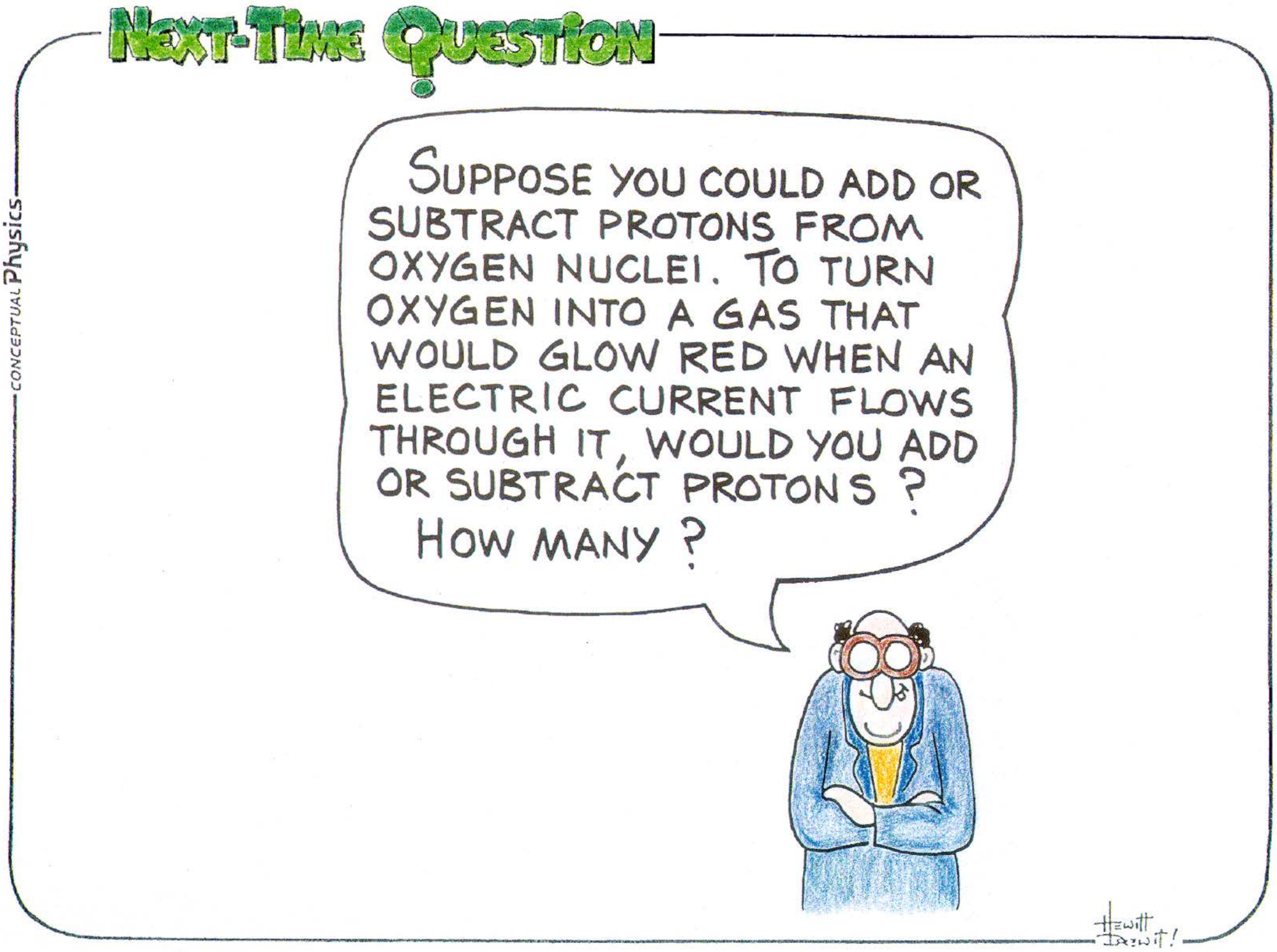
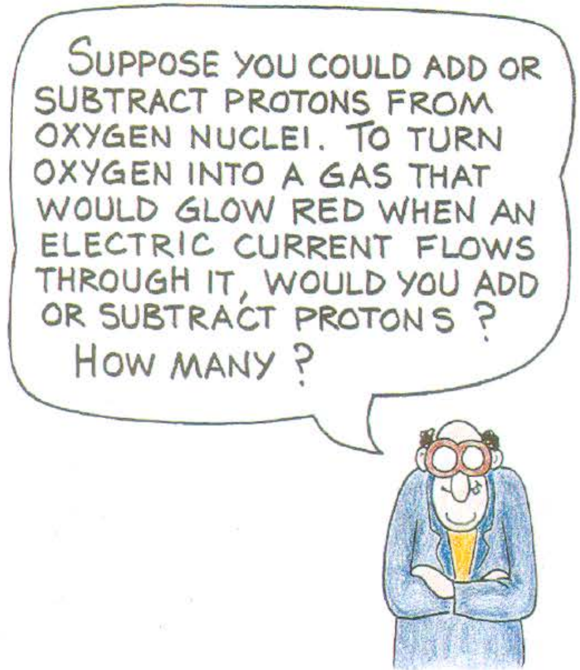

NEXT-TIME QUESTION
CONCEPTUAL Physics
SUPPOSE YOU COULD ADD OR SUBTRACT PROTONS FROM OXYGEN NUCLEI. TO TURN OXYGEN INTO A GAS THAT WOULD GLOW RED WHEN AN ELECTRIC CURRENT FLOWS THROUGH IT, WOULD YOU ADD OR SUBTRACT PROTONS? HOW MANY?
Hewitt Drew it!

NEXT-TIME QUESTION



Answer: add 2 protons

Add two protons to each nucleus of oxygen and you increase the atomic number from 8 to 10. You then have neon, which will glow a very nice red when a current flows through it.

Chapter 13: Liquids

First, concept of **density** (in Ch 12, everything else of which we are skipping)

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Simply related by g = 9.8 N/kg (near earth) ↔

$$\text{Weight density} = \frac{\text{weight}}{\text{volume}}$$

Density measures how compact the matter is, *not* how heavy it is

Eg. A feather quilt may be heavier than a metal spoon, but the spoon is more dense than the quilt.

Only if you have equal sizes (ie. volumes) of two materials, are their relative densities directly related to their weight.

A little more on density…

- Some densities:
  - Osmium (bluish-white metal) is the densest substance on earth. It's an element, whose crystalline form has very closely packed atoms. Density 22.6 g/cm^3.
  - Water has density 1 g/cm^3
  - Ice has less density, 0.92 g/cm^3, because when water freezes, it expands.
  - Seawater has greater density, 1.03 g/cm^3.

