Buoyancy

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

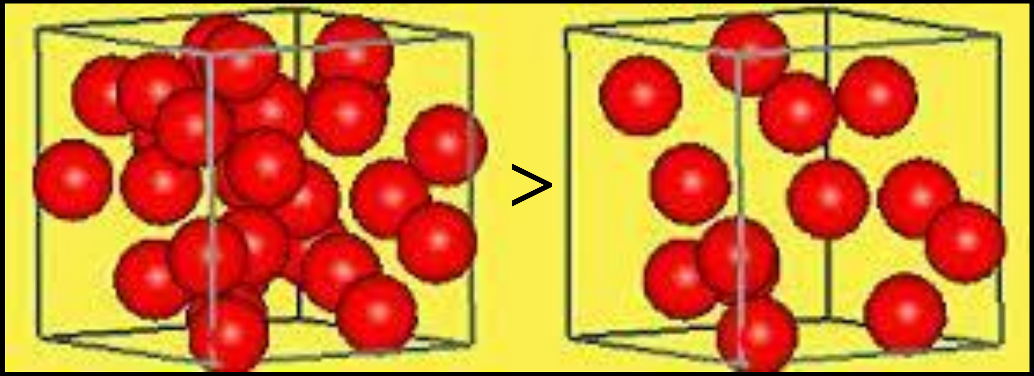
LPT

Terms Used

Density = mass per unit volume

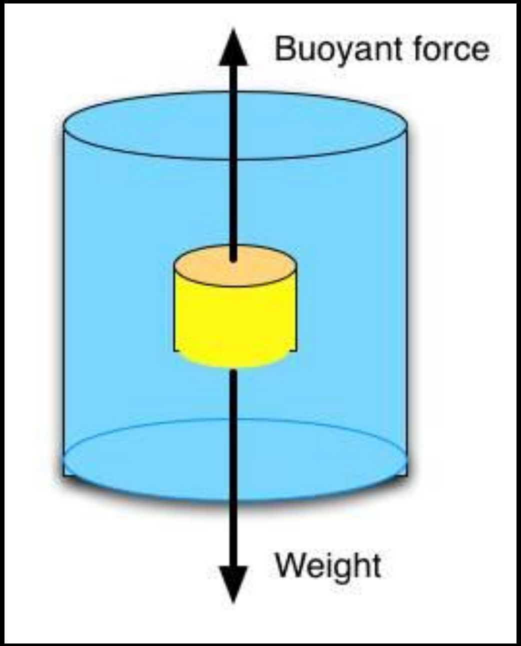
$$\text{Density} = \frac{\text{mass}}{\text{volume}} \qquad D = \frac{m}{v} \qquad V = \frac{m}{D} \qquad m = V \times D$$

Density is a physical property of substances.



A measurement of how much "Stuff" is in a unit volume

LPT



Terms Used

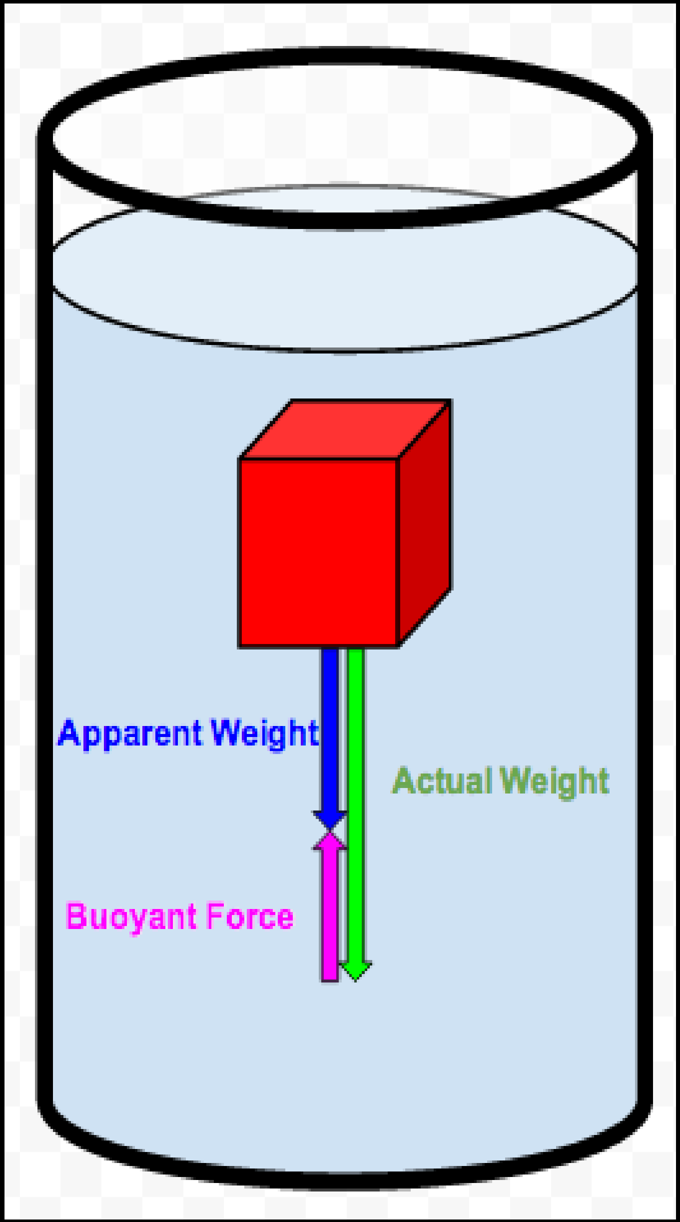
Buoyancy:
Upward force directly opposing weight

Weight:
Downward force
Result of object interacting with gravity

Rigorously: buoyancy is always upward; always positive

Common usage:
Positively buoyant: object floats (density < water)
Neutrally buoyant: object hovers (density = water)
Negatively buoyant: object sinks (density > water)

LPT



Terms Used

Objects seem to decrease weight when submerged

Apparent Weight:

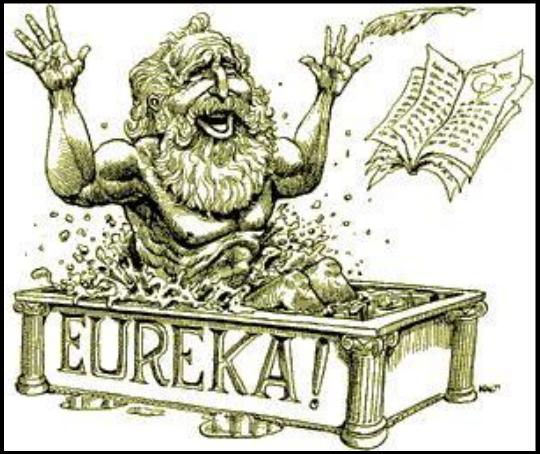
Actual weight - Buoyant Force

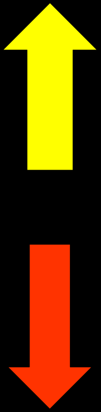
Archimedes Principle

An object partially or wholly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object

Translation (for water):

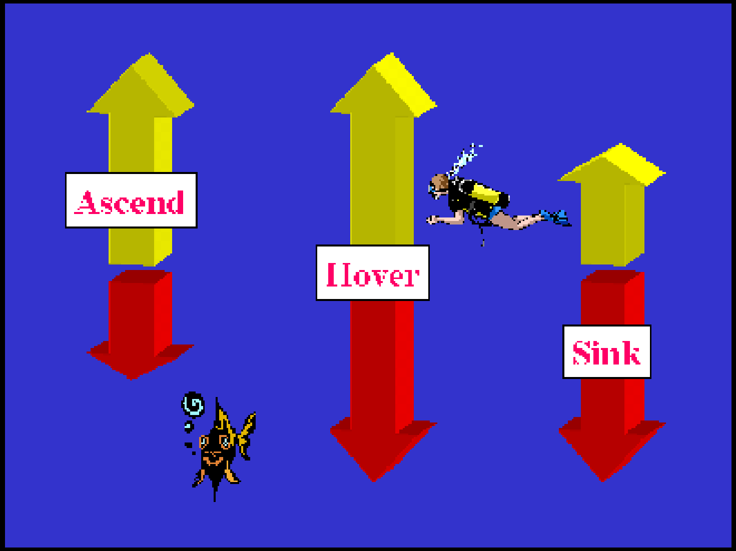
- **objects more dense than water (like lead) will sink**
- **objects less dense than water (like cork) will float**
- **objects of the same density will remain at the same level (hover)**





