

**Today:**

**Finish Chapter 13 (Liquids)**

**Start Chapter 14 (Gases and Plasmas)**

# 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 unlike liquid's
- 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
- Note! An “empty” cup is not really empty – it's filled with air. In fact a  $1 \text{ m}^3$  “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  $0.75 \text{ m}^3$ .

The air in the fridge!

The mass density of air at  $0^\circ \text{ C}$  and normal atmospheric pressure is about  $1.25 \text{ kg/m}^3$  (see last slide). So the mass of air in the fridge is

(mass density) x 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

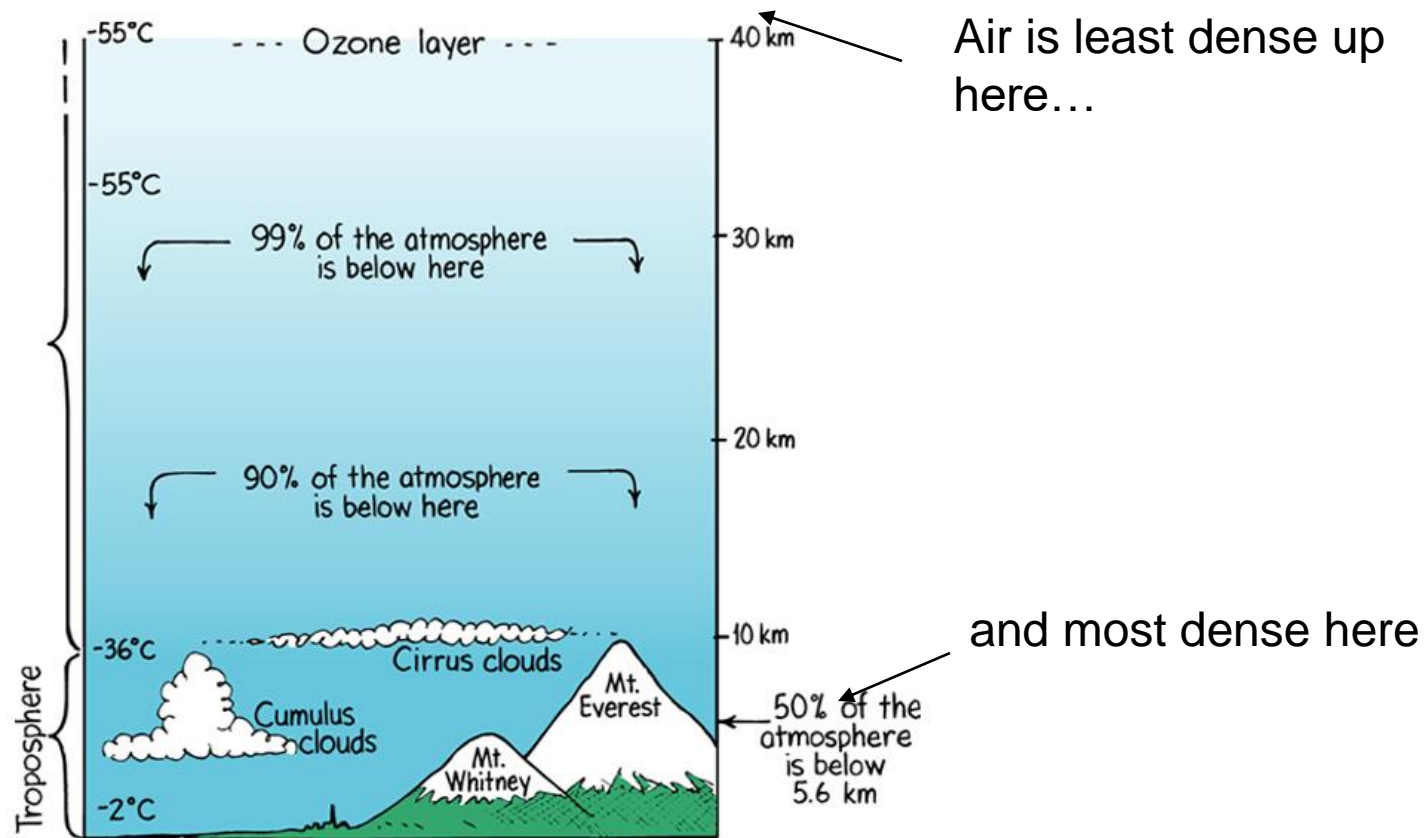
Consider extremes:

- (i) If very little gravity (eg on moon), then molecules would move, collide, and eventually disappear into space. So no atmosphere.
- (ii) If gravity very strong *c.f.* kinetic energy (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!!)