<u>Question:</u>

Which has greater density, 1 liter of water or 1 liter of ice? And which weighs more?

Any amount of water has greater density than *any* amount of ice (it doesn't depend on amount, since density is the ratio of mass to volume).

Since water has greater density, it weighs more than an equal volume of ice.

Pressure

- Why does it hurt so much more when a thumbtack pin is pressed into your hand than when a marble is, pressing equally hard??

Even though the **force** in each case may be the same, one (the pin) acts over a much smaller **area** than the other (marble).

So, define

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

Question: Why is a bed-ridden person less likely to develop bedsores on their bodies if they use a waterbed rather than an ordinary (i.e. more rigid) mattress?

Because more of the body is in contact with the supporting surface on the waterbed than on the mattress, so there is less bodyweight pressure. (Larger area in eqn above, same force, so less pressure)

Pressure in a liquid

- A liquid is composed of molecules that move constantly and bounce off the sides of the container it is in and or bounce off objects (like a swimmer) in the liquid.

  Bouncing creates a force (recall momentum-impulse) – hence a pressure.

due to liquid's weight directly above

Liquid Pressure = weight density x depth

area x depth

"Proof": Pressure = $\frac{\text{force}}{\text{area}} = \frac{\text{weight}}{\text{area}} = \frac{\text{weight density x volume}}{\text{area}}$

= weight density x depth

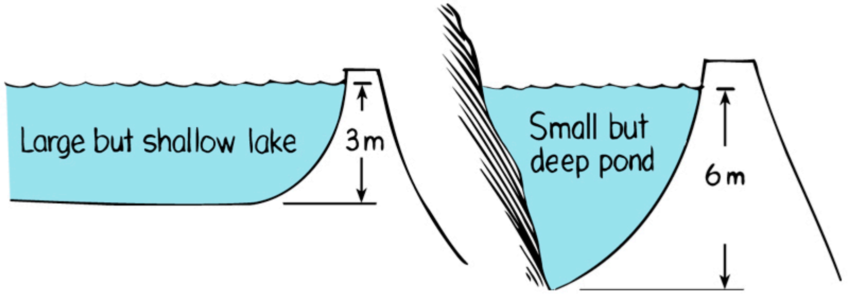
Pressure in a liquid: dependence on depth.

• Pressure at a point twice as deep, is twice as much.

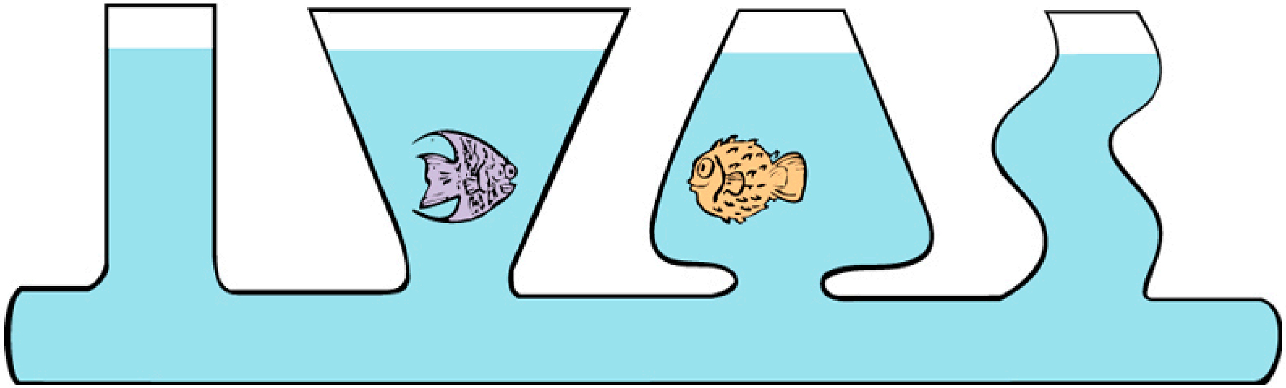
• Consider swimming. Near top surface of the water, don't feel much pressure (depth is near 0). (More precisely, need to add air pressure of the atmosphere but you always feel that).
Go deeper - you feel more pressure (eg in your ears). The deeper you go, the more weight of water is above you, so more pressure you feel.

• It does *not* depend on the volume, only on the *depth*
• Eg. Same water pressure felt when swimming 2m deep in a backyard pool than when swimming 2m deep in a huge freshwater lake.

Eg. The pressure at the bottom of the small but deep pond here is twice as great as the pressure at the bottom of the large shallow lake.



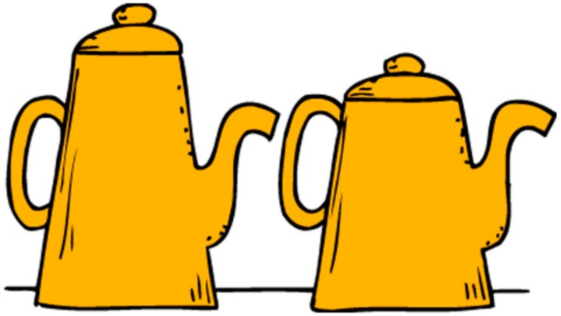
Eg. Different shaped vases all connected – the level of the water in each is the same. Why?



Because, if not, the pressure would be more at the bottom of the vase with higher water level (from eqn, larger depth). This increased pressure would then force water sideways to lower pressure, and then up the vase with lower level. Eventually pressures equalize – which means same water level in each.

Another way to say this is water "seeks its own level.

Question: Which pot holds more tea? (They are identical except that the left one is taller)



The both hold the same! The water can be no deeper than the spouts, which are at the same height.

Eg. Hold a garden hose filled with water, and hold both ends at same height, water stays. Now if raise one end, water flows out lower end, even through an "uphill" path.

Relevant to the unnecessarily elaborate acqueducts the Romans made, very carefully ensuring water would flow downhill at all points – they didn't understand that water *can* flow upwards in between.

Pressure in liquid: density dependence

Recall:

Liquid Pressure = weight density x depth

- If liquid is twice as dense, the liquid pressure is also twice as much.

Eg. Saltwater is more dense than fresh water (see earlier slide on density). So saltwater has more liquid pressure (makes it easier to float in the ocean than in a freshwater lake…see shortly for more on floating).

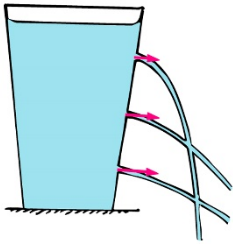
- Liquids are very difficult to compress – so even for a large body of liquid, the density is practically the same at all depths.

