Microscopic view of matter

Select LEARNING OBJECTIVES:

- Compare macroscopic and microscopic models of matter.
- Introduce state variables.
- Convert between molar mass and number of moles as well as number of particles.

TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7th) :: 13-1, 13-2
- Knight (College Physics : A strategic approach 3rd) :: 12.1, 12.2
- BoxSand :: Video

WARM UP: *"If in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms - little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another."*

- Richard Feynman

What makes a solid a solid, a liquid a liquid, and a gas a gas? On the surface, this question may not seem too challenging, however there are levels of complexity that can be brought to the table which require years of study in the material sciences. From our everyday perspective, a macroscopic view suggests: solids seem to maintain their shape, liquids tend to conforms to the container which holds them but won't escape an open container, and a gas also conforms to closed containers but will escape when the container is open. The goal of this lecture is to take a closer look at these 3 types of matter in what is known as the microscopic view.

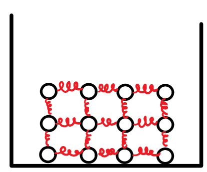
Solid

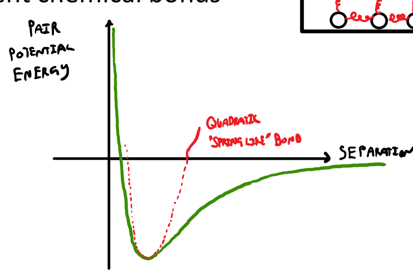
Macroscopic view

Objects that maintain their size and shape and usually require a large force to deform it.

Microscopic view

- Crystalline lattice; regularly repeated sequences of atomic structure (range of symmetry varies).
- Motion of atoms is a vibration about a fixed point.
- Strong spring like bonds which represent chemical bonds between atoms.



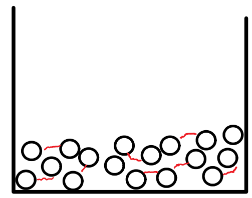


Liquid

Macroscopic view

Something that doesn't maintain a fixed shape, rather it conforms to an open container holding it. Not easily compressed.

Microscopic view



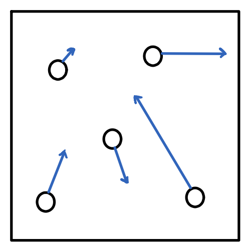
- Molecules vibrate and "roll" around each other.
- Weak bonding.
- Motion of molecules is more random than solid atoms but less random than the motion of gas molecules.
- Little free space between molecules.

Gas

Macroscopic view

Something that has neither fixed size or shape and expands evenly to fill a container. Easily compressible.

Microscopic view



- Random direction and random speeds of molecules (random motion).
- Lots of free space between each particle/molecule.
- Very weak or no long range interactions between particles.

State variables

Now that we have a more detailed picture of what a solid, liquid, and gas is let's begin to study how we quantify some of their properties. Thermodynamics uses ***state variables*** which are properties that describe the equilibrium state of matter. Some example include: pressure (P), volume (V), temperature (T), number of particles (N), thermal energy (E^{th}), entropy (S), chemical potential (μ), magnetization (M), and many more. When studying matter, the trick is to choose the state variables that are relevant to the physics of the experiment. For example, in this class we will not work with magnetic materials and we will consider simplified systems where particles do not exit or enter our systems, thus we will not be using the state variables "magnetization" and "chemical potential". The state variables that we will work quantitatively with in this class are: number of particles, pressure, volume, and temperature.

Number of particles (N)

We will work with 2 ways to quantify the quantity of particles/molecules. The first way is simply by the number of particles for which we use the symbol "N". If there are 10 particles in a box, we would say N = 10. The second way to convey the quantity of matter is by the **mole.** A mole is defined as 6.022×10^{23} basic particles and we use the symbol "n". A basic particle doesn't have to be a single entity, for example oxygen gas is diatomic (there are 2 oxygen atoms that make up a single gas particle). Thus 1 mole of oxygen gas in a box really has $2 \times (6.022 \times 10^{23})$ atoms in the box. In summary:

$$N \equiv \text{NUMBER OF PARTICLES}$$

$$N_A \equiv 6.022 \times 10^{23} \text{ PARTICLES}$$

$$n \equiv \text{MOLES} \equiv \frac{N}{N_A}$$

Often times we are given information about mass rather than number of particles or moles. This requires us to expand our vocabulary into the realm of chemistry.

Atomic mass number (A) - The number of protons and neutrons in an element. Found on the superscript of any atomic symbol.

EXAMPLE: $^{12}C \longrightarrow A = 12$

Atomic mass unit (u) - Measure of mass defined to be exactly equal to one twelfth the mass of a ^{12}C atom. Mass of ^{12}C = 12 u.

$$1\,u \approx 1.66 \times 10^{-27}\,kg$$

Atomic mass (m_{atom}) - The mass of an atom. For our purposes, the atomic mass is basically equal to the atomic mass number A.

EXAMPLE: $m_{He} \approx 4u$

Molecular mass ($m_{molecule}$) - The mass of a molecule which is the sum of the atomic masses of the atoms that form the molecule.

