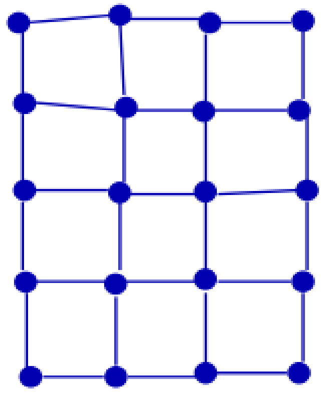
FLUID PROPERTIES

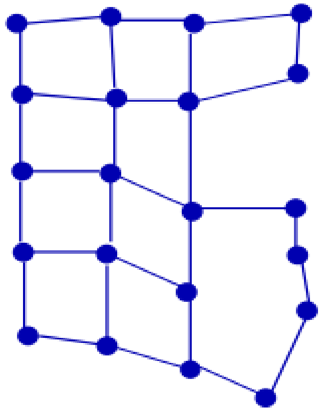
What is a fluid?

Liquid

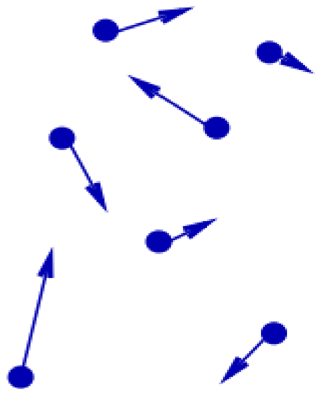
Gas



In a **solid** the atoms are tightly bound by intermolecular forces.



In a liquid the intermolecular forces keep the atoms close together. But, lack of long range order with disruption of molecular forces makes it possible for groups of atoms to slide past each other.



In a gas the molecules can move independently of each other.

- **Ability to Flow:** Fluids can move and flow when subjected to an external force. This means they can change shape and adapt to the container they are in.
- **No Fixed Shape:** Unlike solids, fluids do not have a fixed shape of their own. They assume the shape of the container they are placed in.
- **Constant Volume (Incompressibility):** Liquids are considered nearly incompressible, meaning their volume remains relatively constant even when subjected to pressure changes. Gases, on the other hand, can be compressed and have variable volume.

Fluid mechanics is the branch of physics and engineering that deals with the study of fluids and their behavior, encompassing properties such as pressure, velocity, viscosity, and density. Understanding fluid dynamics is essential in various fields, including engineering (e.g., fluid dynamics in pipelines, aerodynamics), environmental science, and medicine (e.g., blood flow in the circulatory system).

Classification of Fluids

Fluids can be classified based on various characteristics and properties. Here's a brief overview of these classifications:

- Perfect Fluids:

  Perfect fluids are hypothetical and idealized fluids with no viscosity or internal friction. They do not dissipate kinetic energy as heat.

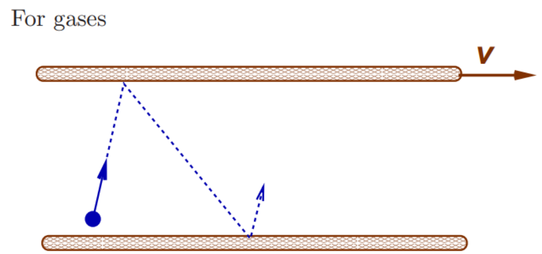
  In reality, no fluid is perfectly "perfect," but this concept is often used in theoretical models, such as in certain aspects of general relativity.

- Viscous or Newtonian Fluids:
  - Fluids can be classified based on their response to **shear stress**. Viscous fluids exhibit a linear relationship between shear stress and shear rate, following **Newton's law of viscosity**.
  - Examples of Newtonian fluids include water and air at typical conditions.

- Compressible or Incompressible Fluids:
  - Fluids can be categorized based on their compressibility, which is a measure of how their density changes in response to pressure changes.
  - Incompressible fluids have nearly constant density and are not significantly affected by changes in pressure (e.g., liquids like water). Compressible fluids can change in density with changes in pressure (e.g., gases like air).