Liquid Pressure: Direction

- Liquid pressure is exerted *equally* in *all* directions.

Eg Swimming underwater, pressure on eardrum is same if tilt head in any direction.

Eg. Water spurts *sideways* from holes in the side

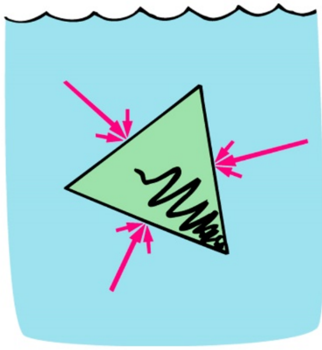


e.g. hydroelectric dam

Eg. Boat on water – water pressure acts *upward* on the boat surface

- Although force has direction, pressure does not (it's a scalar)

At any point on the triangular block shown, force from bouncing molecules are in all directions, but only that normal to the surface doesn't get cancelled out. *Net force is normal (perpendicular) to (any) surface.*



If a hole is punched in the side or bottom of a boat, water spurting in will be

- perpendicular to the surface of the boat interior.
- in an upward direction.
- in such a way as to minimize flow rate.
- conserved.

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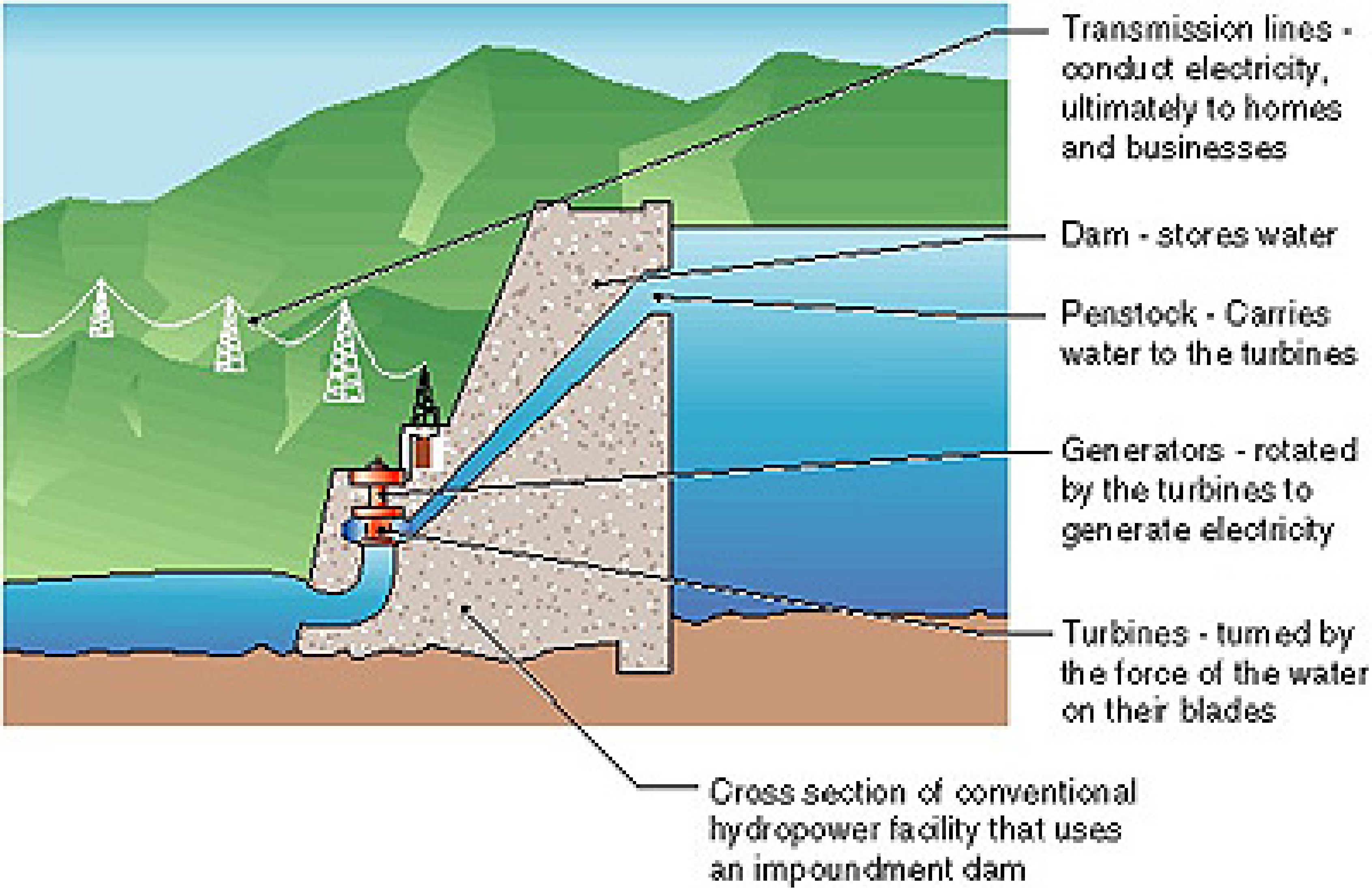

Potential energy of water of mass m = mgΔh

Water pressure at the bottom of a lake depends on the

- weight of water in the lake.
- surface area of the lake.
- depth of the lake.
- All of these.

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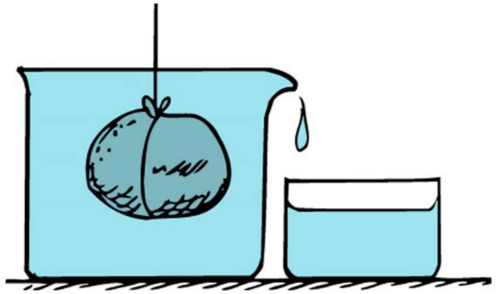
Buoyancy

Before studying buoyancy, first study concept of “volume of water displaced”

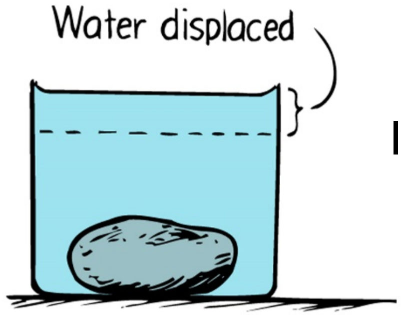
A completely submerged object always displaces a volume of liquid equal to its own volume:



Add a rock to a container full of water

Volume of water dripped out = volume of rock.