EXAMPLE: $m_{O_2} = m_O + m_O = 2m_O = 2(16u) = 32u$

Molar mass ($M_{mol,atom/molecule}$) - The mass in grams for 1 mole of substance. For this class we can get away with using the atomic or molecular mass as the molar mass.

EXAMPLE: $M_{mol,O_2} = 32 \frac{g}{mol}$

Finally, we can define our conversion factor to get to moles.

$$n = \frac{M_{atom/molecule}}{M_{mol,atom/molecule}}$$

MASS IS IN GRAMS!!

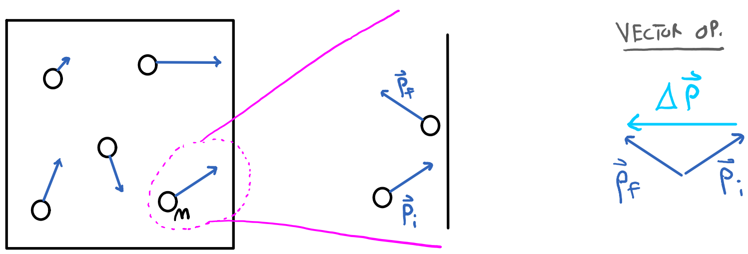
PRACTICE: How many moles are in 10 g of helium gas? How many atoms? Helium gas is monatomic.

Pressure (P)

We will limit our studies to the idea of gas pressure since we will be working with gasses throughout thermodynamics.

Microscopic view

Pressure is a collective force per area from impulses due to the collisions of the particles with the container walls.



MOMENTUM – IMPULSE

$$\vec{J} = \Delta\vec{p} = \Sigma\vec{F}_{wm}\Delta t$$

$$\therefore \Sigma\vec{F}_{mw} \neq \vec{0}$$

FORCE FROM PARTICLE ON WALL

As seen above, we tracked one particle as is collided with the wall and changed its momentum. This one particle thus imparted an impulse on the wall. If we add up all of other impulses that the other particles impart on the wall then we could get a net force on the wall.

Macroscopic view

As we have just seen, collisions from particles on a wall exert a force on the wall. Unfortunately there are a lot of particles, on the order of 10^{23} particles. It is basically impossible to track the motion of all of these particles so our macroscopic definition is the net effect of the microscopic collisions. This definition is a ratio of force to area.

$$P = \frac{F_{\perp}}{A}$$

where the numerator is the perpendicular component of force with respect to the surface an object is touching. The denominator is the cross sectional area of two objects in contact.

In SI, the units are defined as a pascal (Pa).

$$\text{PASCAL} \equiv \text{Pa} \xrightarrow{\text{UNITS}} \frac{\text{N}}{\text{m}^2}$$

Our everyday experience with pressure is usually in units of pounds per square inch (PSI), however we have been and will continue to work with SI units in this course so be careful to convert to pascals and use pascals in any equation you use other SI units with.

PRACTICE: Why does pressure go up when you decrease the volume of a balloon slowly such that temperature is roughly constant?

Volume (V)

Volume is a measure of physical length cubed.

There are various types of systems we might encounter in thermodynamics that best fit under this volume section.

Open system - System can exchange mass and energy (heat) with surroundings. Example, container with a hole in it such that gas can escape.

Closed system - System cannot exchange mass with surrounding, but can exchange energy (heat) with surroundings. Example, a finite volume system, basically a closed container where gas cannot escape.

Isolated system - System cannot exchange mass and or energy (heat) with surroundings. Example, closed system wrapped in an insulation which prevents heat exchange.

Temperature (T)

We will develop a much more in depth understanding of temperature in the kinetic theory of gasses lecture. For now just focus on the macroscopic way we report temperature via a temperature scale. The SI unit of temperature is kelvin (K). Other common scales use degree Celsius (°C) or degree Fahrenheit (°F). Another warning here, kelvin is not our typical everyday temperature lingo, but kelvin is the SI unit of temperature; remember to use SI units for all variables in a single equation. Since we typically report our temperatures in either °C or °F we need to know how to convert back and forth.

$\underbrace{°F}_{\text{KNOWN}} \longrightarrow \underbrace{°C}_{\text{UNKNOWN}}$

$$T(°C) = \frac{5}{9}\left(T(°F) - 32°\right)$$

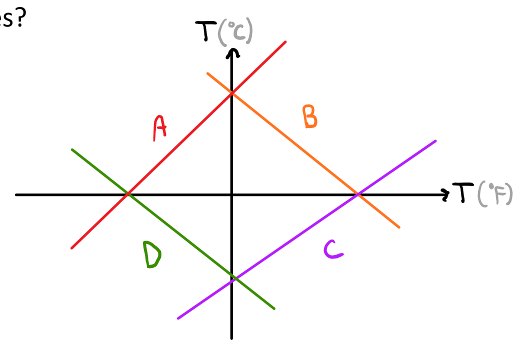
$°C \longrightarrow °F$

$$T(°F) = \frac{9}{5}T(°C) + 32°$$

$°C \longrightarrow K$

$$T(K) = T(°C) + 273$$

PRACTICE: Which of the following curves on the graph below could represent the relationship between Celsius and Fahrenheit temperatures?



Questions for discussion:

(1) Is energy conserved in an open system? Closed system? Isolated system? Provide an example for each case where energy is conserved.