Classification of Fluids

- Conductivity:
  - Fluids can be classified based on their electrical conductivity. Some fluids are conductive and can carry an electrical current, while others are insulators and do not conduct electricity.
  - Examples of conductive fluids include electrolyte solutions, while insulating fluids include non-conductive oils.
- Density:
  - Fluids can be categorized based on their density, which is a measure of mass per unit volume. Different fluids have varying densities.
  - For example, mercury is a dense liquid with a high density, while helium is a less dense gas with a low density.

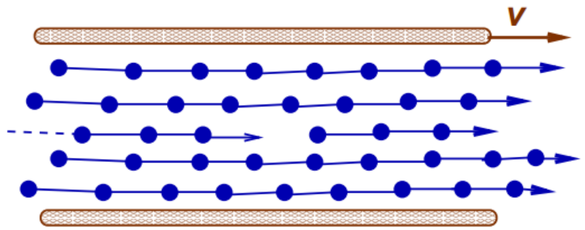


Viscosity in gases

Viscosity in gases, at the molecular level, can be understood through the kinetic theory of gases. Viscosity is a measure of a fluid's resistance to flow, and in gases, it is primarily influenced by the interactions and movements of individual gas molecules. Here's a molecular view of viscosity in gases:

- Molecules bounce between two surfaces.
- During molecule-surface collisions momentum is exchanged.
- Viscosity in gases arises from internal friction due to these molecular collisions. When neighboring gas molecules move at different velocities and collide, they exert forces on each other.
- Viscosity in gases is also temperature-dependent. As temperature increases, gas molecules move with higher average kinetic energy, leading to more frequent and energetic collisions. This typically decreases gas viscosity.
- Pressure can affect viscosity by influencing molecular spacing and collision frequency.

Viscosity in Liquids



Viscosity in liquids, at the molecular level, is influenced by the behavior of molecules within the liquid and their interactions with each other. Here's a molecular view of viscosity in liquids:

Top layer of liquid molecules drags next layer, but at slower speed. And so on, layer by layer.

When an external force is applied to a liquid (shear stress), it results in layers of liquid moving at different velocities. The velocity gradient between these layers creates shear strain and, consequently, a resisting force that contributes to viscosity.

Temperature plays a critical role in liquid viscosity. As temperature increases, the kinetic energy of the liquid molecules also increases, causing them to move more rapidly and collide more frequently. This generally reduces the viscosity of the liquid.

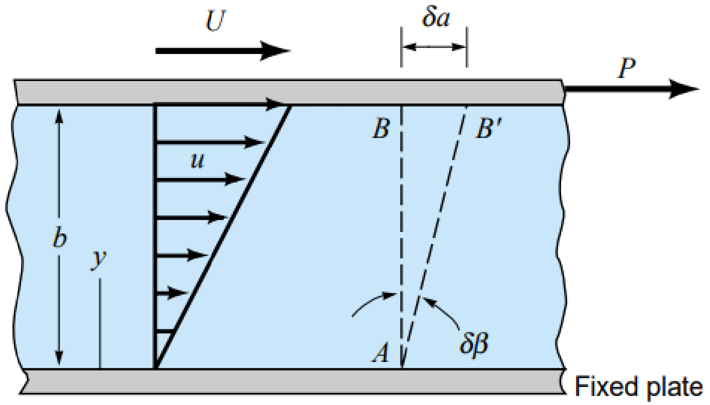
Shearing stress

When a force, P is applied to the plate on a liquid it moves with a constant speed, U . The liquid deforms continuously upon application of the shear stress.