Regardless of weight of rock – eg. a 1-liter container of milk and a 1-liter container of air submerged in water, both displace the same amount of water.

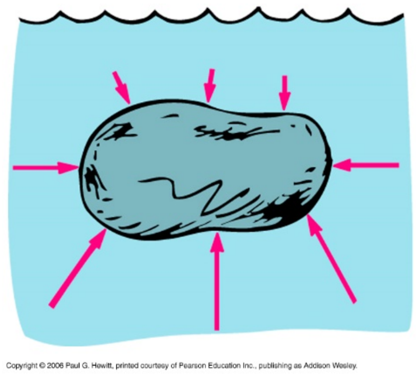


If container is big:

then Increase in volume level = volume of rock

Buoyancy

Buoyant force = upward force acting on an object in liquid, due to pressure on lower part of object being higher than pressure on upper part:



Why? Because liquid pressure is larger for larger depths.

Question: If there's an upward buoyant force on a submerged object, then how come it doesn't accelerate upwards (N's 2nd law) ??

There are also other forces acting – downward gravitational force and water resistance. So whether it accelerates or not, and in which direction (up or down) depends on how these balance.

Eg, Push a light ball under water, it accelerates up once you let go due to buoyant force being dominant.

But if you push a boulder under water, it will sink, as weight (grav force) is larger than the buoyant force.

Buoyancy: Archimedes' Principle

An immersed body is buoyed up by a force equal to the weight of the fluid it displaces.

- Applies to liquids and gases
- Applies to either partially submerged objects or fully submerged objects
- So buoyant force depends on object's ***volume*.**

Eg. What is the buoyant force on a 1-liter container of anything in water so that just *half* of it is in the water?

Same volume, 0.5-liter, of water is displaced, so the buoyant force on it is the weight of 0.5-liters of water = 0.5 x 9.8 N = 4.9 N.

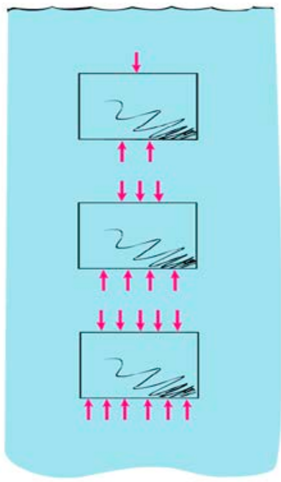
Recall 1-liter of anything is 1000 cm^3. Recall mass density of water is 1g/cm^3, or 1 kg/liter so weight density is = 9.8 N/liter. So weight of 1 liter of water is 9.8 N.

If fully submerged, the buoyant force is greater – equal to 9.8 N in the case of (any) 1-liter object.

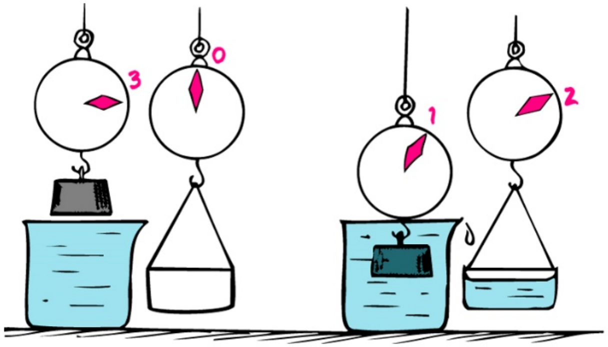
More on Archimedes Principle

- For a fully submerged object, the buoyant force is *independent of depth*, even though the pressure depends on depth:

The ***difference*** between the pressure at the bottom of the object and the pressure at the top is what causes the buoyant force. This *difference* is same at any depth – it just depends on how tall the object is.



- Because of the buoyant force, weight in water is less than weight in air:

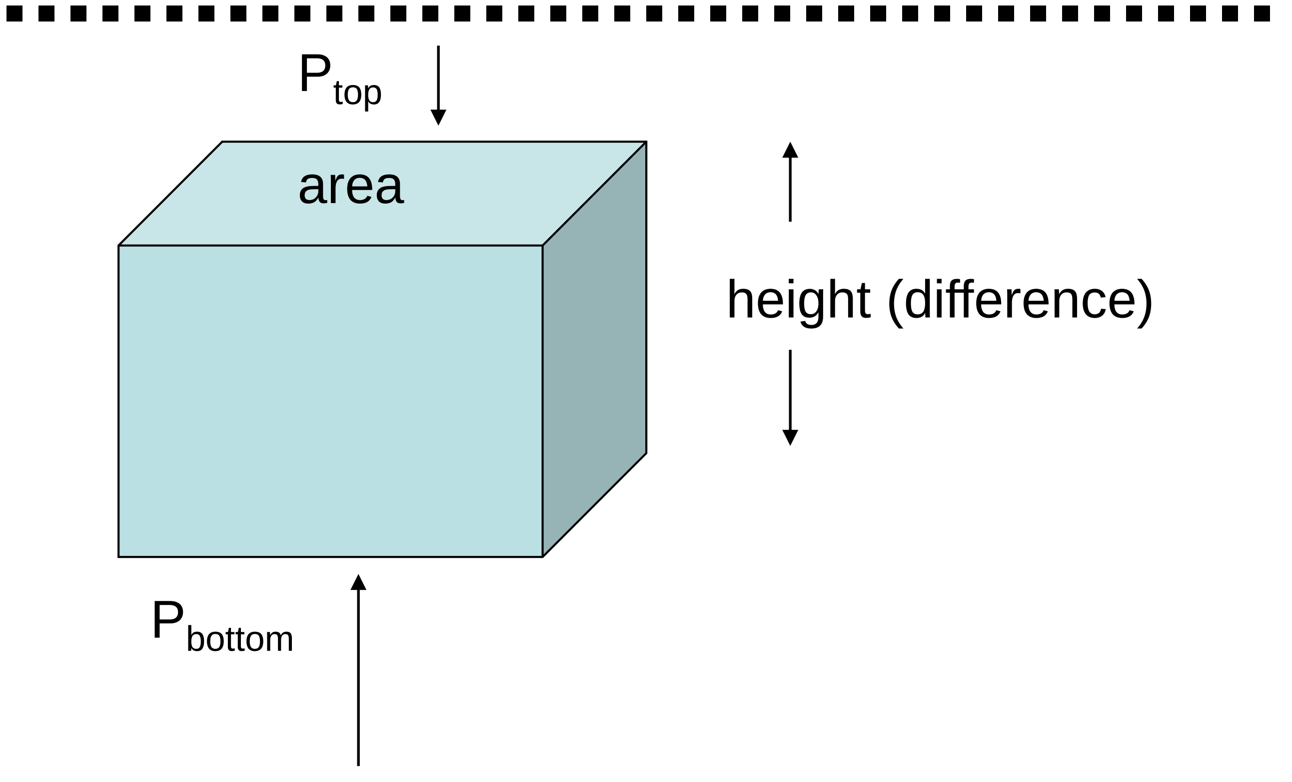


Here, the 3N object displaces an amount of water weighing 2N = buoyant force.

