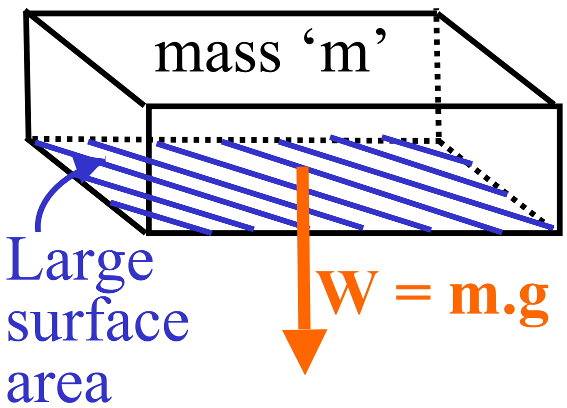
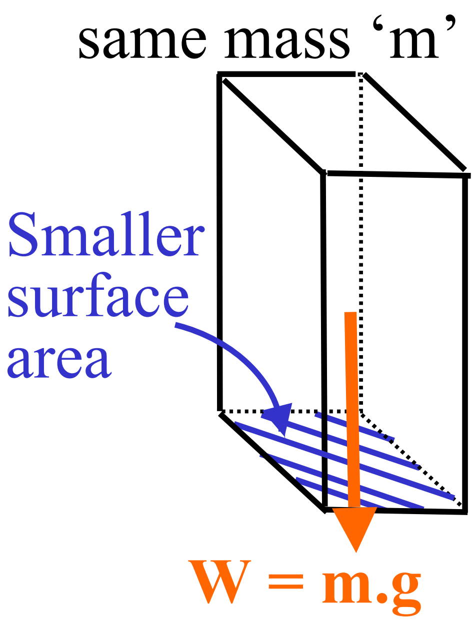
Fluid Behavior (Chapter 9)

- The Earth is **bathed** in **fluids**:
  - The **oceans** cover 70% of the surface area.
  - **Air surrounds the planet** in a deep (100 km thick) blanket protecting us from harmful space radiation.
- Both **air** and **water** are fluids…

  yet one is a **gas** and the other a **liquid**.
- A **fluid** has **no shape** and readily conforms ("**flows**") to the shape of a container.
- A solid object has its own **shape**.
- **Liquids** are usually much **denser** (i.e. heavier) than **gasses** of the same volume.
- **All fluids** are affected by **pressure** which plays a **key role** in describing their **behavior**.
- **Question:** What is pressure?

- When an object (mass ‘m’) rests on a surface it exerts a pressure on it due to its weight ($W = m.g$) and area of contact.
- Both objects exert the **same force** (due to their weight) on the surface but the **pressure** extended is **very different.**





❖ **Pressure is the ratio of the applied force to the area over which it acts:**

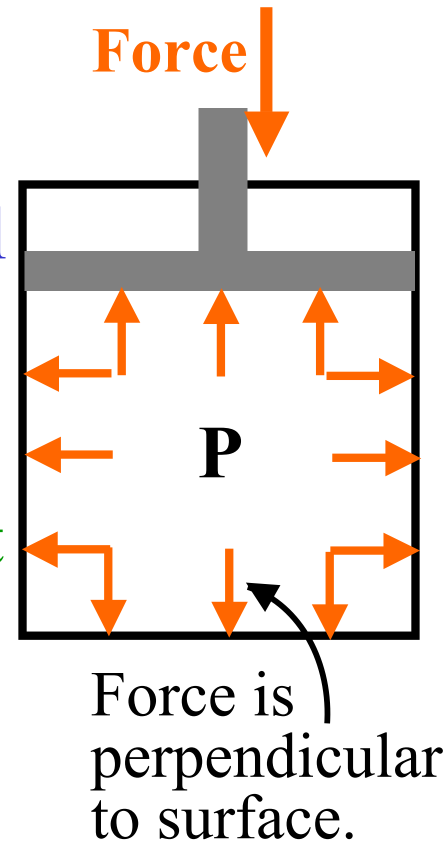
$$P = \frac{F}{A}$$

(Units: $N/m^2 = 1$ Pa) (After Pascal, 17th century)

- Force per unit area (i.e. pressure) is very important quantity. (Large pressure at point of a needle!)
- Pressure determines if a surface will yield or not (not just the force).
- Example: Use snow shoes with large area to walk on top of lightly packed snow.

