

# Fluid Statics

## States of Matter (hottest to coldest)

- **plasma** (most abundant but rarely encountered)
- **gas**
- **liquid**
- **solid**
- **Bose-Einstein condensate** (supercooled)

	fixed shape	fixed volume	
gas	✗	✗	fluid
liquid	✗	✓	fluid
solid	✓	✓	not fluid

## Density

- ratio of mass per volume

$$(\rho) = m / V \quad [\text{kg/m}^3]$$

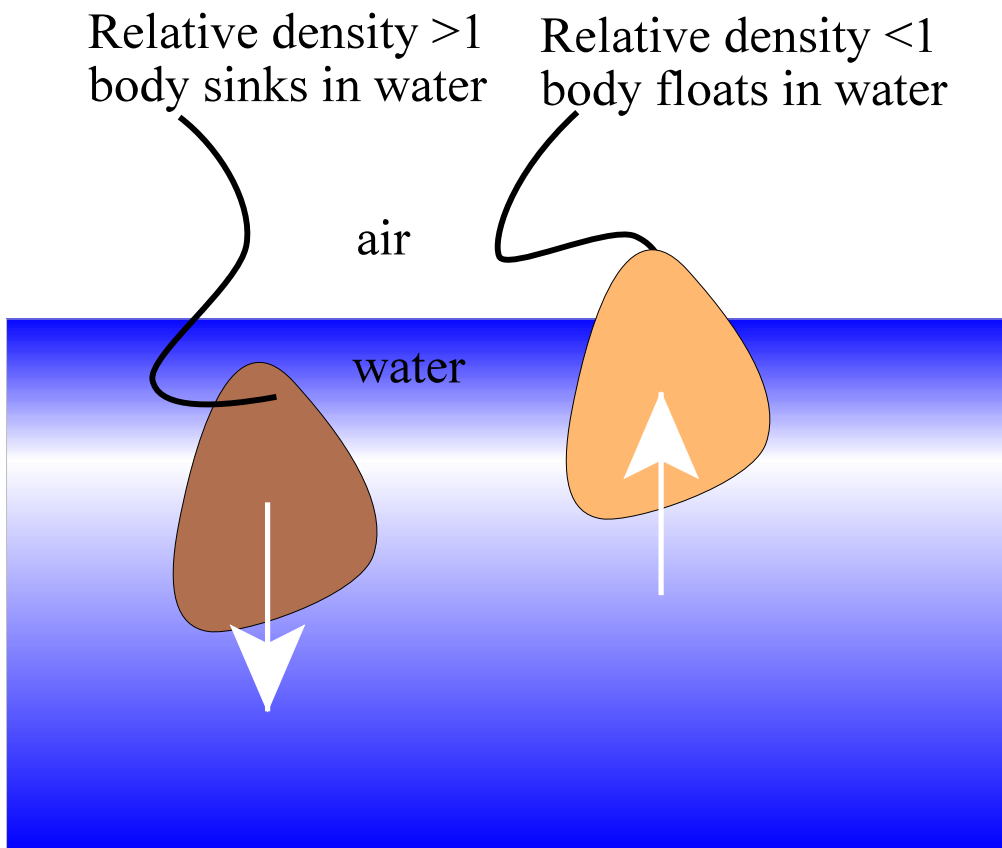
- water is  $1000 \text{ kg/m}^3$  at standard temperature ( $0^\circ\text{C}$ ) and pressure (1 atmosphere) (STP), air is  $1.29 \text{ kg/m}^3$
- muscle and bone are denser than water, fat is less dense
- usually bodies are not uniformly dense but are often assumed to be for simplicity

# Relative Density (formerly Specific Gravity)

## Relative Density

- density of one body relative to the density of water (or a fluid medium)
- denser bodies sink, less dense bodies float

$$\text{relative density} = \frac{\text{density of body}}{\text{density of H}_2\text{O}}$$



# Pressure

## Pressure

$$\text{pressure} = \text{force} / \text{area} = F / A \quad [\text{Pa or N/m}^2]$$