The ability of one layer of fluid to move across another leads to a velocity profile u = u(y) . In the ideal case, u = Uy/b , the gradient is linear and the velocity gradient is

$$\frac{du}{dy} = \frac{U}{b}$$

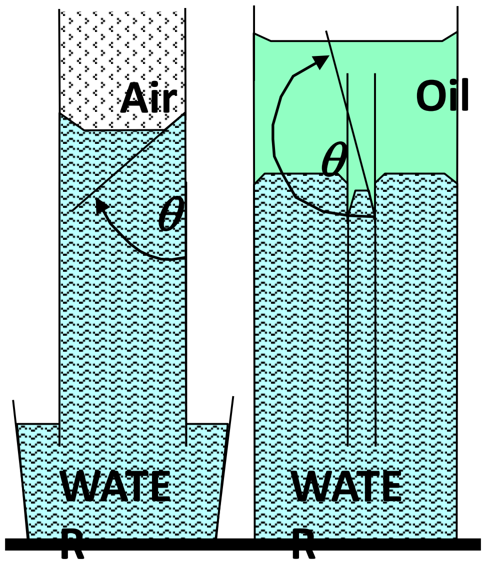
The no-slip condition states that the fluid at the solid boundaries does not move with respect to those boundaries

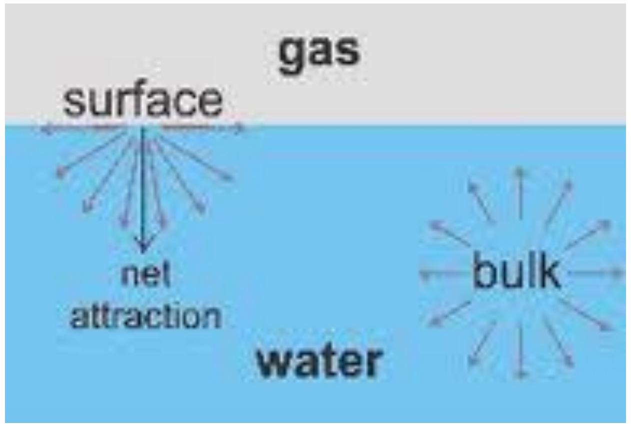


Surface Tension

Pressure difference between inside and outside.

Surface tension is responsible for capillary action, where liquids rise or fall in narrow tubes. In a small-diameter tube, the curvature of the liquid's surface increases, and this is associated with a decrease in potential energy. This is why the liquid rises in the tube.



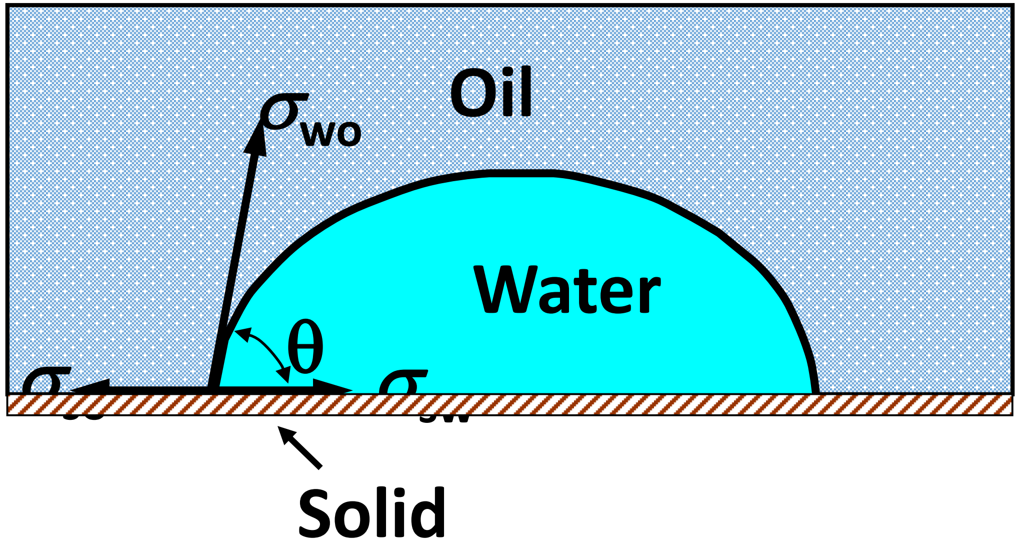


Surface Tension

Surface tension influences whether a liquid will "wet" or "bead up" on a solid surface. For example, water wets glass because it spreads out due to the adhesive forces between water molecules and the glass surface.

