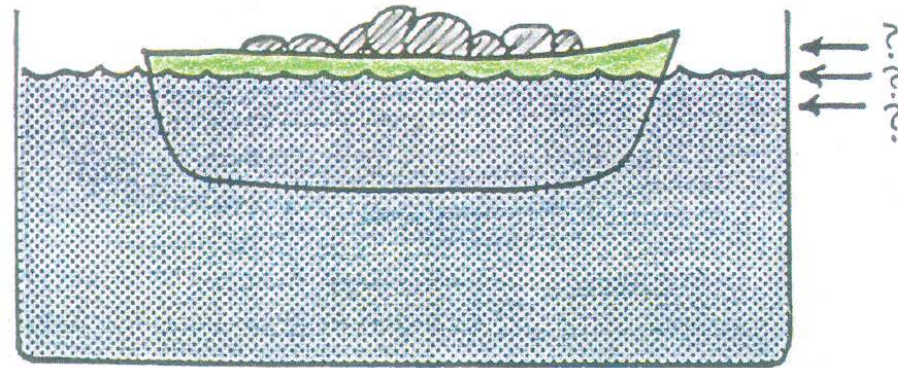


Next-Time Question

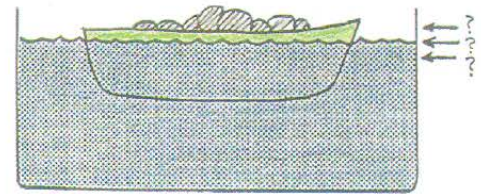
Consider a boat loaded with scrap iron in a swimming pool. If the iron is thrown overboard into the pool, will the water level at the edge of the pool rise, fall, or remain unchanged?



Hewitt
Drewitt!

NEXT-TIME QUESTION

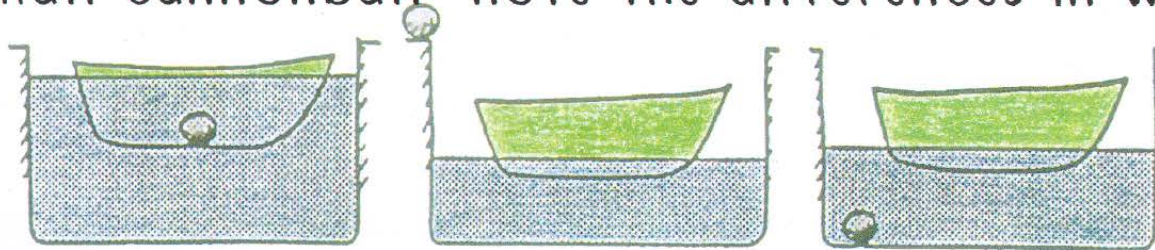
Consider a boat loaded with scrap iron in a swimming pool. If the iron is thrown overboard into the pool, will the water level at the edge of the pool rise, fall, or remain unchanged?



Answer:

The water level at the side of the pool will fall, because the iron will displace less water submerged than when floating. When floating it displaces its weight of water (a lot!)—when submerged it displaces only its volume (less, because iron is more dense than water).

The more exaggerated view shows cases for a very heavy but small cannonball—note the differences in water levels.

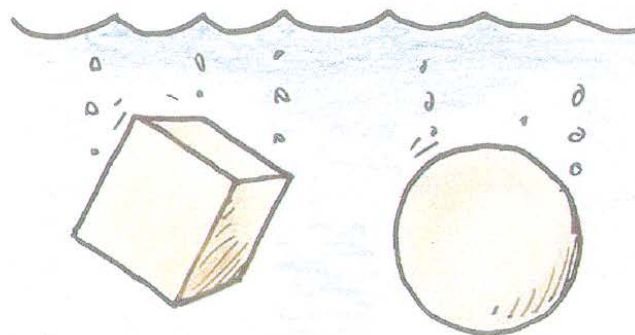


Hewitt
Drewit!

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.



A blend of geometry and physics!



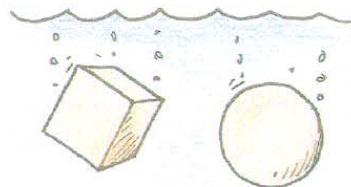
thanx to Hasan Fakhruddin

Hewitt
Draw it!

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.



A blend of geometry and physics!



Answer: b

A sphere confines the largest possible volume within a given surface area. Buoyant force is equal to the weight of displaced water, and the greater-volume sphere displaces a greater volume, and hence greater weight of water than the cube. So the sphere experiences the greater buoyant force.