- units are **pascals** (Pa) or **kilopascals** (kPa)
- 1 atmosphere (average air pressure at sea level) is 101.325 kPa
- 1 pascal is the pressure created by a 1 newton force applied to 1 square metre
- since this is a relatively small pressure kilopascals are more commonly encountered
- 1 lb/in<sup>2</sup> or 1 psi = 6.89 kPa

### Example:

What is the pressure exerted on the calcaneus if its contact area with the ground is 5 cm<sup>2</sup> and the force at heel-strike during a triple jump landing is 4000 newtons?

$$P = F/A = 4000 / 5 = \mathbf{800 \text{ N/cm}^2}$$

To convert to pascals, multiply by 10 000 (i.e., 1 m<sup>2</sup> = 10 000 cm<sup>2</sup>) then to kilopascals or megapascals if needed.

$$P = 800 \times 10\,000 = 8000 \text{ kPa} = \mathbf{8.00 \text{ Mpa}}$$

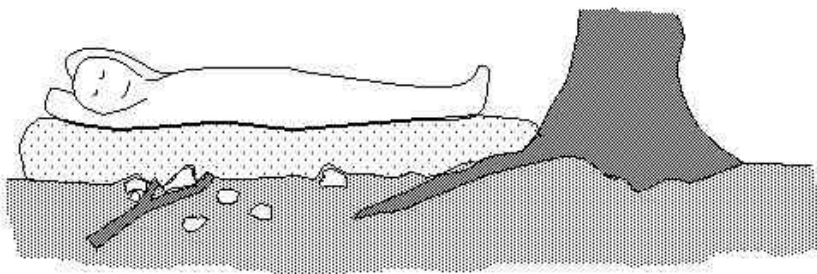
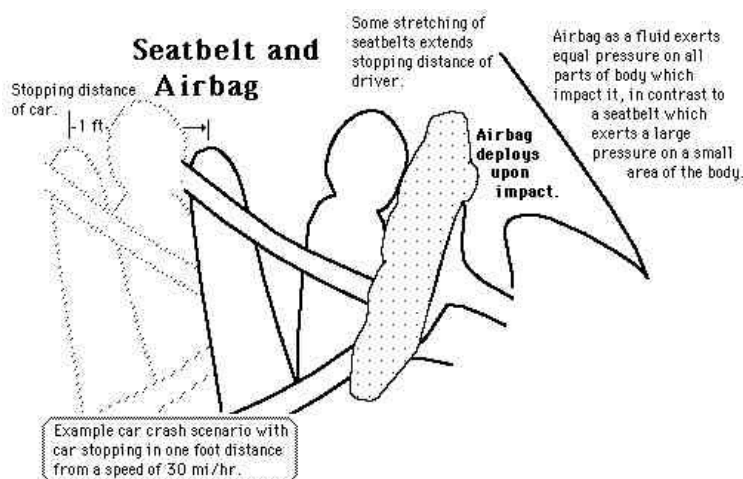
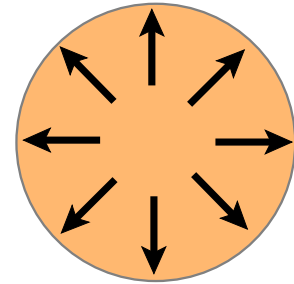
Car tire pressures are around 250 kPa, bicycle tires around 620 kPa. Ballet dancers *en pointe* have toe pressures up to 1000 kPa.