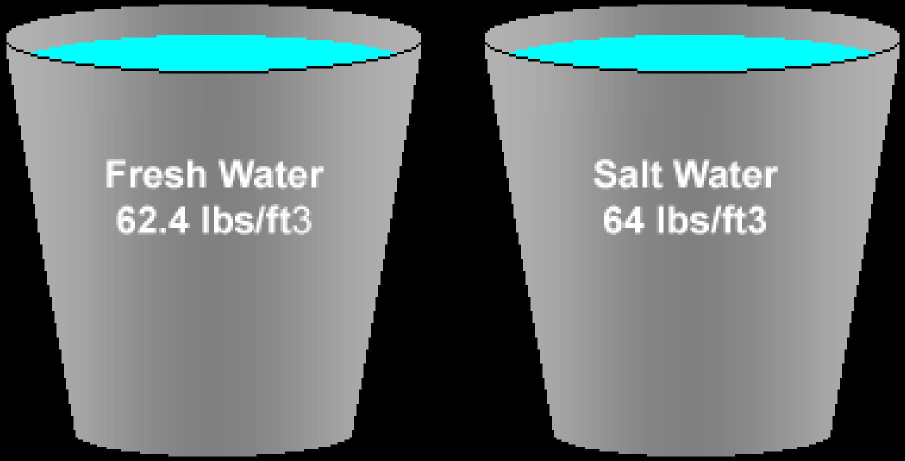
Buoyancy

Weight



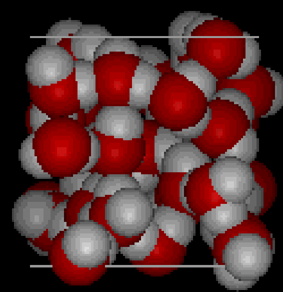
Density: Salt vs. Fresh Water

Salt Water: 64 lb/ft^3
Fresh Water: 62.4 lb/ft^3

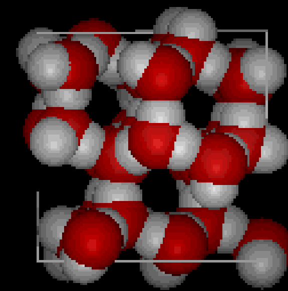


Same object floats higher in salt water

Water & Ice



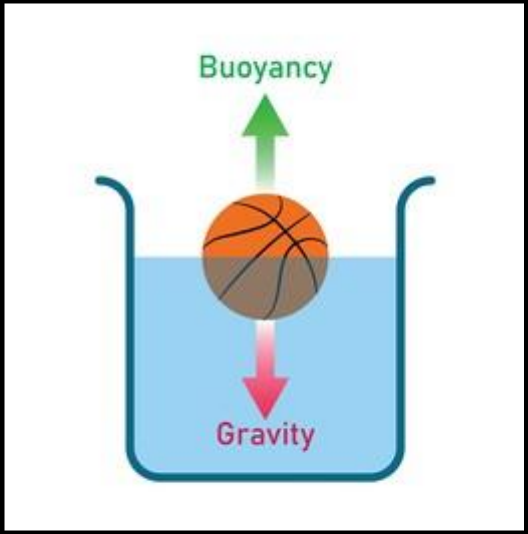
Water

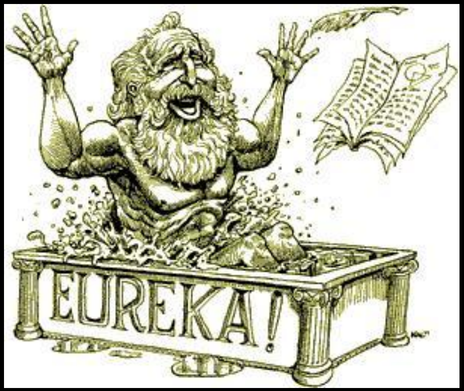


Ice

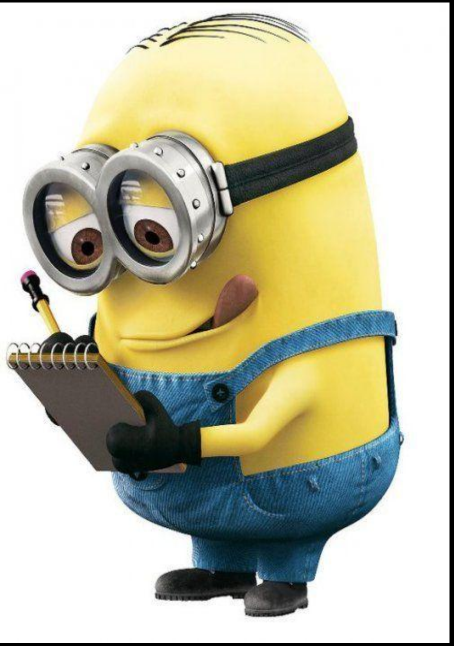
Ice less dense than water, so it floats

If ice did not float, most fresh water critters would not survive winter





Buoyancy Problems



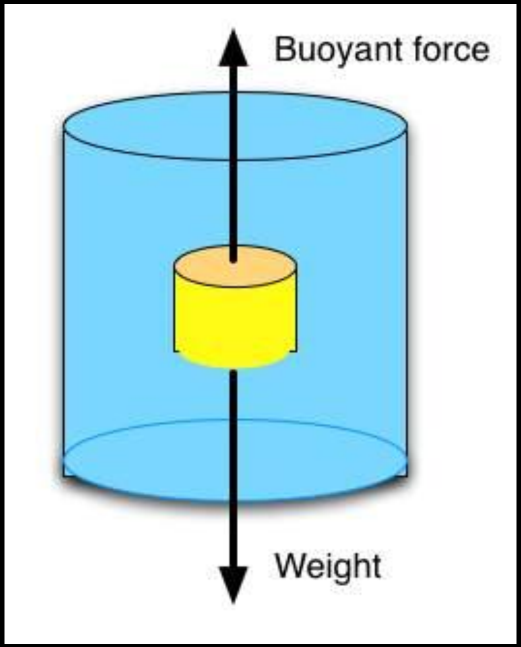
LPT

“Force Arrows” (Vectors)

Problems involving forces

Often solved with “force arrows”

line showing magnitude and direction



↑ Represents buoyancy (upward force)

↓ Represents gravity (downward force)

LPT

What is the buoyancy in seawater of a 2000 lb piece of wood that measures 6 ft x 2ft x 3ft?

For Wood:

Weight: 2000 lbs

Volume: 6 ft x 2 ft x 3 ft = 36 ft^3

Density: 2000 lb/ft^3 / 64 lb/ft^3 = 55.6 lb/ft^3

Weight of equal volume of seawater:

36 ft^3 x 64 lb/ft^3 = 2304 lb

Weight wood < Weight water

Wood object would float

What is the buoyancy in seawater of a 2000 lb piece of wood that measures 6 ft x 2ft x 3ft?

Determine buoyancy using forces

Weight wood: 2000 lb ↓
Weight displaced water: 2304 lb ↑
Net (Buoyant) force: 304 lb ↑

Determine Apparent Weight:

2000 lb – 304 lb = 1696 lb

How much of the wood is submerged?

Wood density: 55.6 lb/ft3
Water density: 64 lb/ft3

Density (lb/ft^3) Ratio: 55.6 / 64 = 0.869
So ~ 87 % of wood submerged

A fully suited diver weighs 200 pounds.
The diver displaces 3.0 cubic feet of sea water.
Will the diver sink or float?

Weight Diver: 200 lb

Weight Displaced Volume of Seawater:

$$3.0\ ft^3 \times 64\ lb/ft^3 = 192\ lb$$

Determine buoyancy using forces

Weight diver:	**200 lb**	↓
Weight displaced water:	**192 lb**	↑
Net Force:	**8 lb**	↓

Diver is too heavy (by 8 lb) and will sink

LPT

A wet suit diver weighs 210 pounds. In fresh water, this diver needs 18 pounds of weight to hover ("Neutrally Buoyant"). How much weight will the diver need to use this same configuration in sea water?

Total weight of hovering diver:

Diver: 210 lb ↓

Weight: 18 lb ↓

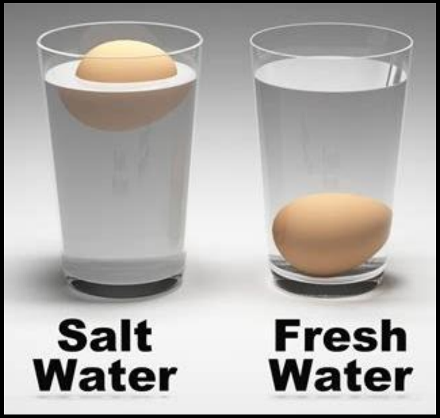
Total Weight: 228 lb ↓

Volume of displaced water:

Volume = Mass / Density

Volume = 228 lb / 62.4 lb/ft^3 = 3.65 ft^3

A wet suit diver weighs 210 pounds. In fresh water, this diver needs 18 pounds of weight to hover ("Neutrally Buoyant"). How much weight will the diver need to use this same configuration in sea water?