The cube is made of less brass, has less volume, and experiences less buoyant force.

The surface areas of soap bubbles and water drops are minimized by surface tension. Similarly, the surface areas of stars and planetary bodies are minimized by gravitational forces pulling matter inward. A sphere is the shape of minimum surface area for any substance.



Hewitt
Drawit!

Today:

Chapter 14 (Gases and Plasmas)

Chapter 14: Gases and plasmas

Preliminaries

- Will now apply concepts of fluid pressure, buoyancy, flotation of Ch.13, to the atmosphere.
- Main difference between a liquid like water and a gas like air is that in the gas, the density can vary hugely; our atmosphere's density is depth dependent.
- Gases vs liquids: both are fluids but molecules in gas are far apart and can move much faster, free from cohesive forces.
- A gas will expand to fill all space available
- An “empty” cup is not really empty – it's filled with air. In fact a 1 m^3 “empty” cube of air has a mass of 1.25 kg (at sea level).

Example

Before you go grocery shopping you check what's in the refrigerator and find only a large orange.

Which weighs more, the air in the fridge, or the orange? The fridge has a volume of about 0.75 m^3 .

The air in the fridge!

The mass density of air at 0° C and normal atmospheric pressure is about 1.25 kg/m^3 . So the mass of air in the fridge is

(mass density) \times volume = $1.25 \times 0.75 = 0.94 \text{ kg}$. i.e ~ 2 pounds.

This is more than a large orange.

Note: We don't notice the weight of air because we are submerged in air. If someone handed you a bag of water while you were submerged in water, you wouldn't notice its weight either.

A fish also "forgets" about the weight of water just like we don't notice weight of air.

The atmosphere

- What determines the thickness of our atmosphere?

Balance between:

kinetic energy of molecules

vs

gravity

↑
spreads molecules apart

↙
holds molecules near earth

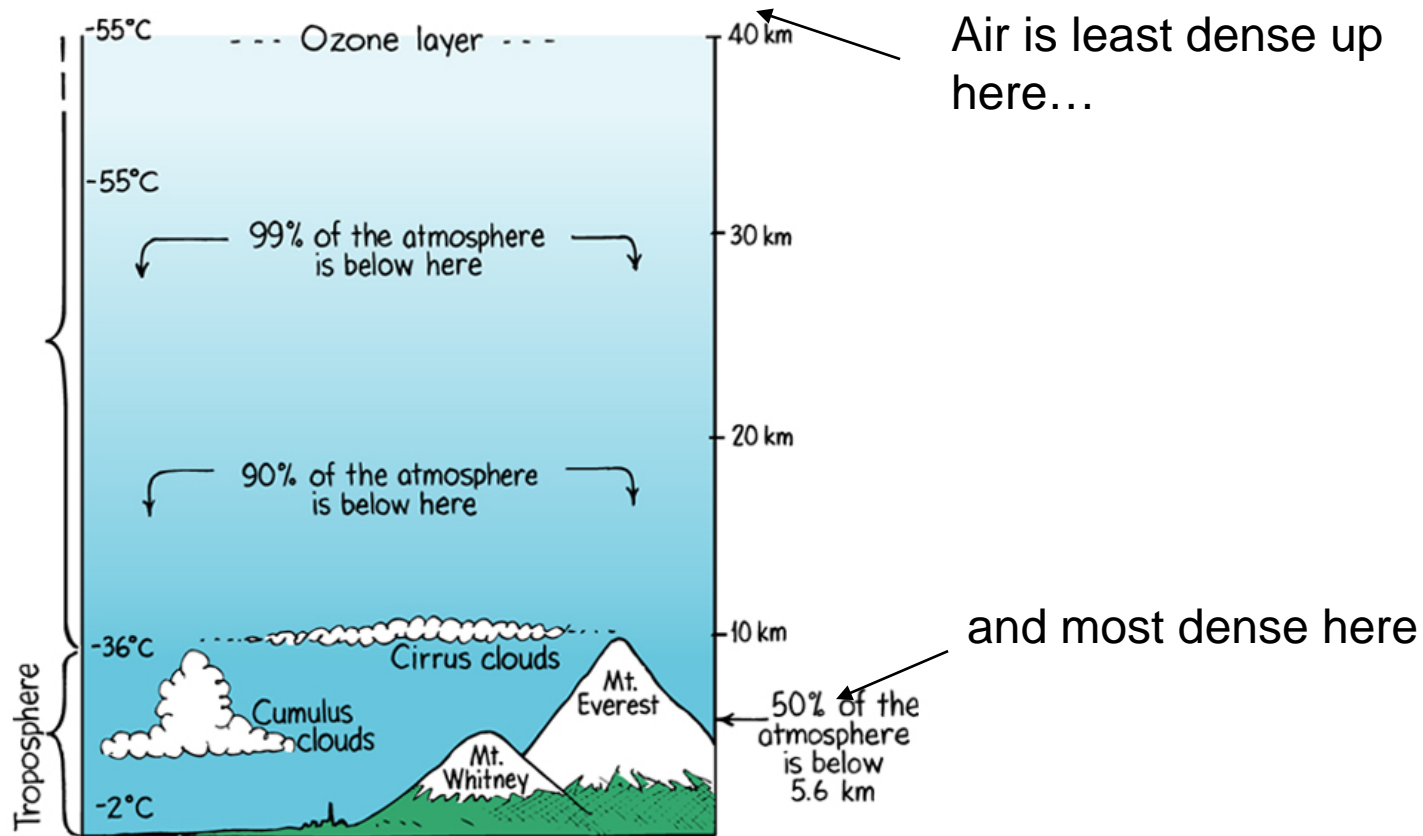
Consider extremes:

- (i) In very little gravity (eg on moon) molecules move, collide, and eventually disappear into space. Hence no atmosphere.
- (ii) If gravity is very strong and kinetic energy not too high (next class – temperature) (eg on a remote planet), molecules move too slowly, and form a liquid or solid, like the planet itself – so again no atmosphere.

Earth – balance between the two effects, so we do fortunately have an atmosphere!
(we can breathe!!)

- Exactly how tall is the atmosphere?

Not a meaningful question, since it gets thinner and thinner as you go higher and higher. Even in interplanetary space, have about 1 gas molecule (mostly hydrogen) every cubic cm..



Atmospheric Pressure

- Atmosphere exerts pressure, like water in a lake. We are at the bottom of an “ocean of air”.
- “Madeburg hemisphere” experiment (1654): Make sphere from 2 copper hemispheres, $\frac{1}{2}$ m in diameter. Evacuate the sphere with vacuum pump. Two teams of 8 horses each couldn’t pull the spheres apart! (see note about Newton III, p.269)



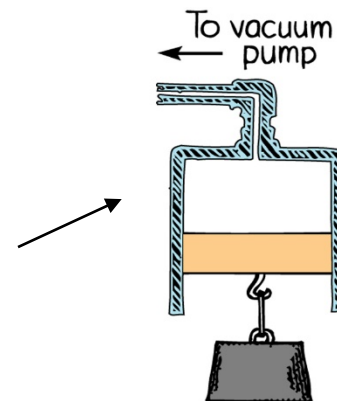
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What is holding the two hemispheres so tightly together?

Atmospheric pressure outside, no pressure inside (vacuum).

Rather than being “sucked together”, they are **“pushed together”** by air molecules.

Same idea behind why the weight is lifted when air is pumped out here – no pressure inside cylinder, so unbalanced atmospheric pressure outside pushes piston upwards, raising the weight.



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Atmospheric pressure cont.

- Unlike water, density of atmosphere varies with height, so pressure relation in terms of depth is not as simple. Not uniform.
- At sea level, 1 m³ of air has mass of 1.25 kg
At 10km height, 1 m³ of air has mass of 0.4 kg
(So you need additional mass of air to pressurize airplanes).

Recall Pressure = Force/area = weight/area.

So to find pressure at sea level, need to calculate weight of a column of air rising up to “top” of atmosphere, say about 30 km.

Find that a 1m² area cylinder, 30 km high, has mass of 10 000kg.

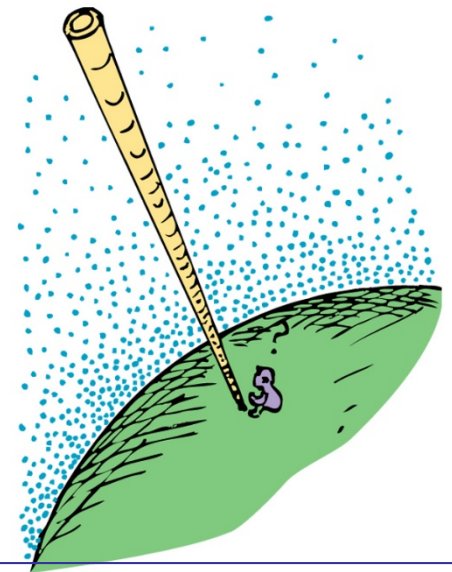
i.e. weight of 100 000 N.