So its weight in water is reduced to 1N.

Optional:

$(P_{bottom} – P_{top})$ x area = buoyant force =
weight density (of fluid) x height x area,
but height x area = volume;
Hence F_B = weight density x volume = weight (of fluid)



The buoyant force on a submerged object acts in an upward direction because

- the force is opposite to that of gravity.
- it moves in a direction toward floating, which can only be upward.
- upward pressure against the bottom exceeds pressures elsewhere on the object.
- the density of water increases with increasing depth.

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- the density of water increases with increasing depth.

Explanation:

Figure 13.14 nicely illustrates this.

Interactive Buoyancy

The buoyant force that acts on a 20,000-N ship is

- somewhat less than 20,000 N.
- 20,000 N.
- more than 20,000 N.
- dependent on whether it floats in saltwater or in freshwater.

The buoyant force that acts on a 20,000-N ship is

- somewhat less than 20,000 N.
- **20,000 N.**
- more than 20,000 N.
- dependent on whether it floats in saltwater or in freshwater.

Question:

Upon which is the buoyant force larger – a fish that has eaten a huge meal, or its hungry identical twin? (Assume that the full fish holds its belly in so that its volume is the same but its mass and density are greater).

The buoyant force is the same on each, since both fish have same volume so displace the same amount of water.

Very Important!!!

It's the *volume* of the object that determines the buoyant force, not the weight!

Eg. A small steel ball experiences less upward buoyant force than a large styrofoam ball. The steel ball sinks because its downward gravitational force is much bigger –

Sink or float depends on the objects weight as well – next slide..

Sinking vs Floating

- Depends on whether object's weight is greater (sink) or less (float) than buoyant force.

upward force → buoyant force; downward force → weight

Since weight = weight density x volume, and

buoyant force = fluid density x volume, then sinking vs floating depends on the *relative density* of the object to fluid:

(i) If object is denser than fluid, it will sink

(ii) If object is less dense than fluid, it will float

(iii) If same density, then it will neither sink nor float.

Eg. If you are very muscular, it's hard for you to float in water, as you are too dense! Taking a huge breath to inflate your lungs could help to reduce your average density temporarily, or wear a life jacket – this increases your volume but decreases average density since it is so light.

Example: Fish normally have about the same density as water (so neither sink nor float). They have an air sac that they can contract or expand.

Question: If a fish wanted to swim upward, then what should it do with its air sac? How about if it wanted to move downward?

To move up, want to increase buoyant force, so decrease density. Since density = mass/volume, this means increasing volume by expanding the air sac would make fish move up.

To move down, contract air sac.

Another point about the buoyant force:

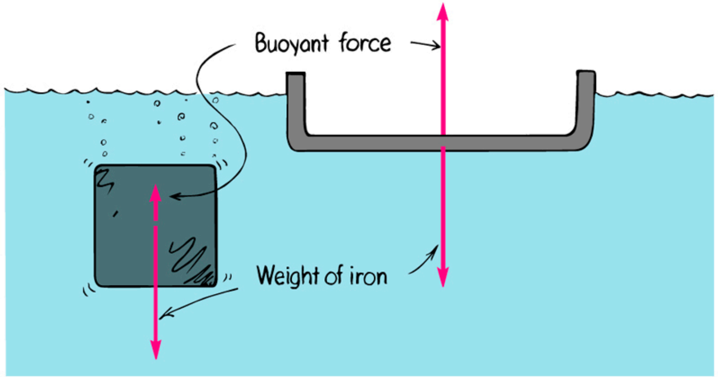
Something that may sink in water, may float in salt water (more dense), or in mercury (even more dense).

Why? Because denser fluids have more weight for same volume displaced, so greater buoyant force.

Hence, easier to float in ocean's seawater than freshwater pool (recall earlier). And, iron floats in mercury but sinks in water…

Flotation

Since iron is more dense than water, how can ships made of iron float??



It's because effective density is less since it is filled with air or lighter things:

Iron has 8 x density of water, so if a block, it sinks.

Instead, shape it into a boat, it displaces a greater volume of water (in a sense, the boat has a larger effective volume). So greater buoyant force – when it equals its weight, it will no longer sink.

"Principle of flotation": A floating object displaces a weight of fluid equal to its own weight.

So, when building ships etc, need to make them wide enough.

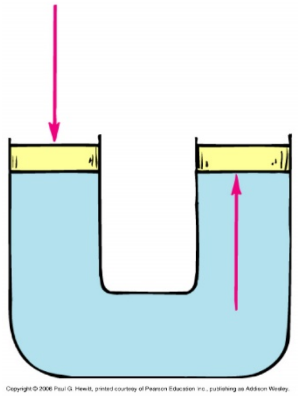
Pascal's Principle

A change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid.

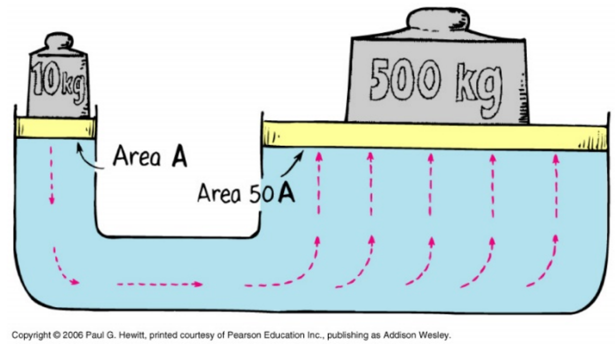
Eg. Water pipes in a city. If pumping station increases pressure by certain amount, then pressure increases by that same amount in pipes throughout city.

Pascal's principle enables large weights to be lifted via small forces:

Consider first simple U-tube: Pressure exerted downwards on left piston transmitted through tube to force right piston upwards – same pressure,same force.



Now consider making right-side much wider. Same pressure throughout means the output force (= pressure x piston area) is larger by factor of the area. Hence large weights can be lifted by small forces.