Determine sea water displacement:

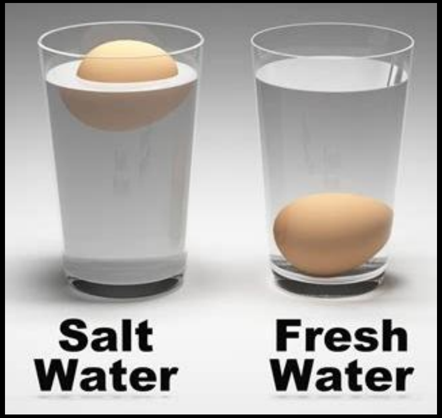
$3.65\ ft^3 \times 64\ lb/ft^3 = 233.6\ lb \rightarrow 234\ lb$

Determine sea water buoyant force:

Sea water buoyant force:	**234 lb ↑**
Diver weight:	**210 lb ↓**
Net force:	**24 lb ↑**

Diver needs 6 more pounds (24 lb – 18 lb) for sea water

A wet suit diver weighs 210 pounds. In sea water, this diver needs 18 pounds of weight to hover ("Neutrally Buoyant"). How much weight will the diver need to use this same configuration in fresh water?



Total weight of hovering diver:

Diver: 210 lb ↓

Weight: 18 lb ↓

Total Weight: 228 lb ↓

Volume of displaced water:

Volume = Mass / Density

Volume = 228 lb / 64 lb/ft^3 = 3.56 ft^3

Diver needs 6 less pounds (18 lb – 12 lb) for sea water

A diver wants to lift a 1600 pound object from a flat silt free lake bottom using 55 gal lifting pillows (weighing 20 pounds each). How Many 55 gallon devices is needed for the lift? 1

Determine device water displacement:

Weight = Density x Volume

1 gal = 0.134 ft^3

62.4 lb/ft^3 x 55 gal x 0.134 ft^3/gal = 460 lb

Determine device lifting capacity:

Weight of displaced water:	460 lb	↑
Weight of device:	20 lb	↓
Net Lifting capacity:	440 lb	↑

Each lifting device can manage to lift ~ 440 lb

LPT

A diver wants to lift a 1600 pound object from a flat silt free lake bottom using 55 gal lifting pillows (weighing 20 pounds each). How Many 55 gallon devices are needed for the lift?

Determine number of lifting devices needed:

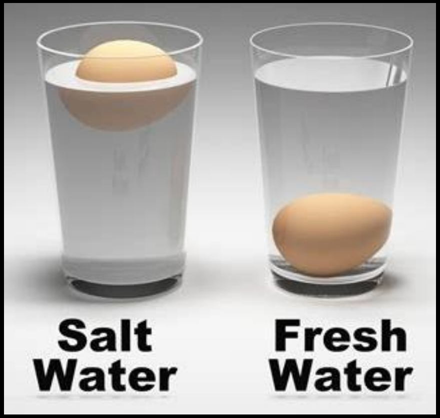
Weight needed to lift: 1600 pounds

Lifting capacity per device: 440 pounds

1600 lb x 1 device / 440 lb =3.63 devices

Diver needs four 55 gallon lifting pillows

A wet suit diver weighs 210 pounds. In sea water, this diver needs 18 pounds of weight to hover ("Neutrally Buoyant"). How much weight will the diver need to use this same configuration in fresh water?



Determine fresh water displacement:

$3.65\ ft^3 \times 62.4\ lb/ft^3 = 222.1\ lb \rightarrow 222\ lb$

Determine fresh water buoyant force:

Freshwater buoyant force:	**222 lb ↑**
Diver weight:	**210 lb ↓**
Net force:	**12 lb ↑**

Non-Diving Significance of Density

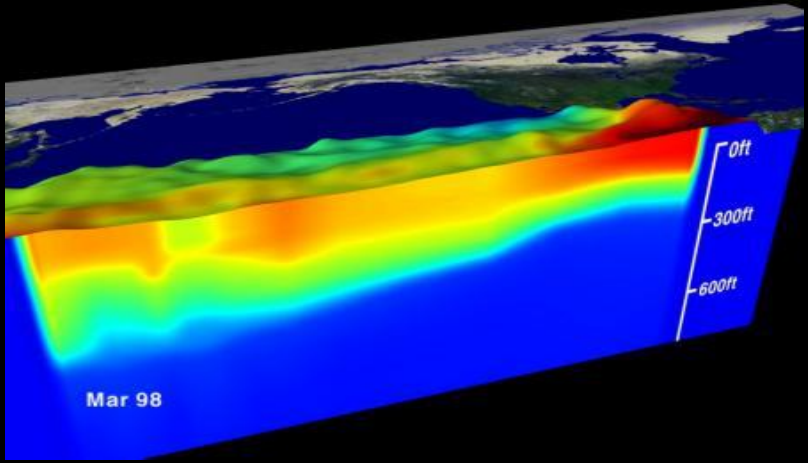
Extra "Stuff"

LPT

Fluids Layer Based on Density

May be based on chemical composition
Salt water more dense than fresh
Cold water more dense than warm
Fluids of different density resist mixing

Moving thru halocline



Water layers by temperature

Glacial melting is altering Arctic water density-driven-currents
Potential to destroy the Atlantic Gulf Stream (force an Ice Age)

Visible Bubbles Decrease Density of Liquids
(Gases less dense than liquids)

Methane bubbles from volcanic vents, especially in the Mid-Atlantic
Some believe some ship losses can be from encountering “mega-bubbles”