So pressure = 100 000 N/ (1 m)²

= 100 kPa

1 Pa = 1 N/m² = Pascal

Precisely, sea-level atmospheric pressure = 101.3 kPa
a.k.a 14.7 psi



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Question:

Why doesn't the pressure of the atmosphere make our building collapse ?

Atmospheric pressure is exerted on both the inside and outside of the walls of our building, so there is no net force.

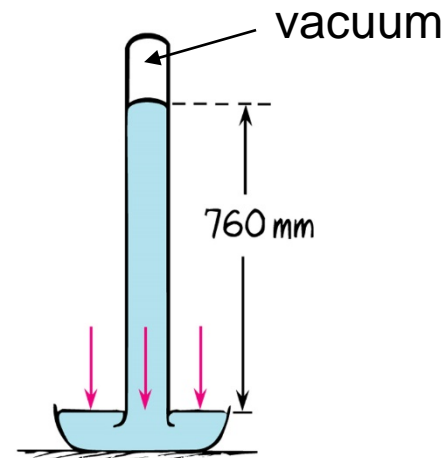
Note that the building (or at least glass windows) can collapse if the pressure is changed a lot on one side (eg tornadoes...)

Barometers

- Measure pressure of atmosphere

- Simple mercury barometer:

Fill tube with mercury and then turn upside down into dish. Mercury runs out into the dish until level in tube is 76 cm, as shown.



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Why 76cm?

Because, of pressure balance: barometer balances when weight of liquid in tube exerts same pressure as atmosphere outside.

It's 76cm, regardless of how wide the tube is: weight of any 76cm column of mercury equals weight of same width column of 30 km of air.

If atmospheric pressure increases, then air pushes down harder on the mercury , so column pushed up higher than 76 cm.

Barometers cont.

- How about a barometer made of water?

Why not – but how tall would the glass tube have to be?

The weight of the water column would need to be the same weight as 76cm column of mercury, but density of water is 13.6 x less than the density of mercury – hence, water barometer would have to be (at least) $13.6 \times 76\text{cm} = 10.3 \text{ m}$ tall. Again, regardless of tube's width.

- This also explains why you can't get water to be more than 10.3m tall, with a vacuum pump.
- [How to make a vacuum? Read in your book a little about it (we won't go into it much here).]
- Just like barometer, when you drink through a straw, it's the atmospheric pressure outside the straw that is pushing the water up. See next slide.

Question: Why is it hardly possible to drink sodas on the moon with straws?

Because what makes the drink go up the straw is the atmospheric pressure and this is essentially zero on the moon. It's this that pushes the drink up the straw, in which your sucking has created much less pressure.



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DEMO: (tease your friends at the bar with this!) You can't get much drink this way, because of the straw poking outside – the pressure inside your mouth is not reduced.

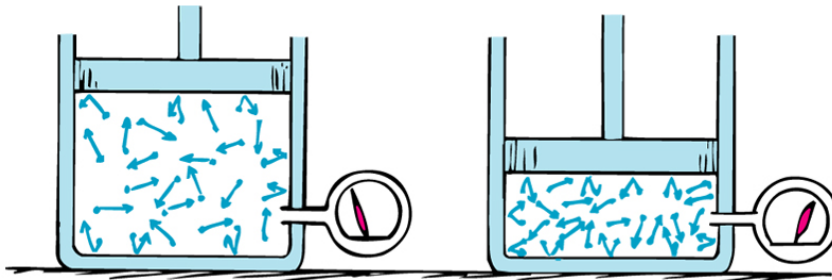


Boyle's Law

- When you increase the pressure of a confined gas, how does the volume change? And vice-versa? This is Boyle's law:

$$P_1 V_1 = P_2 V_2 \quad \text{for a fixed temperature.}$$

i.e. - If you halve the volume of container, the pressure is doubled, since more collisions (bouncing) between molecules and with walls.



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Effectively, the density is doubled.

pressure \sim density (at fixed temp)

proportional to

Notes: (i) fixed temperature means fixed average speed of molecules (next class)

(ii) strictly speaking, Boyle's law applies to "ideal gases" – i.e. when neglect any "sticky" forces between molecules and treat them as point particles.

At normal temps and pressures, air is well-approximated to be an ideal gas.

Buoyancy of Air

An object surrounded by air is buoyed up by a force equal to the weight of the air displaced.

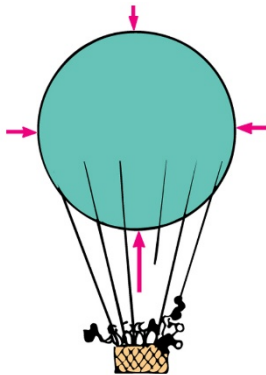
c.f. Archimedes principle for liquids in the previous chapter.