Adhesion tension is expressed as the difference between two solid-fluid interfacial tensions.

$$A_T = \sigma_{so} - \sigma_{sw} = \sigma_{wo} \cos \theta_{wo}$$



- A positive adhesion tension indicates that the denser phase (water) preferentially wets the solid surface (and *vice versa*).
- An adhesion tension of zero indicates that both phases have equal affinity for the solid surface

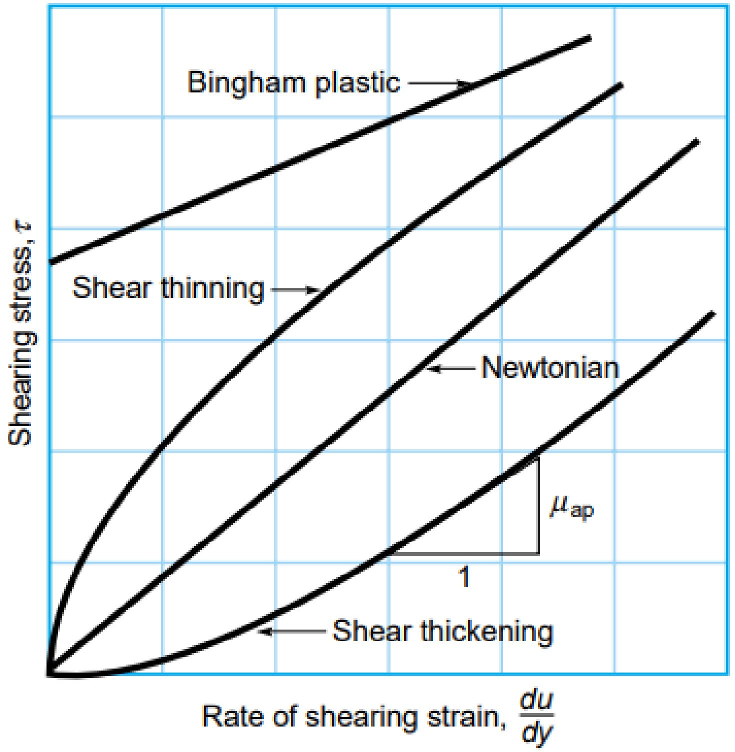
NON-NEWTONIAN FLUIDS

Non-Newtonian fluids are a category of fluids that do not follow Newton's law of viscosity, which states that the shear stress (force per unit area) in a fluid is directly proportional to the velocity gradient (rate of change of velocity) in the fluid.

$$\tau = \mu \dot{\gamma} = \mu \frac{du}{dy}$$

In other words, Newtonian fluids exhibit a constant viscosity, while **non-Newtonian fluids** have a variable viscosity that depends on the **shear rate**, **pressure, or other factors.**

Non-Newtonian fluids often display complex and nonlinear behavior.



There are several types of non-Newtonian fluids, including:

- **Shear-Thinning (Pseudoplastic) Fluids:**
  - Shear-thinning fluids become less viscous as the shear rate increases. In other words, they flow more easily when subjected to higher shear forces.
  - Common examples include ketchup, mayonnaise, and certain paints.
- **Shear-Thickening (Dilatant) Fluids:**
  - Shear-thickening fluids become more viscous as the shear rate increases. They resist flow under higher shear forces.
  - A well-known example is a mixture of cornstarch and water, often called "oobleck."
- **Bingham Plastic Fluids:**
  - Bingham plastic fluids behave like solids below a certain critical shear stress (yield stress) and flow like a viscous fluid above that stress level.
  - Drilling mud and toothpaste are examples of Bingham plastics.
- **Thixotropic Fluids:**
  - Thixotropic fluids become less viscous over time when subjected to continuous shear stress. When the shear stress is removed, they gradually return to their original, more viscous state.
  - Certain types of printer inks and clay suspensions exhibit thixotropic behavior.
- **Viscoelastic Fluids:**
  - Viscoelastic fluids exhibit both viscous (flow-like) and elastic (solid-like) properties. They can store and release energy, making their behavior more complex.
  - Polymer solutions, certain biological fluids, and some food products can be viscoelastic.