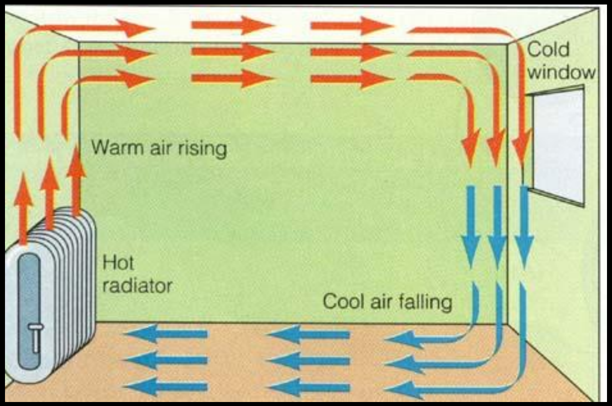
Star Trek Special Effects: Transporter

Swirling mix of salt water, fresh water, and metallic flakes

LPT

Warm Fluids Typically Less Dense

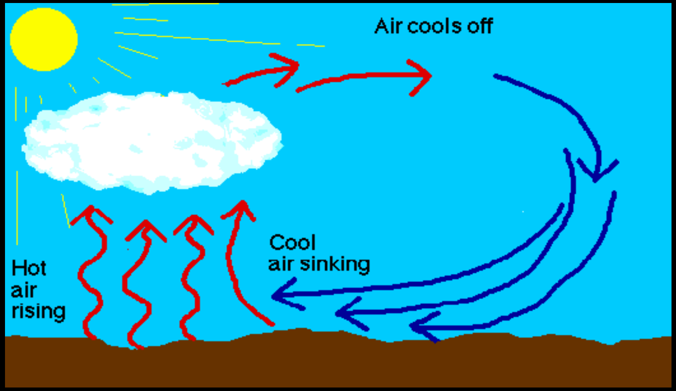
Lava Lamps



Convection Flow

Galileo
Air Thermometer

Hot-Air Balloon

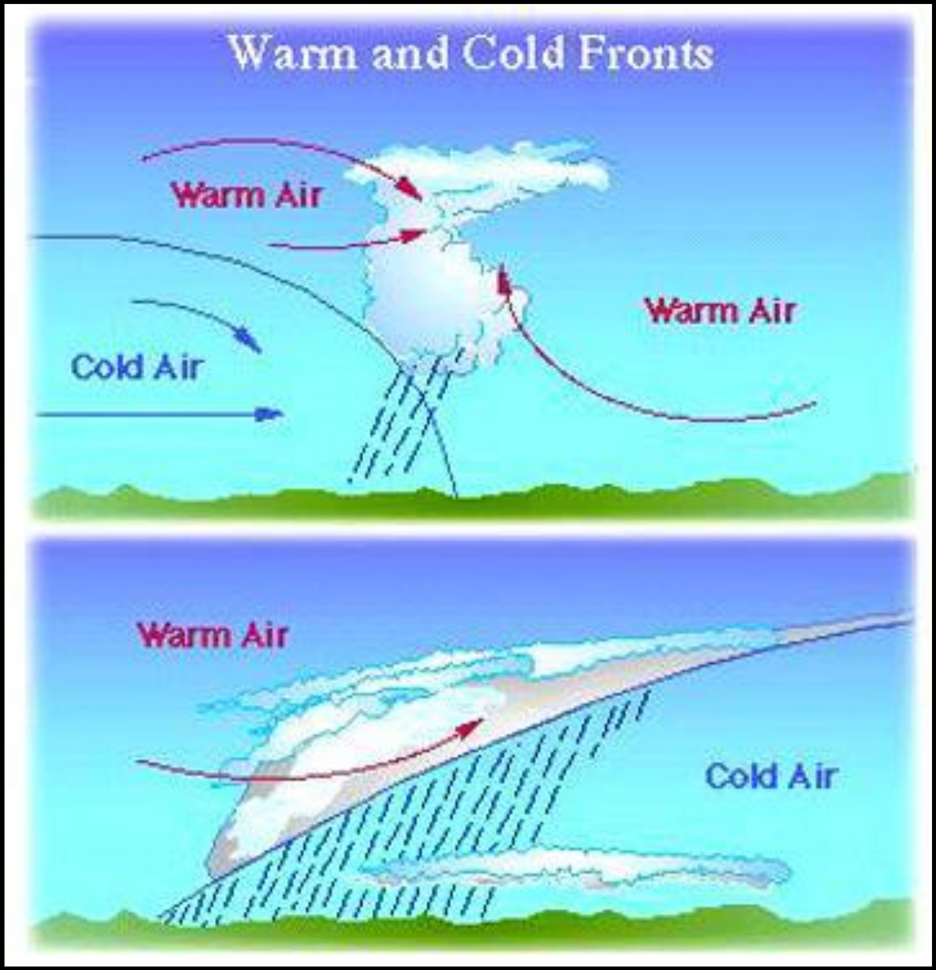


Breezes

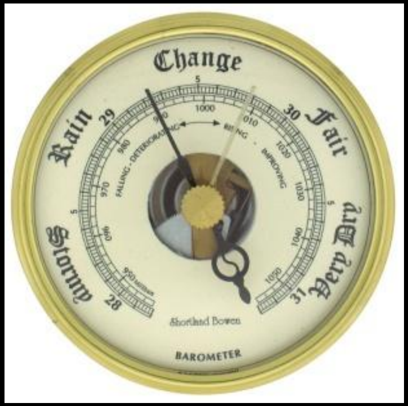
LPT

Much of Weather is Conflict Between Different density Air Masses

Cold air more dense than warm air



Fluids of different density
Resist mixing

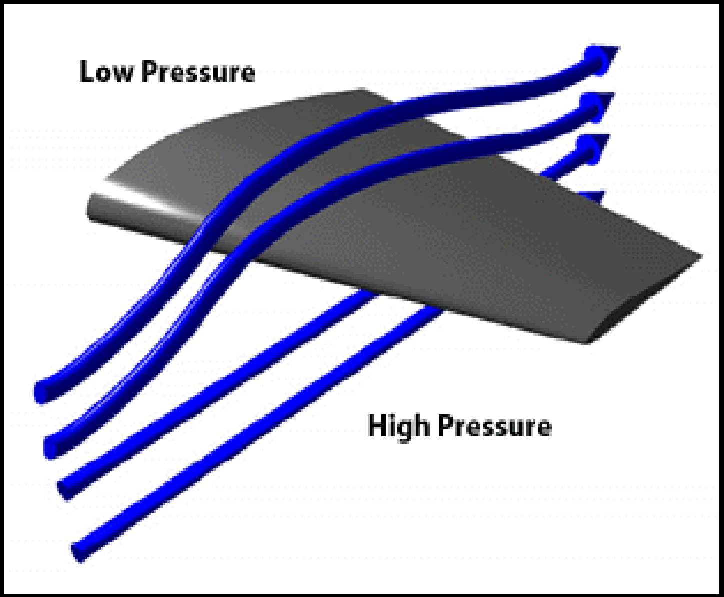


Barometer
Measures weight of air

"Lift"

