States of Matter

- Comes in three states – solid, liquid, gas
- So far we have only dealt with solid objects → blocks, sticks, balls, etc.
- The study of fluids is more complicated because fluids are complicated → they do not have any particular shape.

Atoms – the basic pieces of stuff

- All matter is composed of atoms (atomic hypothesis)
- If we imagine cutting an object into smaller and smaller pieces, we eventually get down to atoms
- Diameter about $10^{-10}$ m
- Acceptance of the atomic hypothesis evolved over about a century 1800-1900

Differences between solids, liquids and gases

- The main difference is the distance between the atoms, and
- The strength of the forces between the atoms

Greater separation between atoms

Solids liquids gases

Stronger forces between atoms

Mass Density ($\rho$, rho)

- The density of a substance is one way to characterize it
- The mass density is the amount of mass that you find in a unit volume of the stuff
- It is measured in kilograms per cubic meter ($\text{kg/m}^3$)

Typical Mass Densities

<table>
<thead>
<tr>
<th>Substance</th>
<th>Density [kg / m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>lead</td>
<td>11,000</td>
</tr>
<tr>
<td>water</td>
<td>1,000</td>
</tr>
<tr>
<td>air</td>
<td>1.25</td>
</tr>
<tr>
<td>aluminum</td>
<td>2,700</td>
</tr>
</tbody>
</table>
The air molecules (oxygen and nitrogen) in the box bounce around in all directions. When they hit the wall, they give it an impulse. The average effect of many, many molecules hitting the walls produces a force on the wall. The size of this force depends on the surface area of the wall — which depends on the container. It makes more sense to give the force on a unit surface --- pressure.

### Definition of pressure

- **Pressure** = force per unit area
  \[ P = \frac{\text{force}}{\text{area}} = \frac{F}{A} \]
- The unit of pressure is Newtons per m²
- One N/m² is called one Pascal (Pa)
- Another commonly used unit is pounds per square inch (psi). These are the units on a typical tire pressure gauge.

### The pressure in a gas

- The more molecules in the box (the number per unit volume) the larger the pressure.
- The pressure of a gas is also larger if the molecules have larger speeds.
- At a higher temperature the molecules have more energy and thus higher speeds.
- Thus the pressure depends on 2 factors:
  \[ \text{pressure} \propto \text{number density} \times \text{temperature} \]

### The Earth's atmosphere

- The atmosphere is a thin layer of air surrounding the earth.
- It extends upward to about 6 miles.
- It is held in place by gravity.
- The moon has no atmosphere because its gravity is not strong enough to hold on to one.

### Atmospheric pressure

- At the earth's surface the pressure due to the atmosphere is about 100,000 N/m² (1 atm).
- units: 1 N/m² = 1 Pa (Pascal).
- This means that over a 1 square meter of surface area the atmosphere exerts a force of 100,000 N/m² × 1 m² = 100,000 N.
- This amounts to about 22,500 lbs or 11 tons!
- This corresponds to a mass of 10,000 kg.
- **Why don't we notice this force?**

### The power of atmospheric pressure

- We typically do not 'feel' atmospheric pressure because it is the same on all sides (inside and outside) of objects.
- For example, the pressure is the same on both sides of a window.
- The pressure inside our bodies is the same as the pressure outside.
- You feel atmospheric pressure on your eardrums when you go up a mountain or an elevator to the top of a tall building.
**Magdeburg hemispheres**

When under vacuum there is about 1 ton of force holding the hemisphere’s together.

---

**Atmospheric pressure in action**

When the air is removed from inside the gas can, atmospheric pressure on the outside is unbalanced and crushes the can.

---

**Liquids**

- Liquids cannot support themselves
- One layer of a fluid cannot exert a shear force to prevent slipping

Liquids must have a container.

---

**Variation of pressure with depth in a liquid**

- Anybody who does scuba diving knows that the pressure increases as they dive to greater depths
- The increasing water pressure with depth limits how deep a submarine can go - crush depth
- About 2400 ft for the US Seawolf class subs

---

**The deeper you go the higher the pressure**

- Hypothetical volume, area $A$, height $h$
- $P = F/A \rightarrow F = PA$
- Water is at rest so net force $= 0$
- $P_{\text{top}}A + W = P_{\text{bottom}}A$
- $W = (P_{\text{bottom}} - P_{\text{top}})A$
- If water is at rest then $P_{\text{bottom}} > P_{\text{top}}$
- Pressure difference $P_{\text{bottom}} - P_{\text{top}} = \rho gh$
- At surface, $P_{\text{top}} = P_{\text{atm}}$
- So $P(h) = P_{\text{atm}} + \rho gh$

$p$ is the density of the water in kg per cubic meters.

---

**How much does P increase**

- At the surface of a body of water the pressure is 1 atm $= 100,000 \text{ Pa}$
- As we go down into the water, at what depth does the pressure double, from 1 atm to 2 atm or 200,000 Pa
- Want $\rho \cdot g \cdot h = 100,000 \text{ Pa}$
- $1000 \text{ kg/m}^3 \times 10 \times h = 100,000$
- So $h = 10$ meters or about 30 feet
Why does pressure increase with depth?

The column of liquid is held up by the pressure of the liquid in the tank. Near the surface this pressure is atmospheric pressure, so the atmosphere holds the liquid up.

Barometric pressure

Atmospheric pressure can support a column of water 10.3 m high, or a column of mercury (which is 13.6 times as dense as water) 30 inches high → the mercury barometer

Today's weather

Pascal's Vases

• The fluid levels are the same in all each tube irrespective of their shape