V
\]
Kinetic-Molecular Theory for Gaseous Behavior

- Principal Issues (drawbacks)
  - Negligible Volume and No interaction
    - Hold only at low P, high T; for dilute gases
  - Elastic Collisions
    - Only in Newtonian mechanics is the reverse of an event as likely as the event itself.
    - In the real world you cannot “unscramble” eggs because of entropy effects resulting from large ensembles of molecules
Root Mean Square Speed $<v>_{\text{rms}}$

- Is the speed of an oxygen molecule....
  faster than a speeding car?
  faster than a speeding plane?
  faster than a speeding bullet?

DO THE CALCULATION
FIND THE SURPRISING RESULT
Distribution of Speeds
Effect of Changing $T$ on the Distribution of Speeds
Measuring Molecular Speeds
Gaseous Diffusion/Effusion

Diffusion of Ammonia and HCl

Effusion enrichment of UF₆
$\text{UF}_6$
Boyle's Law
Homework
Homework Problem

COMBUSTION is central to the consumption of most power.

Significant Exceptions:
   Nuclear
   Geothermal
   Solar.

Natural gas can be burned for home heating or electric lighting and the chemistry looks like this:

\[ \text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(g) \]

Direct conversion (home heating)

Indirect conversion, via steam to turbine electricity (lighting)
About 5-6 ounces of methane are required to provide enough heat for a comfortable bath for an average-sized adult in a tub appropriate in size for containing 20 gallons of water.

Do a Best Estimate/Good guess/Back-of-the-envelope approximate calculation to validate that assumption.
(1) To take 20 gallons of water from say 15°C → 45°C

20 gal = 80 qt = 80 L = 80 kg = 80,000 g

sp. ht of water = 4.184 J/g/deg

heat = mass × sp. ht × ΔT

= (80,000 g)(4.184 J \( \frac{g}{g \ deg} \))(45 - 15)deg

= 10,041,600 J
(2) Methane required to do that job:

\[
(10,041,600 \text{ J})(\frac{1 \text{ mol}}{890 \text{ kJ}})(\frac{1 \text{ kJ}}{1000 \text{ J}}) = 11.28 \text{ mol}
\]

\[
(11.3 \text{ mol})(\frac{16 \text{ g}}{1 \text{ mol}})(\frac{1 \text{ lb}}{454 \text{ g}})(\frac{16 \text{ oz}}{1 \text{ lb}}) = 6 \text{ oz}
\]

........ or about 0.4 lb
or if propane (C\textsubscript{3}H\textsubscript{8}) is combusted, then about 2.5 ounces of fuel..... which means the heat of combustion of propane must differ from methane by a factor of ..... 

\[
\frac{6}{2.5} \times 890 \text{ kJ/mol} = 2250 \text{ kJ/mol}.
\]
Hydrogen energy system would release little carbon dioxide to the atmosphere

Centralized H₂ production plants

Atmosphere
CO₂ (from small fraction of carbon in feedstocks)

Carbon-rich feedstocks
(Natural gas, petroleum, coke, municipal solid waste, biomass, coal)

CO₂ (accounting for most carbon in feedstocks)
Underground storage

Compressed H₂
Compressed H₂ transmission and distribution network

Residential buildings
Fuel cells
Electricity
Heat

Commercial buildings
Fuel cells
Electricity
Heat

Vehicle refueling stations

Compressed H₂
Fuel-cell vehicles

Source: Robert H. Williams
Chrysler Smart Car
Hybrid Vehicle
Chlorine Destroys Ozone

*but is not consumed in the process*
Paul Crutzen

Holland (The Netherlands)

Max-Planck-Institute for Chemistry
Mainz, Germany

1933 -
Mario Molina

USA (Mexico)

Department of Earth, Atmospheric and Planetary Sciences and Department of Chemistry, MIT

Cambridge, MA, USA

1943 -
F. Sherwood Rowland

USA

Department of Chemistry, University of California
Irvine, CA, USA

1927 -
Nearly a third of U.S. bridges rated deficient

But the money to fix them just isn't there, state officials say.

WASHINGTON -- Almost a third of the nation's bridges are dilapidated or too narrow or too weak to carry the traffic crossing them, federal records show.

By JONATHAN D. SALANT
The Associated Press