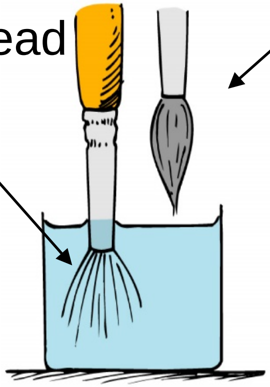
Idea behind hydraulic press. Simple machine: force multiplier (but same energy – distance moved up on right is less by factor of area than distance moved down on left)

Surface tension

- Surface of a liquid tends to contract – called surface tension. Liquid tries to minimize surface area.

Example:

Paintbrush in water – hairs spread out, as they would if dry in air.



But when raised, the surface film of the water contracts and pulls hairs together

- Surface tension is why liquid drops are spherical – surfaces tend to contract so force each drop into the shape with least surface area, ie a sphere (ball).

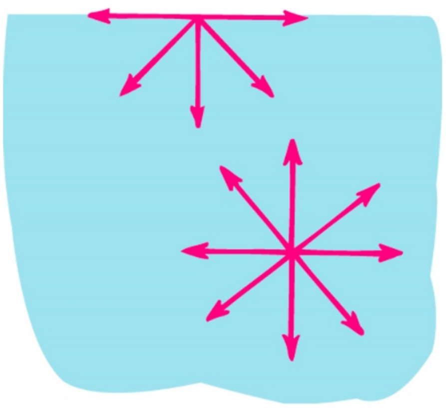
Best seen with small drops, since gravity flattens larger ones.

Surface tension cont.

• Surface tension caused by molecular attractions: "sticky molecules"

Below surface, molecule pulled by all neighbors, all directions equally. So no net pull.

At surface, there are no molecules above, so net pull is downward into the liquid – leads to minimization of surface area.



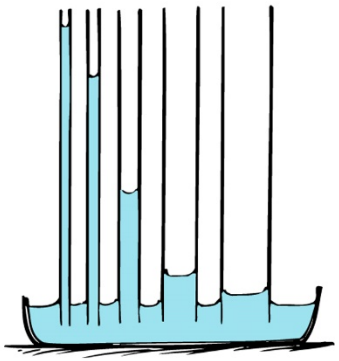
• Water – unusually high surface tension compared to common liquids. Soap or oil floating on water tends to get pulled out into a film entire surface, so to minimize surface area of the *water*.

• Surface tension depends on temperature: Cold water – larger surface tension than hot, since molecules are not moving as fast, so more strongly bonded.

So in hot soups, oil or fat bubbles can form spherical droplets floating on top. When soup cools, the fat is drawn over the entire soup forming a film – "greasy soup". Big reason why cold soup tastes different from hot!

Capillarity

• Another effect of “sticky molecules” in liquid – liquid tends to rise up thin (glass) tubes. The thinner the tube, the greater the rise. Called capillarity.



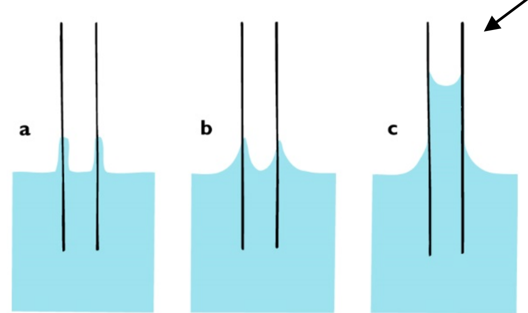
<u>How exactly does this work?</u>

Molecules stick more to glass than to themselves.

adhesion

cohesion

So liquid drawn up to glass surface and then contracts. Steps:

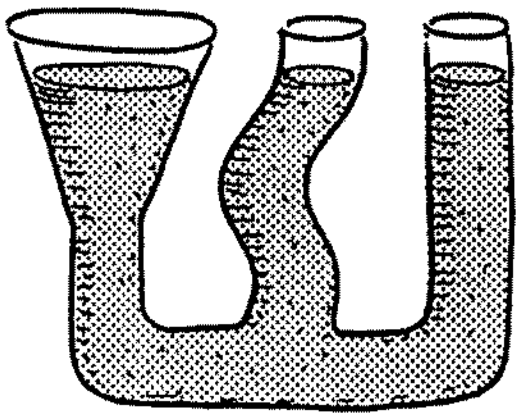


Height reached is determined by balance between upward adhesive force and downward grav. force on column

• Responsible for why if one end of a towel hangs down into water, it soaks upwards

• Essential for plants – how they get the water from the ground into roots and sap up to high branches

Everybody knows that “water seeks its own level,” but very few people know why water seeks its own level. The reason has most to do with



1. atmospheric pressure.
2. water pressure depending on depth.
3. water’s density.

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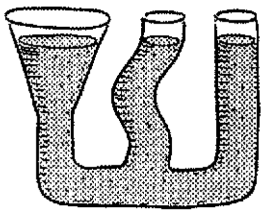


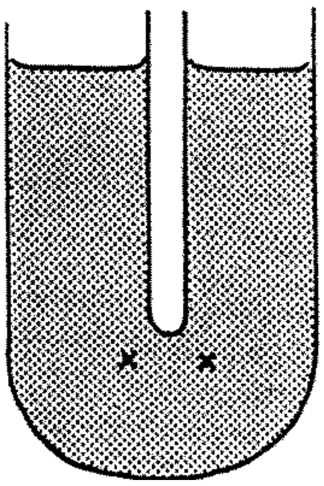
1. atmospheric pressure
2. **water pressure depending on depth.** ✔
3. water's density