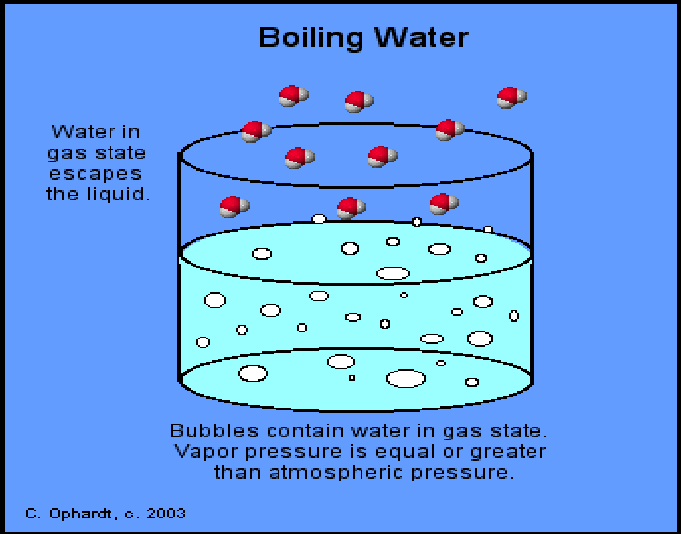
Shape of wing causes rapid air flow on upper surface

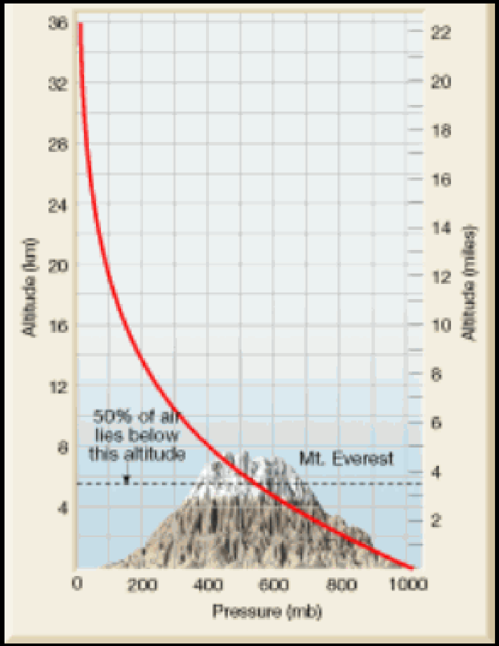
Creates density differences above/below wing

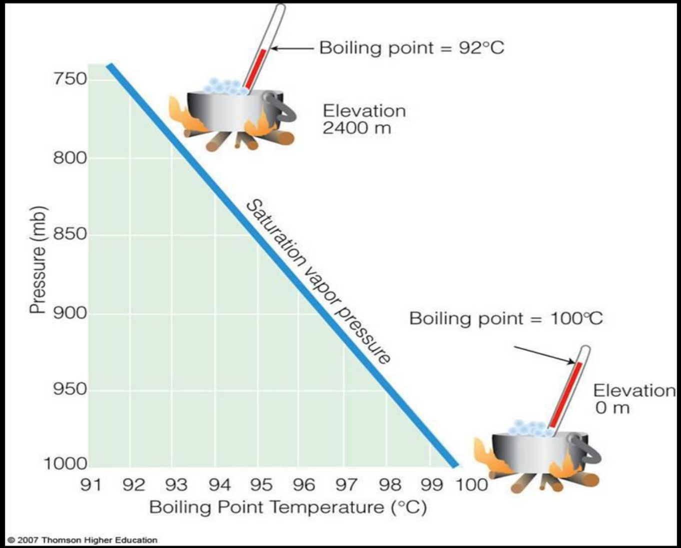


Lower density above wing = lift

Boiling Point: Function of Weight of Air







At high altitudes:

Boiling point water lower

Cooking temperature less

Food takes longer to cook

Freezing Point: Depressed By Dissolved Solids

Polar ocean water temperatures: ~ - 2 ºC (28 ºF)

Below water freezing point

LPT

Fat Floats

Weight in-water
Weight out-of-water

Difference ➔ % Body Fat

Fatty tissue less dense than muscle tissue

Michigan: 5th Most Obese State
By 2030, estimated > 60 % MI will be obese
Type II Diabetes now considered an epidemic
Health care costs ➔ trillions