- An object will rise in air (ie float upward) if its density is less than the density of air:

Why?

Downward grav force (= weight-density x volume) is then less than upward buoyant force (= weight-density-of-air x volume). So there is a net upward force.

Eg. He-gas filled balloon (or heated air balloon – since hot air is less dense than normal air)



Greater buoyancy if the helium could be evacuated – but not practical since how would keep the balloon sides from collapsing in? Could use stronger material but then weight is too large, so wouldn't rise at all...

Question

A large block of styrofoam and a small block of iron have identical weights on a weighing scale.

Which has greater mass?

Hint: First answer which experiences a larger buoyancy force?

Because of its greater volume, the styrofoam displaces more air so experiences larger buoyancy force upwards. The weight of anything measured in air is its “true weight” (mg) minus buoyant force – if this net force is same for both, then the mg of styrofoam must be larger, i.e. it has a greater mass.

Differences with buoyancy in air and liquid

- Important differences:
 - (i) due to the air density becoming less as you go higher (liquid density remains about the same). So **buoyant force decreases as you rise** in atmosphere (but stays same while rise in water).
 - (ii) there is no “top” to the atmosphere (it just keeps thinning out), unlike liquid surface.
- Consequence: a light balloon released from bottom of ocean will rise all the way to water’s surface; whereas if released from surface of earth, will stop rising at a certain height.
- Why, and how high will a helium balloon rise?

When buoyant force on balloon equals its weight, it will stop accelerating upwards. (Buoyant force = displaced-weight-of-air, so for same volume of balloon, this decreases as it rises because air is becoming less dense).

May continue to rise at the const. speed it reached (but will slow due to air resistance).

If balloon material is able to expand, then it will as it rises, as there’s less pressure outside, so will displace a greater volume of air – net effect is that buoyant force remains same. If it continues to expand, it will eventually pop...

Moving fluids

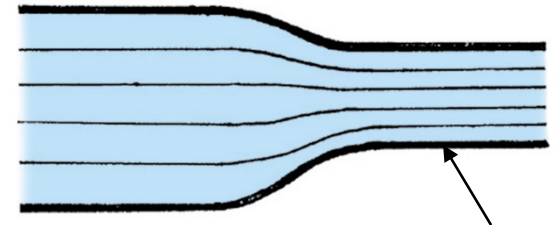
- So far, talked about stationary fluids (*hydrostatics*). When fluids are moving, (*hydrodynamics*), have additional effects.
- Consider water moving through pipe of varying thickness:

The volume passing through any cross-section is the same in a given time interval.

So, in narrower region, speed must be faster.

Eg. Squeeze on end of garden hose, water speeds up.

Eg. River entering a narrow gorge speeds up.



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Water flows faster here

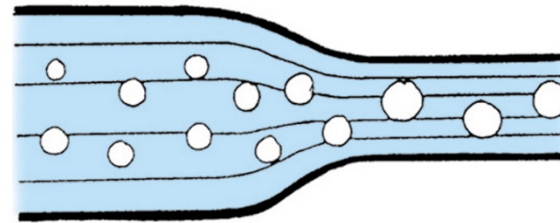
- Streamlines –(eg thin lines above) represent paths (trajectories) of parts of fluid. So are closer together in narrower regions where flow is faster.

Bernoulli's Principle

Where the speed of a fluid increases, internal pressure in the liquid decreases.

Can see from increase in size of bubbles in narrower regions:

(how big a bubble is depends on the surrounding water pressure)



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- Bernoulli's principle is actually a consequence of energy conservation, but we won't get into that here (can read a bit about it in the text).
- Bernoulli's principle holds when
 - (i) the *temperature, density, and elevation* of fluid remains about *constant*.
 - (ii) when flow is *laminar* (i.e. smooth, steady), and not turbulent (i.e chaotic)

Note: Distinction between internal and external pressure
within liquid → exerted by fluid on something

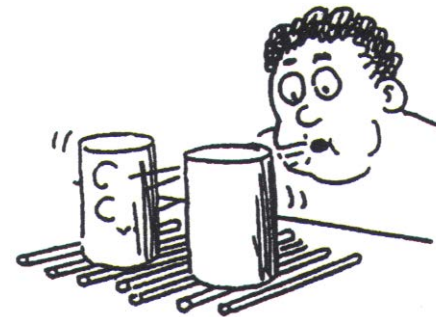
Eg. using high-speed water jets to cut steel – external pressure

Examples

DEMO: Hold piece of paper horizontally up to mouth and blow across it. What happens?