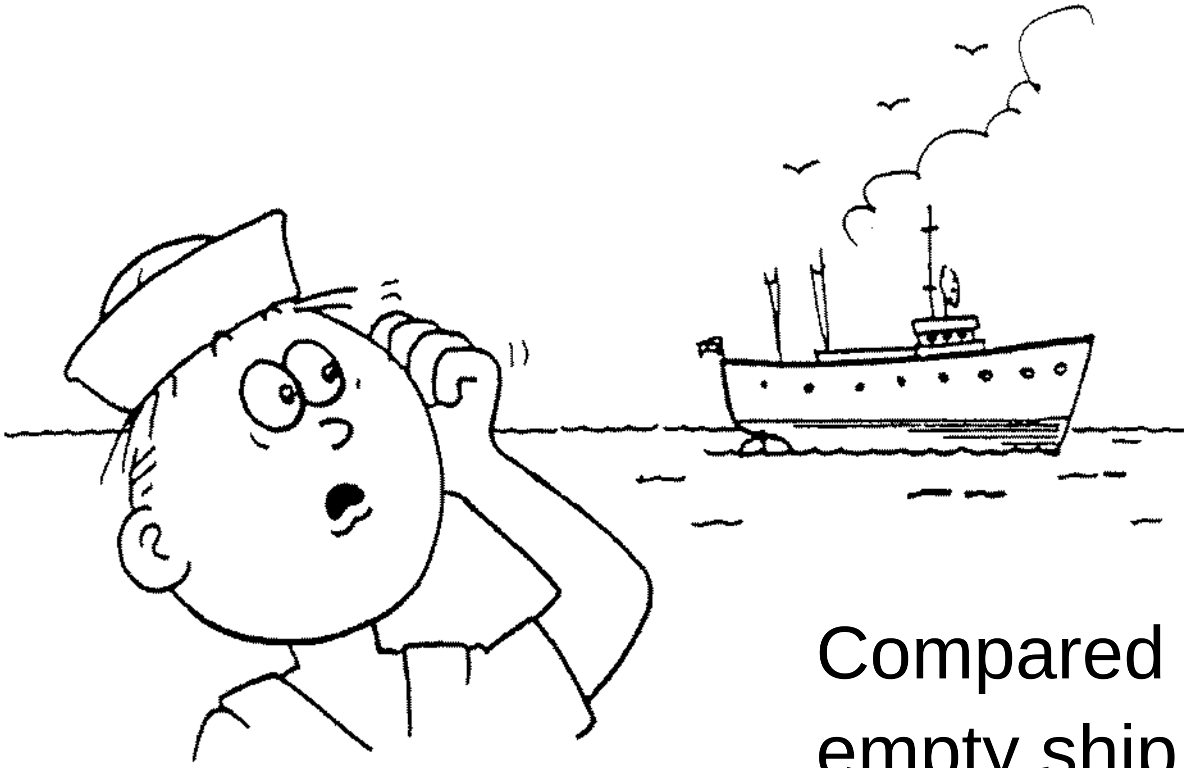
Answer: 2

Water pressure depends on depth, so only at equal depths of water will the pressure be equal.

Consider the U-tube. If water is at rest where each X is, the pressures must be equal—otherwise a flow would occur from the region of higher to the region of lower pressure until the pressures equalize. For this to happen, the depths below the surfaces must be equal.

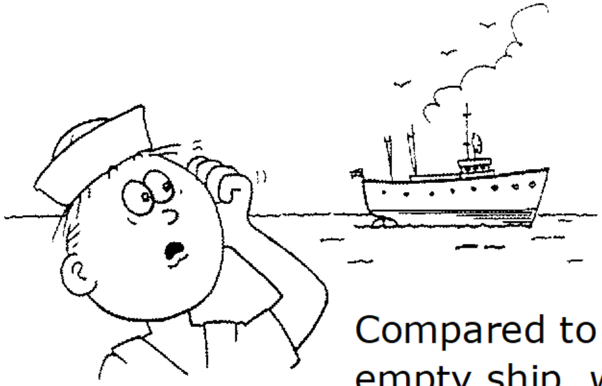
This is true whatever the density of water or whether or not there is atmospheric pressure.





Compared to an empty ship, will a ship loaded with a cargo of Styrofoam float lower in water or higher in water?

1. Lower in water
2. Higher in water



Compared to an empty ship, will a ship loaded with a cargo of Styrofoam float lower in water or higher in water?

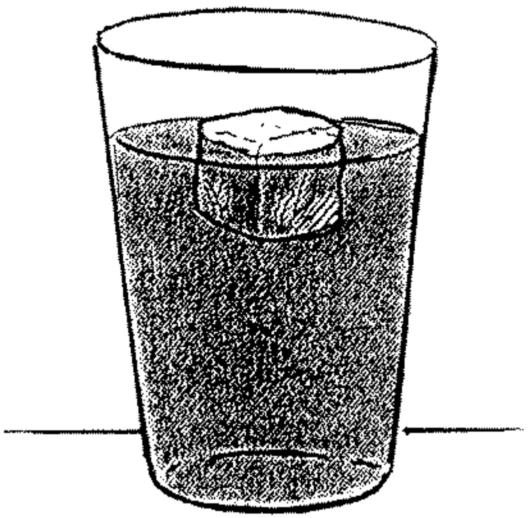
✔ **1. Lower in water** 2. Higher in water

Answer: 1, Lower in water

The ship loaded with Styrofoam will float lower in water. A ship will float highest when its weight is least—that is, when it is empty. Loading any cargo will increase its weight and make it float lower in the water. Whether the cargo is a ton of Styrofoam or a ton of iron, the water displacement will be the same.

An astronaut on Earth notes that in her soft drink an ice cube floats with 9/10 its volume submerged. If she were instead in a lunar module parked on the Moon, the ice in the same soft drink would float with

1. less than 9/10 submerged.
2. 9/10 submerged.
3. more than 9/10 submerged.



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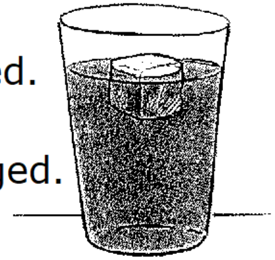
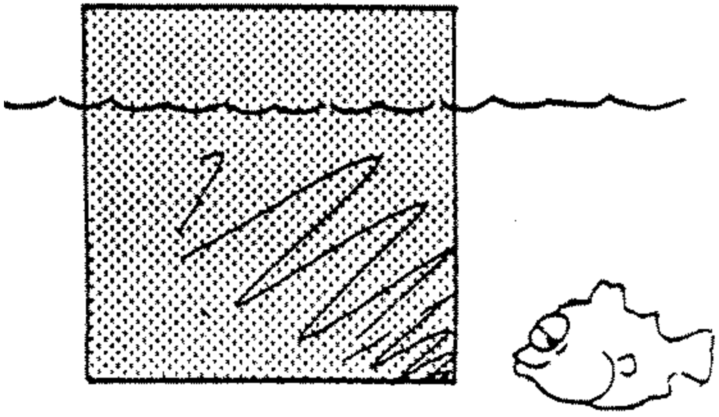


Answer: 2

How much a floating object extends below and above the liquid depends on the weight of the object and the weight of the displaced fluid, both of which are proportional to *g*. Lower *g* or increase it; the proportion floating above and below is unchanged.

The density of the partially submerged block of wood floating in water is

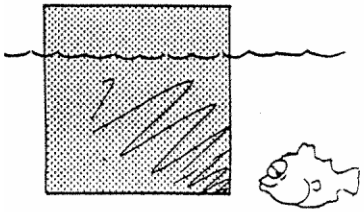


1. greater than the density of water.
2. equal to the density of water.
3. less than half that of water.
4. more than half the density of water.
5. … not enough information is given.