LPT

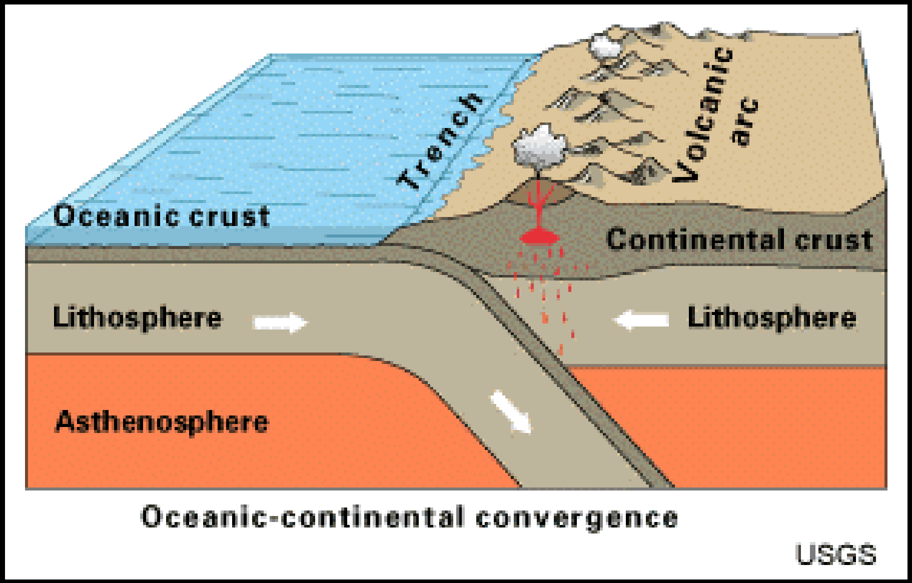
Sand/Water More Dense than People

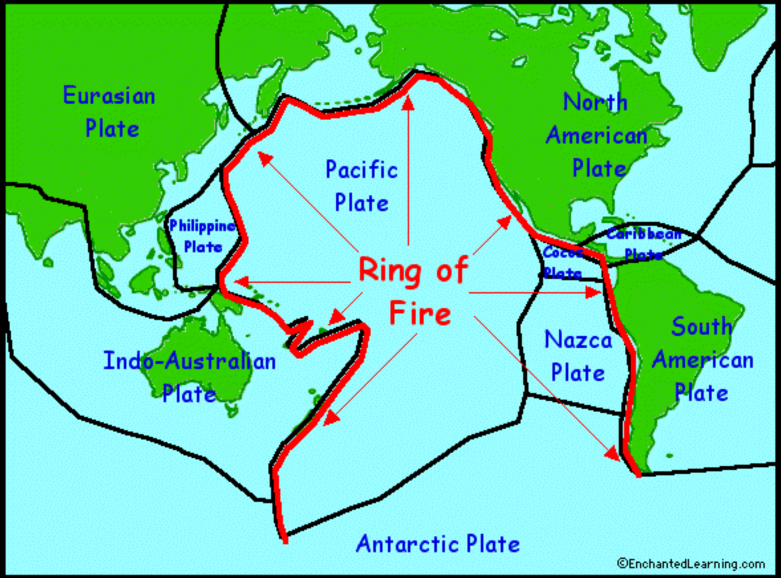
Hollywood Horror Movie “Quicksands” Not Likely

Sometimes “Hollywood” is not exactly scientifically accurate

LPT

Continental Crust Less Dense Than Oceanic Crust





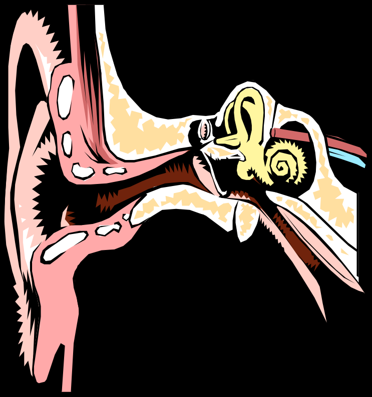
Earthquakes and Volcanoes:

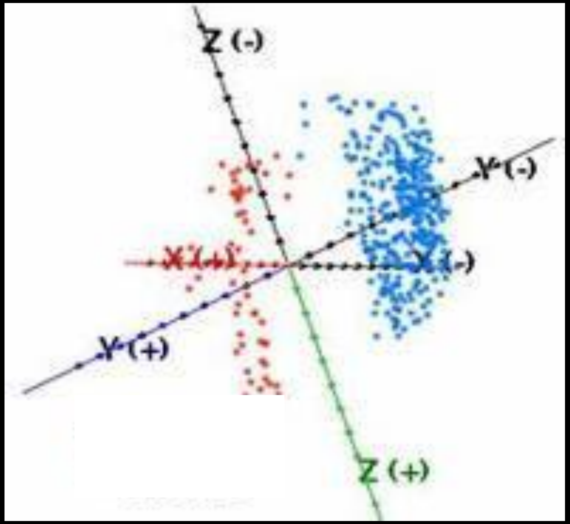
Driven By Density Differences in Continental Plates

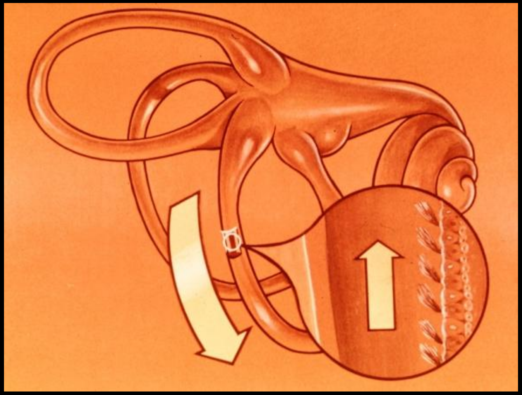
LPT

Balance Determined by Fluid Motion in Inner Ear

Alcohol alters density of fluid in semi-circular canals

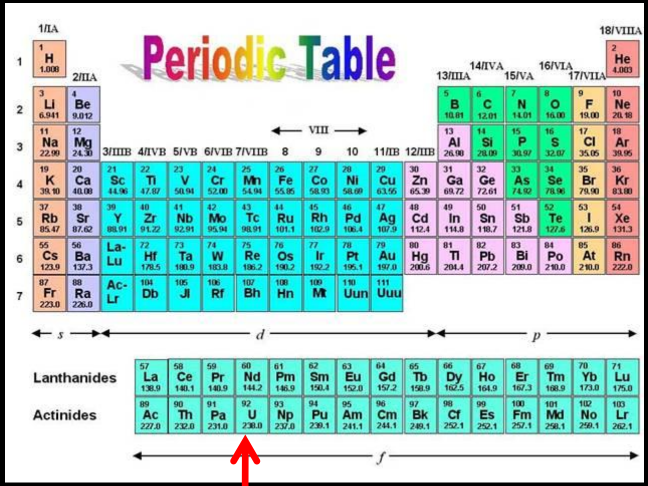






Inner ear is the last organ in the body to clear alcohol
May take 10-18 hours for alcohol to clear from inner ears

Depleted Uranium Weapons are NOT Nuclear Devices



Uranium

Density (g/mL)

Al = 2.70

Fe = 7.96

Pb = 11.4

Hg = 13.53

U = 19.07

Au = 19.30

Os = 22.67

Kinetic Energy = ½ mv^2

Greater density = more momentum on impact

LPT

Concentration Determined By Density

Aquarium Salinity

Radiator Protection

Sugar in Maple Syrup

Alcohol in Moonshine

LPT

Determining Gold Composition

A presumed gold ring has a mass of 2.832 g. When placed in a a 10-mL graduate cylinder , the water level goes from 5.00 mL to 5.15 mL. Is the ring gold (d = 19.3 g/mL) ?