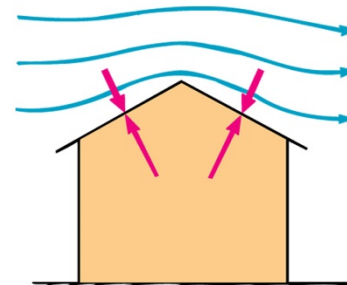
Paper rises! Blowing causes greater air speed above, so decreases internal pressure above c.f. below.

ANOTHER DEMO: (try also at home!)
Balance two empty light bottles or cans on straws and blow between them – they move together!



Eg. Messed up hair while riding in a car with open top – your hair rises! Pressure outside is less since air is moving (relatively) whereas air inside is static.

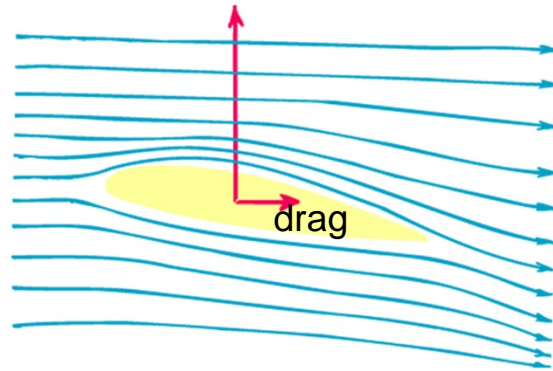
Eg. Why during storm, roof might blow off: fast moving air above (bunched up streamlines), so less air pressure above than inside.



More examples/applications

- Eg. Bernoulli's pr. is not always a bad thing – eg design of airplane wings, make air flow faster over the top surface, by a tilt in the wing, called *angle of attack*. Also, the shape of the wing is designed for lift.

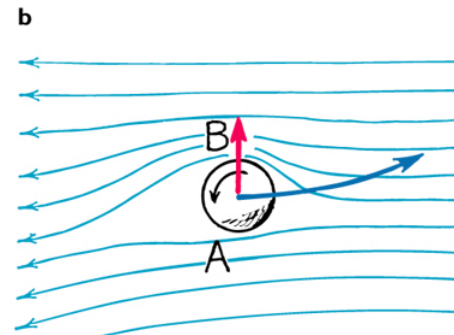
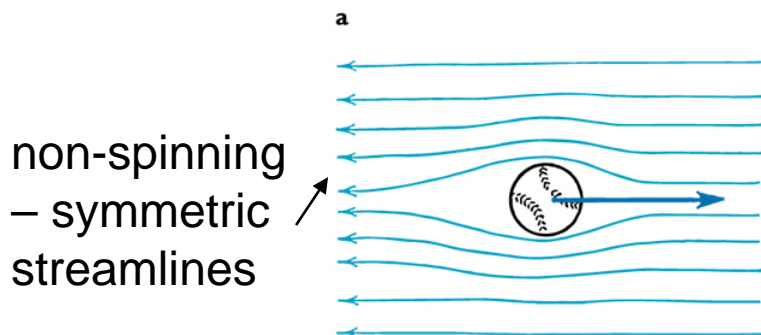
net upward force (*lift*)



Increased lift for larger wing surface area and larger speeds.

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- Eg. Spinning baseball – drags a thin layer of air around with it (frictional effect) :



Motion of air relative to ball

spinning – air pressure greater at B than A, so ball curves up

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- See book for many more interesting examples! (from insects to shower curtains...)

Plasma

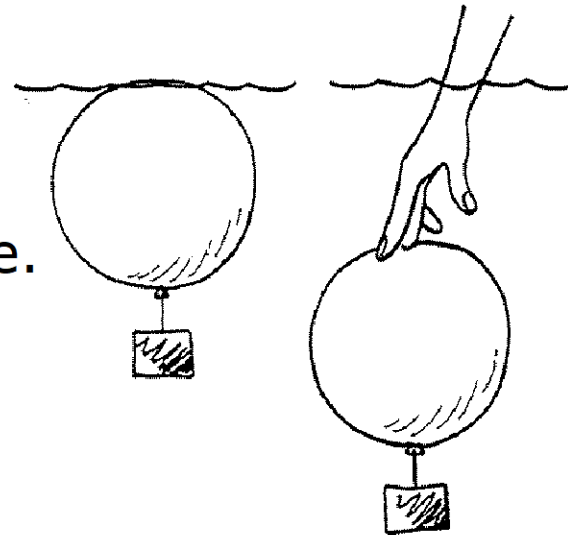
- Fourth phase of matter: **electrified gas**.
- Least common in every day life and environment, but most common in the universe as a whole. The sun and other stars are mostly plasma.
- Made of **ions and free electrons**
atoms/molecules stripped of one
or more electrons. So is positively charged.