Answer: 4

A very-low-density object, like an inflated balloon, floats high on the water, and a denser object, like a piece of hardwood, floats lower into the water. An object half as dense as water floats halfway into the water (because it weighs as much as half its volume of water). Wood that floats 3/4 submerged, is 3/4 as dense as water—like the block in question—more than half the density of water.

The density of the block of wood floating in water is



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2. equal to the density of water.
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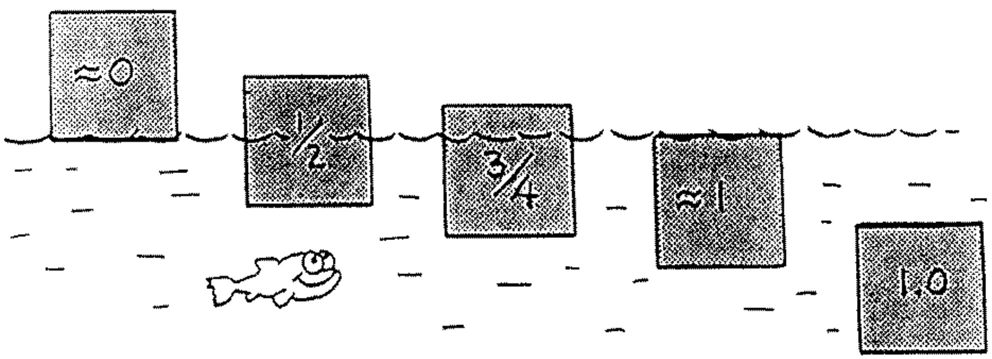
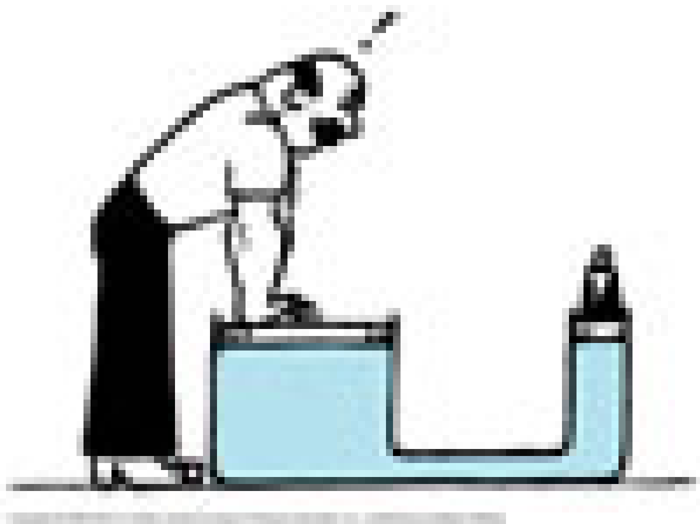
4. ✔ **more than half the density of water.**
5. ~~... not enough information is given.~~



The density of the block compared to the density of water is the same as the fraction of the block below the water line.

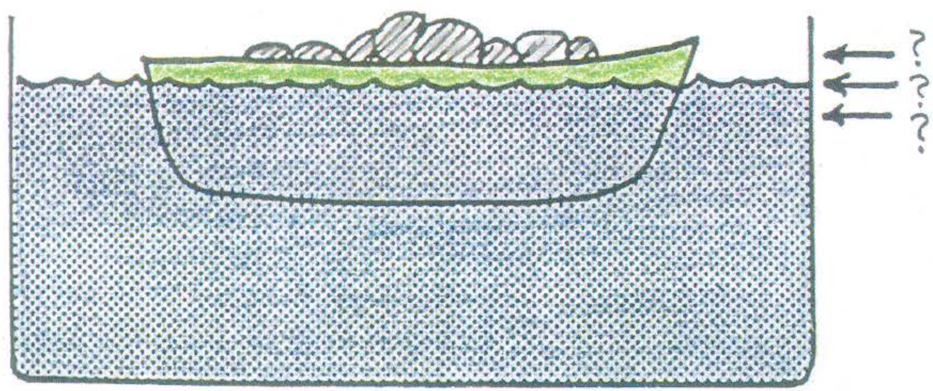
In the hydraulic arrangement here, the larger piston has an area equal to 50 times that of the smaller piston. The strong (not necessarily smart) man hopes to exert enough force on the large piston to raise the 10 kg mass atop the small one. Do you believe he will succeed? Why?



The strong man will be unsuccessful. He will have to push with 50 times the weight of the 10 kilograms. The hydraulic arrangement is arranged to his disadvantage. Ordinarily, the input force is applied against the smaller piston and the output force is exerted by the large piston—this arrangement is just the opposite.

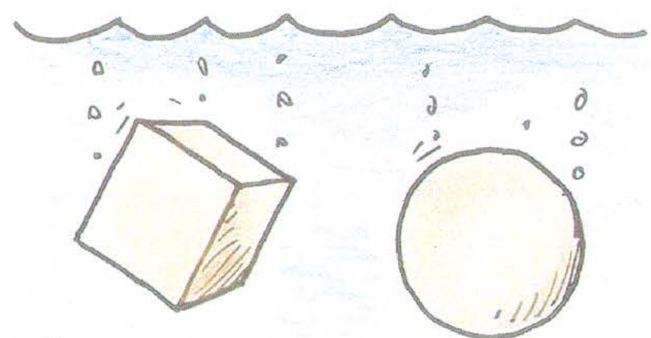
NEXT-TIME QUESTION

Consider a boat loaded with scrap iron in a swimming pool. If the iron is thrown overboard into the pool, will the water level at the edge of the pool rise, fall, or remain unchanged?



Next-Time Question

Consider a solid brass cube and a solid brass sphere that have *equal surface areas.* When both are completely submerged in water, the one experiencing the greater buoyant force is the

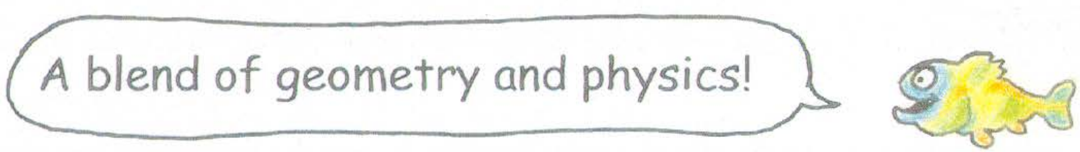


a) cube.

b) sphere.

c) … both the same.

d) … not enough information to say.



thanx to Hasan Fakhruddin

Hewitt Drew it!