Pascal's Principle

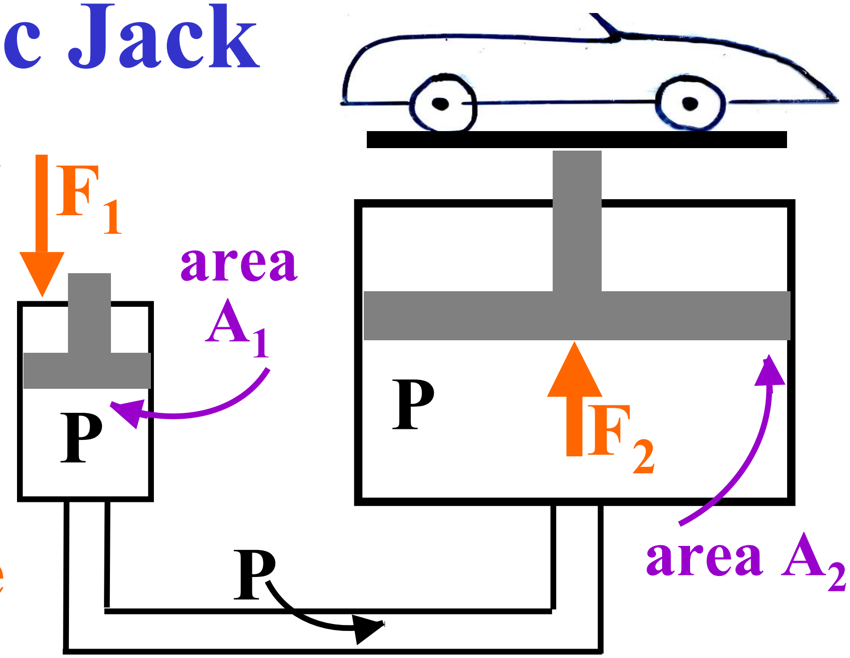
- What happens inside a fluid when pressure is exerted on it?
- Fluid experiences a compression force.
- Volume may reduce (especially in a gas).
- By Newton's 3rd law, the pressurized fluid will "react back" and exert an equal and opposite force on piston (like a compressed spring).
- However, it will push **outward uniformly** in **all directions** on **all surfaces** of container (not just the piston).



❖ **Any change in pressure of a fluid is transmitted uniformly in all directions throughout the fluid.**

- **Pascal's principle** is the basis for many **hydraulic devices** including the jack, car brakes, flight control lines, engines, landing gears…

Hydraulic Jack



- Depends on principle of uniform **transmission of pressure** throughout the fluid.

Method:

- Apply a force F_1 to piston of **small area** (A_1) to create a **large pressure** increase ($P = F_1/A_1$).
- Increased pressure P then acts uniformly on **large area piston** (A_2) to create an **amplified force** ($F_2 = P.A_2$).
- This force can then lift heavy objects (e.g. car).

As pressure is equal throughout system: $$\frac{F_2}{F_1} = \frac{A_2}{A_1}$$

- The mechanical advantage (ratio F_2/F_1) is given by ratio of piston areas.
- **Mechanical advantage** of hydraulic systems is **higher** than **simple** machines (as it depends on area).

- However, the **work done** by jack **cannot exceed** the work input to system (conservation of energy).
- As Work = Force x Distance, the smaller piston must **move a greater distance** (equal to the mechanical advantage of the system).