Volume of ring = 5.15 mL – 5.00 mL = 0.15 mL

$d = \frac{\text{mass}}{\text{volume}} \rightarrow \frac{2.832 \text{ g}}{0.15 \text{ mL}} \rightarrow 18.9 \text{ g / mL} \rightarrow 19 \text{ g/mL}$

Density slightly less than pure gold, so it is a gold ring with some metal alloy to give it strength.

24k (d= 19.32 g / mL) generally > 99% gold.
24 k too soft for jewelry, so gold jewelry is alloyed for strength
Alloying metals: Ag, Cu, Zn, Ni, Pb, and Pt
14 karat density varies from ~ 12 to 14 g/mL

"karat" value differs from country to country.

Why Freezing Pipes Burst

Liquid water at 4 ^oC has a density of 1.000 g/mL
Solid water at 0 ^oC has a density of 0.920 g/mL

What volume will 100. g of water have at these temperatures?

100. g x mL / 1.000 g = 100. mL

100. g x mL / 0.920 g = 109 mL

% change:

[(109 – 100) / 100] x 100 = 9 %

Expanding solid water can crack pipe

Planning Explorations

Your probe lands on Titan (Saturn moon) to investigate a liquid methane sea (density liquid methane: 422.6 kg / m^3).

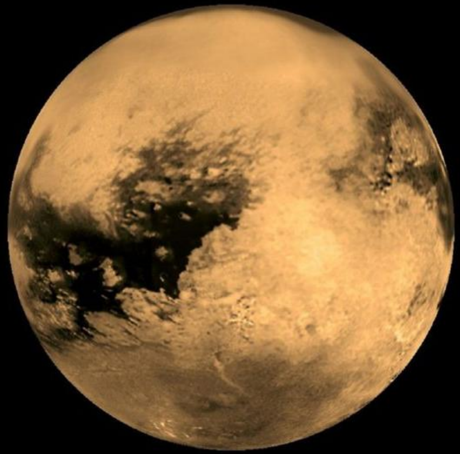
a. Express the methane density as g/ cm^3

$$\frac{422.6\ \text{kg}}{\text{m}^3} \times \frac{1000\ \text{g}}{1\ \text{kg}} \times \frac{1\ \ \text{m}}{100\ \text{cm}} \times \frac{1\ \ \text{m}}{100\ \text{cm}} \times \frac{1\ \ \text{m}}{100\ \text{cm}} = 0.4223\ \text{g} / \text{cm}^3$$

b. Will your instruments (density 1.53 g / cm^3) sink or float in this sea? Why?

Package is more dense than the fluid, so it sinks.





LPT

Loading Cargo

A boy scout troop has collected 2536 lbs of aluminum soda cans. If the density of the cans is 2.70 g/cm^3, what is the minimum volume needed to transport this material to a recycle center?

$$2536\text{ pounds} \times \frac{454\text{ g}}{1\text{ lb}} \times \frac{1\text{ cm}^3}{2.70\text{ g}} \times \frac{1\text{ inch}}{2.54\text{ cm}} \times \frac{1\text{ inch}}{2.54\text{ cm}} \times \frac{1\text{ inch}}{2.54\text{ cm}}$$

Continuing (without isolation):

$$\times \frac{1\text{ ft}}{12\text{ in}} \times \frac{1\text{ ft}}{12\text{ in}} \times \frac{1\text{ ft}}{12\text{ in}} = 17.7824\text{ ft}^3 \rightarrow 17.78\text{ ft}^3$$

In 1983 Air Canada flight 143 crew manually calculated (Canada was in process of converting to metric system) the volume of fuel needed for a full load of 22,300 kg . They used a density of 1.77 (no units). Turns out the density they used was in units of pounds (not kg) per liter.

Gimli Glider

This is what they did (V = M / D)

$$V = \frac{22,300}{1.77} = 1.26 \times 10^4 \text{ liters}$$

They loaded a total 1.26×10^4 liters of fuel.

This is what they should have loaded:

$$22,300 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{1 \text{ liter}}{1.77 \text{ lb}} = 2.31 \times 10^4 \text{ liters}$$

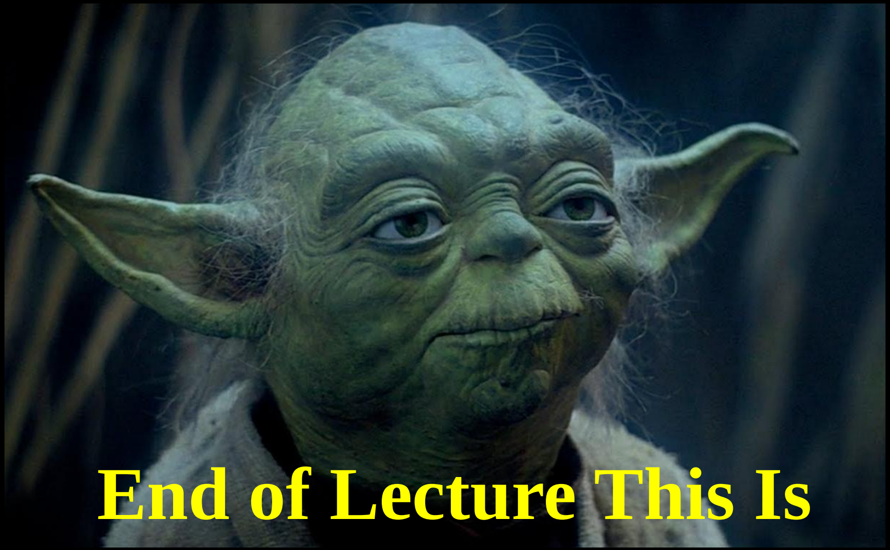
This Air Canada flight ran out of fuel at 41,000 feet one hour into the flight and glided 20 km (12.4 miles) to a safe landing.

Let the units drive the solution

LPT


"That's all Folks!"


Woo Hoo!
All done!


End of Lecture This Is


Dive long and prosper

LPT