Plasma as a whole is neutral, since electrons' charges cancel ions' charges.

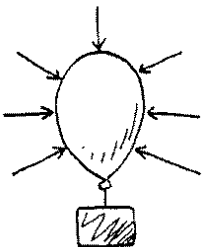
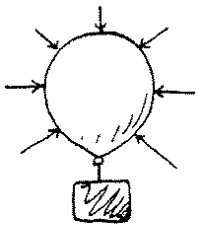
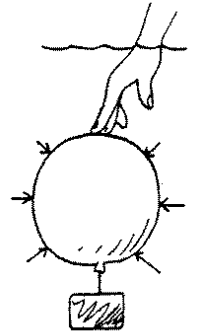
- Conducts electric current, absorbs radiation that gases would be transparent to, can be shaped and moved by electric and magnetic fields.
- To create in a lab: either heat gas very high, to “boil” off electrons, or, can bombard atoms with high-energy particles or radiation to strip off electrons
- Naturally found in our sun and other stars, ionosphere, van Allen radiation belts around Earth, aurora borealis/australis
- Fluorescent lamps, neon lights
- Read (a bit) more in your book if you are interested.

Consider an air-filled balloon weighted so that it is on the verge of sinking—that is, its overall density just equals that of water. Now if you push it beneath the surface, it will

1. sink.
2. return to the surface.
3. stay at the depth to which it is pushed.



NOTE: the balloon is compressible.

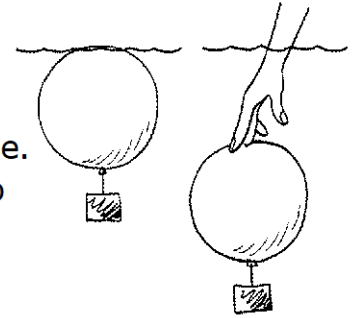


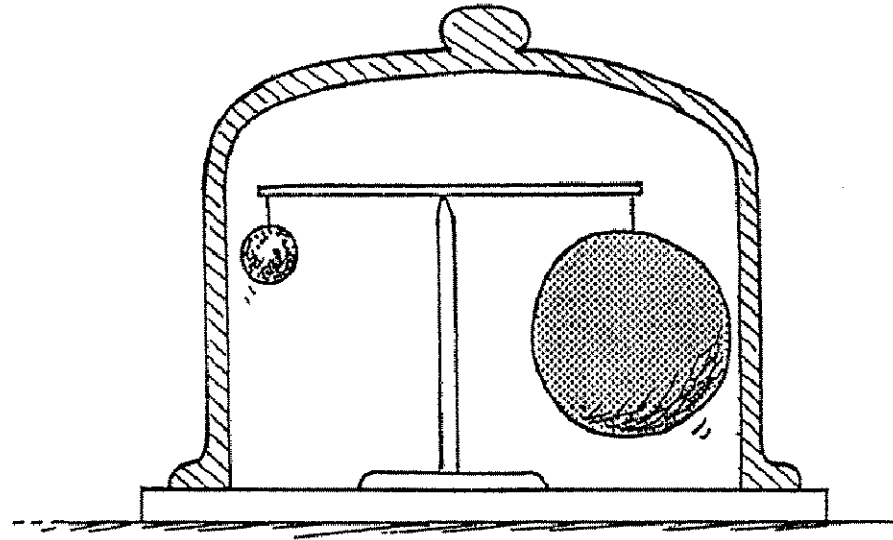
Answer: 1, sink

Because at deeper levels the surrounding water pressure is greater and will squeeze and compress the balloon—its density increases. Greater density results in sinking. Or look at it this way: at the surface its buoyant force is just adequate for equilibrium. When the buoyant force is reduced—it's inadequate for equilibrium.