Example: Jack operation: $F_1 = 20$ N, $A_1 = 2$ cm^2, $A_2 = 1$ m^2

$$\text{Pressure in fluid} = \frac{F_1}{A_1} = \frac{20}{2 \times 10^{-4}} = \mathbf{10^5\ Pa}$$

$$\text{Force on lifting piston} = F_2 = P.A_2 = 10^5 \times 1 = \mathbf{10^5\ N}$$

($\equiv$ 10,000 kg)

$$\text{Mechanical advantage} = \frac{A_2}{A_1} = \frac{1}{2 \times 10^{-4}} = \mathbf{5 \times 10^3}$$

- This all looks great until you realize:

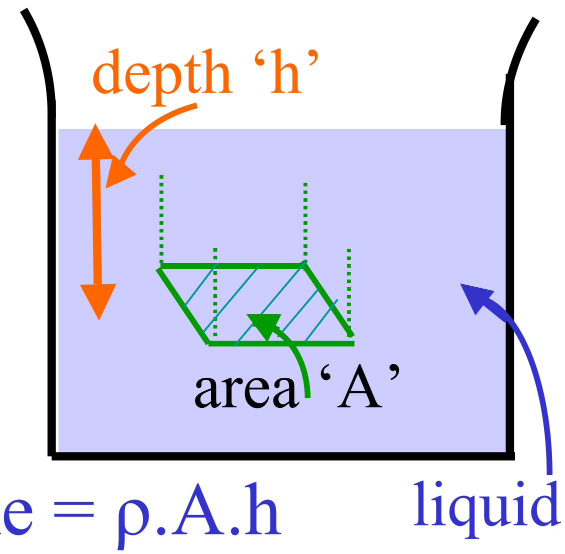
1. To raise jack 1 m, the small piston would need to move 5 km!
2. High pressures can cause system failure!

Result: Need more practical mechanical advantage e.g. 100:1, and high quality pressure systems.

Gravity and Hydrostatic Pressure

- In a fluid **at rest** pressure acts **perpendicular** to the **surfaces** of container /body.
- Pressure is a scalar quantity and has magnitude but **no** direction.
- Gravity is the cause of hydrostatic pressure resulting in an increase in pressure with depth.

Question: What is pressure on area 'A' at depth 'h' parallel to surface?



- Downward force on top of area must equal weight of column of liquid above it.

Volume column = A.h

Mass of column = density x volume = ρ.A.h

Thus weight force = m.g = ρ.A.h.g

$$\text{Pressure} = F/A = \rho.g.h$$

(**Note**: Density of fluid = Mass / Volume)

Example: What is pressure (due to water only) at 20 m below sea surface?

Density (ρ) of salt water = 1.025×10^3 kg/m^3

Depth h = 20 m.

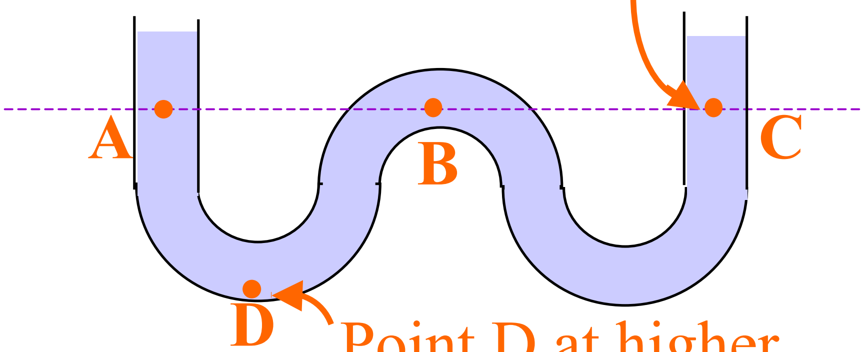
$\mathbf{P = \rho.g.h} = (1.025 \times 10^3) \times 9.81 \times 20$

$P = 2.0 \times 10^5$ Pa

(Note: **Pressure change** for each **1 m = 10^4 Pa**)

Pressure in a Container

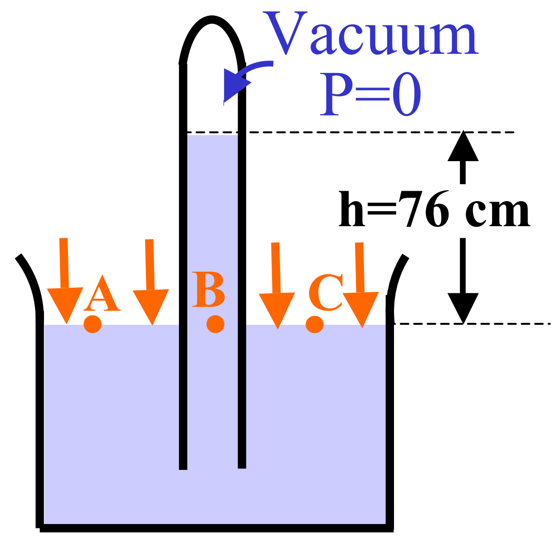
Pressure at every point at a given horizontal level in a single body of fluid at rest is the **same**.