# Pascal's Law

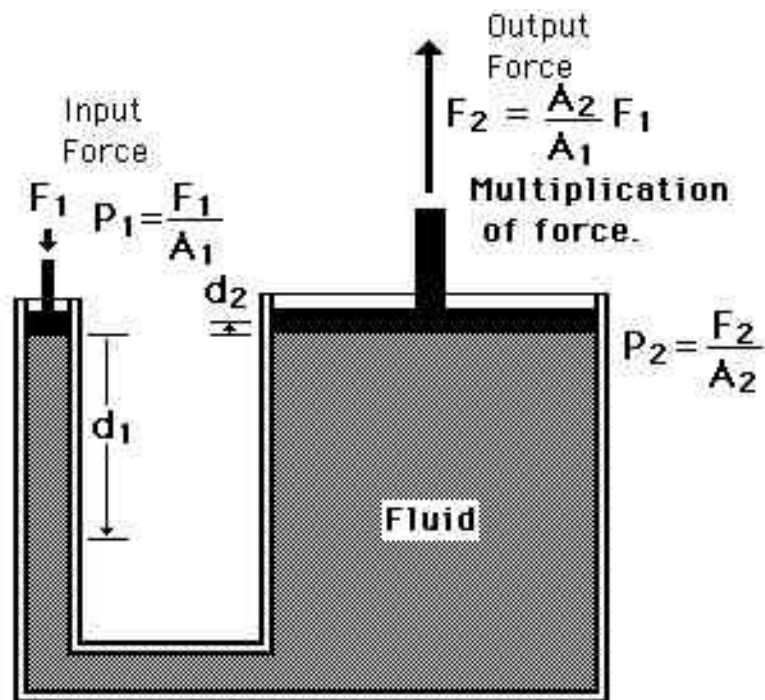
“A change in pressure applied to an enclosed fluid is transmitted undiminished to every part of the fluid and to the walls of the containing vessel.”

- relevant principle in **hydraulics** (study of the transfer of forces through fluids)
- principle behind how a **manometer** is able to measure blood pressure
- **Heimlich maneuver** is an application of Pascal's Law because airway must be closed before compression (i.e., “an enclosed vessel”)
- air bags, air mattresses and water beds spread loads to larger areas reducing point loading and peak forces



## Hydraulic Press or Hydraulic Lift

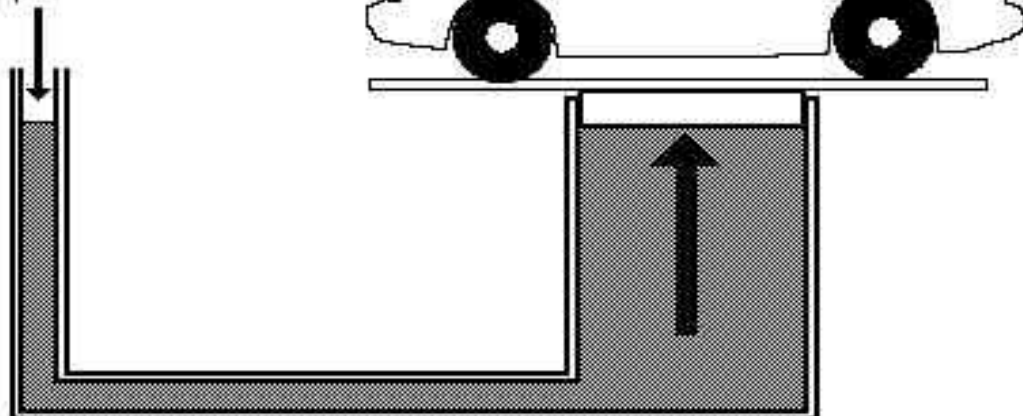
In two connected pistons, a force at the smaller diameter piston creates a greater force at the larger diameter piston (i.e., similar to mechanical advantage of a lever).



$$F_1 d_1 = F_2 d_2$$
$$d_1 = \frac{F_2}{F_1} d_2 = \frac{A_2}{A_1} d_2$$

You have to pay for the multiplied output force by exerting the smaller input force through a larger distance

Pressure on fluid in small cylinder, usually supplied by an air compressor.



# Archimedes's Principle

## Archimedes' Principle

“A body partially or wholly immersed in a fluid will be buoyed up by a force equal to the weight of the fluid displaced by the body.”

- reason why a heavier-than-water object floats
- e.g., ship's bottom has large area therefore will displace more water, ship will descend until the **buoyant force** is equal to the vessel's **weight**
- used to indirectly measure density

## Densitometry

Recall: **density** =  $m / V$

- mass is determined by weighing on a balance scale

How do you determine volume? Difference between weight in air and weight underwater equals weight of displaced water.