Consider an air-filled balloon weighted so that it is on the verge of sinking—that is, its overall density just equals that of water. Now if you push it beneath the surface, it will

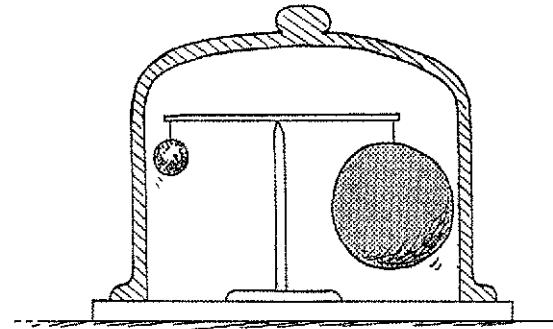
- ✓ **1. sink.**
- 2. return to the surface.
- 3. stay at the depth to which it is pushed.





In the presence of air, the small iron ball and large plastic ball balance each other. When air is evacuated from the container, the larger ball

1. rises.
2. falls.
3. remains in place.



In the presence of air, the small iron ball and large plastic ball balance each other. When air is evacuated from the container, the larger ball

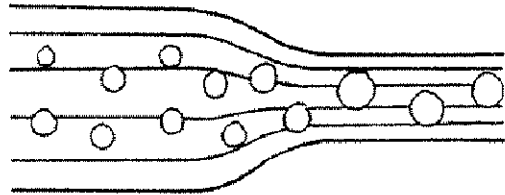
1. rises.
- ✓ 2. **falls.**
3. remains in place.

Answer: 2

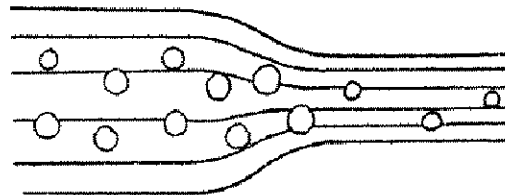
This is just like the example on an earlier slide during lecture.

Before evacuation, the forces acting on each ball are the gravitational force, the force exerted by the balance beam and the upward buoyant force exerted by the surrounding air. Evacuating the container removes the buoyant force on each ball. Since buoyant force equals the weight of air displaced, and the larger ball displaces the greater weight of air, the loss of buoyant force is greater for the larger ball, which falls.

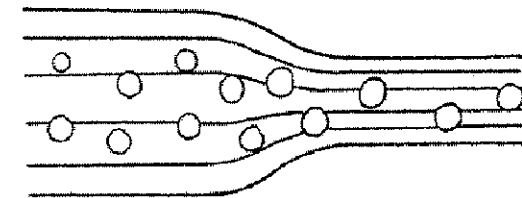
Water with air bubbles flows through a pipe that becomes narrower. In the narrow region the water gains speed and the bubbles are



1. larger.

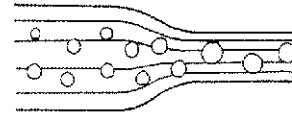


2. smaller.

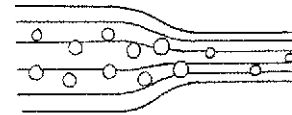


3. the same size.

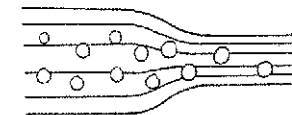
Water with air bubbles flows through a pipe that becomes narrower. In the narrow region the water gains speed and the bubbles are



✓ **1. larger.**



2. smaller.



3. the same size.

Answer: 1 larger

As water gains speed, pressure in the water decreases from Bernoulli's principle. Decreased water pressure squeezes less on air bubbles, allowing them to expand—so that air pressure and surrounding water pressure match. If the flowing water continues its flow into a wider section of pipe, speed decreases, pressure increases, and the bubbles become smaller.

A little girl sits in a car at a traffic light holding a helium-filled balloon. The windows are closed and the car is relatively air-tight. When the light changes and the car accelerates forward, her head pitches backward but the balloon pitches forward. Explain.



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The air tends to pitch toward the rear (law of inertia), becoming momentarily denser at the rear of the car, less dense in the front. Because the air is a gas obeying Boyle's law, its pressure is greater where its density is greater. Then the air has both a vertical and a horizontal "pressure gradient." The vertical gradient, arising from the weight of the atmosphere, buoys the balloon up. The horizontal gradient, arising from the acceleration, buoys the balloon forward. So the string of the balloon makes an angle. The pitch of the balloon will always be in the direction of the acceleration. Step on the brakes and the balloon pitches backwards.

Why do airplanes extend wing flaps during takeoff and landing?

Greater wing area produces greater lift, important for low speeds where lift is less. Flaps are pulled in to reduce area at cruising speed, reducing lift to equal the weight of the aircraft.

Why are runways longer for takeoffs and landings at high altitude airports such as those in Denver and Mexico City?

The thinner air at high-altitude airports produces less lift for aircraft. This means aircraft need longer runways to achieve correspondingly greater speed for takeoff.