Note: Shape of container is not important!

Atmospheric Pressure

- We live immersed at the bottom of a sea of air!
- Air (oxygen) is essential for life on Earth but pure air is colorless and odorless.
- We feel air by wind pressure or as a resistance to high speed motion (e.g. skydiver).
- Air is a **fluid** in which **pressure** is generated by **gravity** just as in liquids.
- 17th century student of Galileo (Torricelli) investigated atmospheric pressure and in doing so invented the barometer.
- Torricelli used mercury as it is much more dense (13.6 times) than water.
- Pressure at A,B,C is same.
- Pressure at A, C is due to weight in atmosphere.
- Pressure at B is due to weight of mercury (as pressure at top tube = 0).



Barometer

- Thus the height of mercury is a direct measure of atmospheric pressure.

  i.e. Atmospheric pressure = mercury pressure (at point B)

  $= \rho.g.h = (13.595 \times 10^3) \times (9.81) \times (0.76)$

  Thus: Atmospheric pressure $= 1.01 \times 10^5$ Pa (at sea level)

  or: atmospheric pressure = 14.7 lbs / $inch^2$

  or: = 76 cm (29.9" Hg)

- This pressure is due to a mass of **~ 5 x 10^{18} kg** of air pressing down on the Earth!
- Atmospheric pressure is very powerful…e.g. the force on a 1 m diameter sphere:

  $\text{Force} = (1.01 \times 10^5) \times \pi = 3.14 \times 10^5$ N

  (or force = 71,581 lbs!)

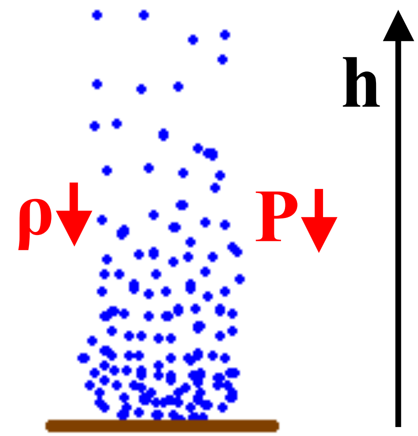
  area = $4 \pi r^2$ (= π)

  force = P x A

- This was demonstrated in a famous experiment where two teams of eight horses each tried in vain to pull an evacuated sphere apart. (von Guericke's experiment , 17th century)

Variations in Atmospheric Pressure

- Living in Utah we are well aware of fact that air pressure (and amount of oxygen) is **less** here than at sea level.
- Atmospheric pressure and density decrease rapidly (exponentially) with height.



- Most of the atmosphere resides within 10-15 km of surface (the troposphere). However neutral gas is detectable up to ~ 100 km altitude.
- Weather disturbances also affect atmospheric pressure. (Moist air is lighter and pressure reduces -a 'low'; dry air is heavier and pressure increases - a 'high').
- **Example pressures:**

Center of Sun	2×10^{16} Pa
Center of Earth	4×10^{11} Pa
Deepest ocean	1.1×10^{8} Pa
Spiked heel	$\sim 10^{7}$ Pa
Best lab vacuum	$\sim 10^{-12}$ Pa

Venus atmosphere 90×10^{5} Pa (very dense, mainly CO_2)

Mars atmosphere ~ 700 Pa (very thin, mainly CO_2)

Pressure Earth's atmos:	
Sea level	1×10^{5} Pa
1 km	90×10^{3} Pa
10 km	26×10^{3} Pa
100 km	~ 0.1 Pa