- weigh body underwater then:

$$\text{weight}_{\text{air}} - \text{weight}_{\text{underwater}} = \text{density}_{\text{water}} \times \text{volume} \times g$$

$$\text{density}_{\text{water}} = 1000 \text{ kg/m}^3 (= 1 \text{ g/cm}^3)$$

$$V = (\text{weight}_{\text{air}} - \text{weight}_{\text{water}}) / (\text{density}_{\text{water}} \times g) \quad [\text{m}^3]$$

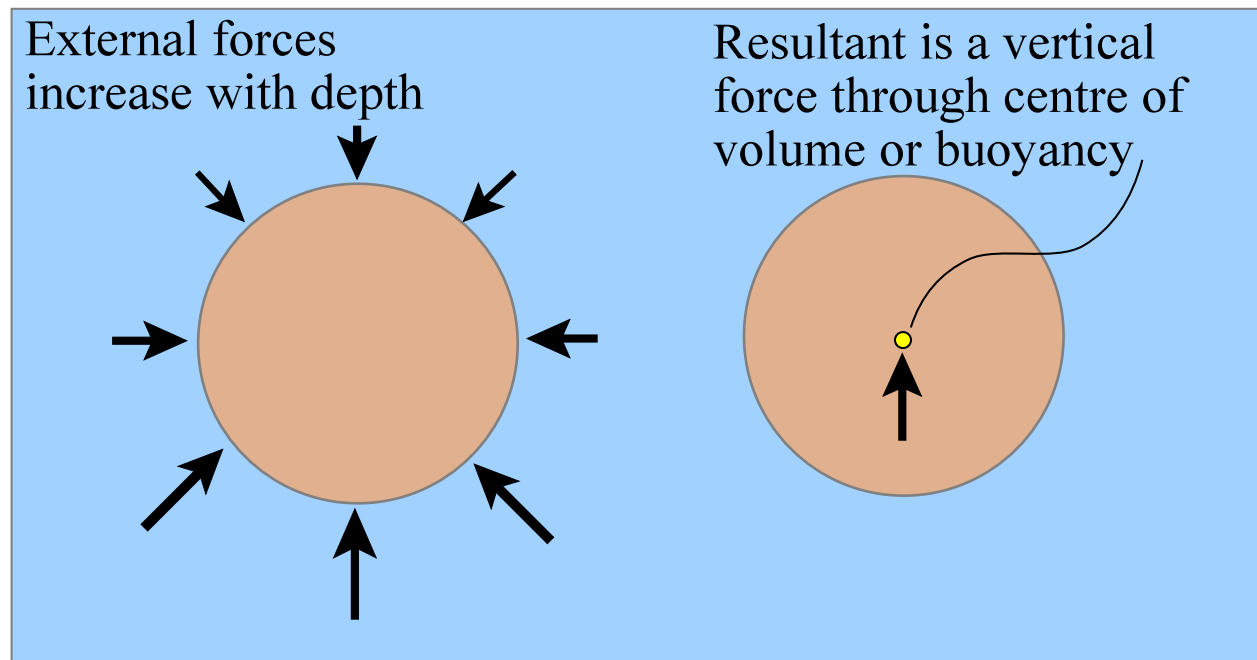
$$\text{density}_{\text{body}} = m / V \quad [\text{kg/m}^3]$$

## Buoyant Force

- force equal to the weight of the **fluid displaced** by a submerged body
- direction is vertical through **centre of volume** also called **centre of buoyancy**
- displaced fluid's weight is equal to fluid's volume times its density times  $g$  ( $9.81 \text{ m/s}^2$ )

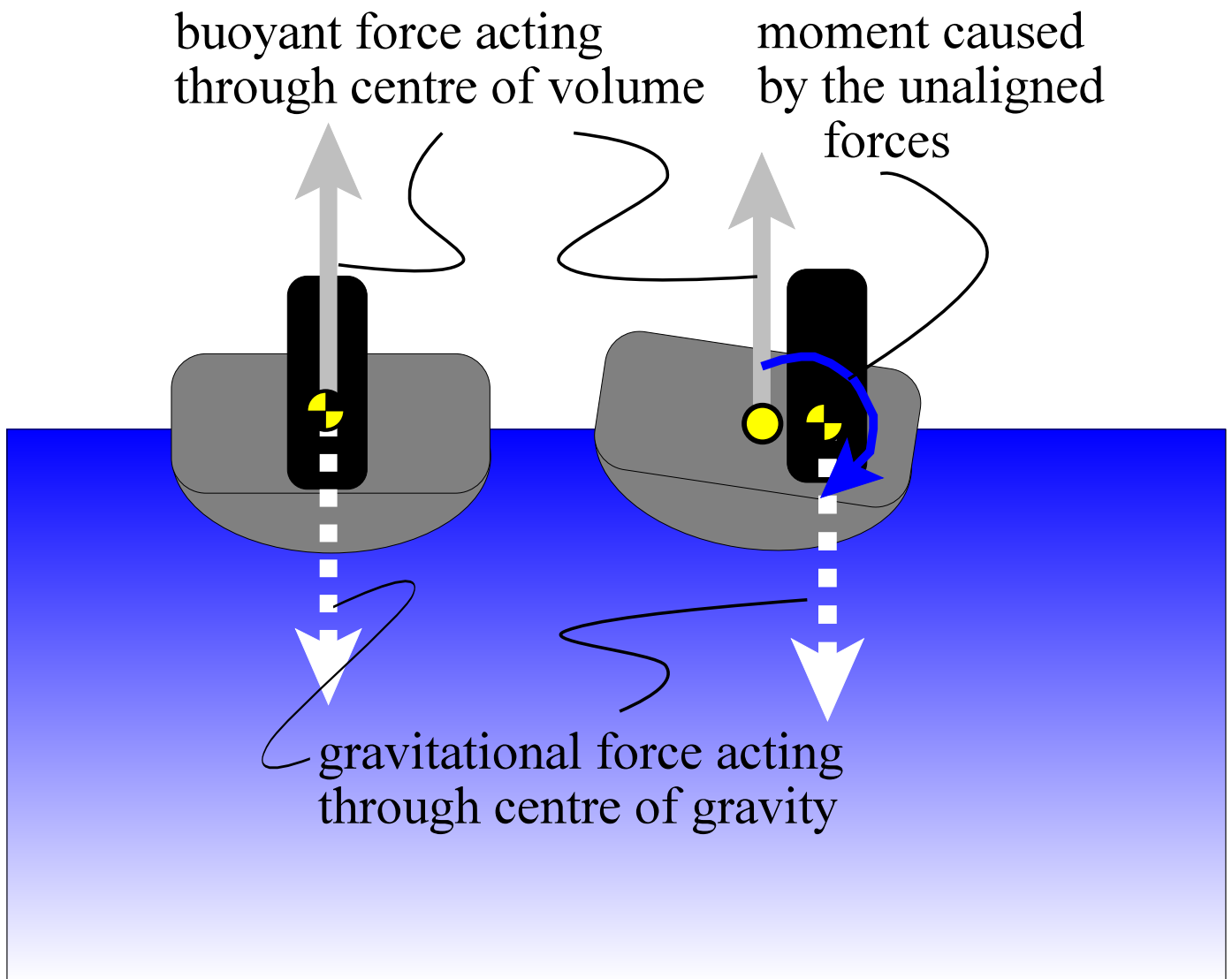
$$F_{\text{buoyant}} = m g = V \rho g = \text{volume} \times \text{density} \times 9.81$$

(newtons = metres<sup>3</sup> × kilogram/metres<sup>3</sup> × m/s<sup>2</sup>)



## Buoyancy vs. Gravity

When centre of volume and centre gravity are misaligned a moment of force is created that can overturn the boat.



## Buoyancy and Floatation Devices

Floatation devices should create a moment of force to bring the head to the surface and the mouth out of the water especially when the person is unconscious.