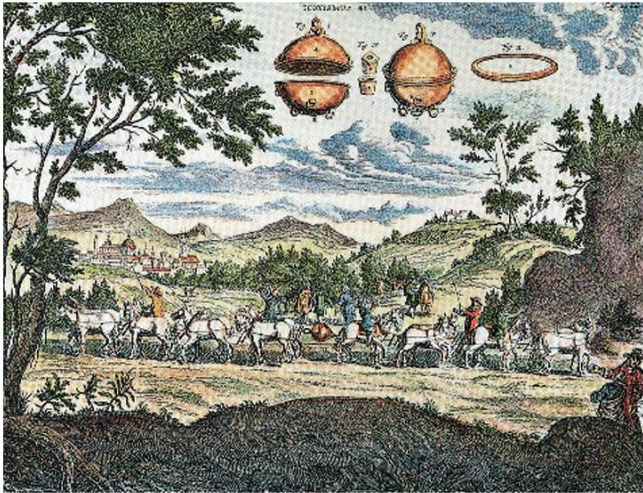
- Exactly how tall is the atmosphere?

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 meter.



# Atmospheric Pressure

- Atmosphere exerts pressure, like water in a lake. We are at the bottom of an “ocean of air”.
- “Magdeburg 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!



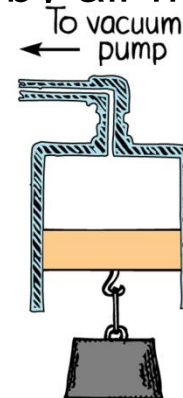
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What is holding the two hemispheres so tightly together?

Atmospheric pressure outside, no pressure inside (since 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 atmos pressure outside pushes piston upwards, raising the weight.



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

Because what makes the drink go up the straw 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.

i.e. when drinking with a straw, it's the atmospheric pressure that pushes the drink up to your mouth where there is less pressure since by sucking you're reducing the air pressure in your mouth.

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



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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 m<sup>3</sup> of air has mass of 1.25 kg  
At 10km height, 1 m<sup>3</sup> of air has mass of 0.4 kg

(this is why 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.

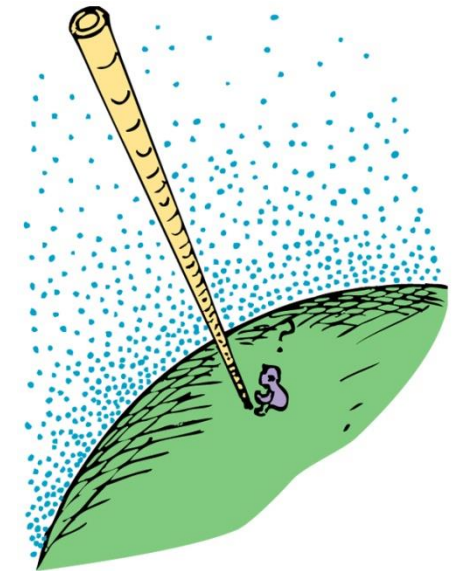
Find that a 1m<sup>2</sup> area cylinder, 30 km high, has mass of 10 000kg.

i.e. weight of 100 000 N.

So pressure = 100 000 N/ (1 m)<sup>2</sup>

= 100 kPa

1 Pa = 1 N/m<sup>2</sup> = Pascal



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Precisely, sea-level atmospheric pressure = 101.3 kPa



# **Clicker Question**

# 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.

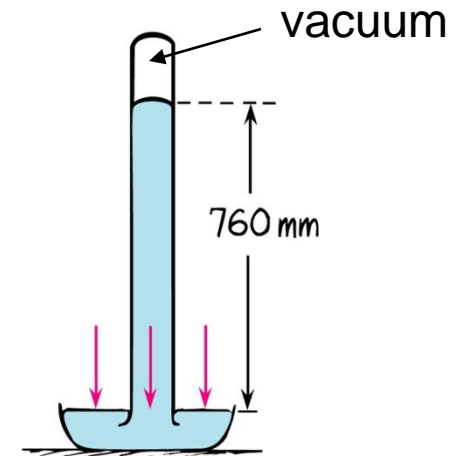
Note that the building (or at least glass windows) can collapse if the pressure is changed a lot on one side (eg tornadoes...)

# 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.

# Buoyancy of Air

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

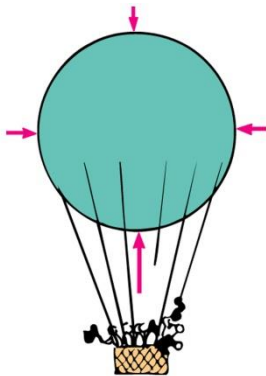
*c.f.* Archimedes principle for liquids in the previous chapter.

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

Why? (*c.f.* sinking vs floating in previous chapter)

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...

# **Clicker Question**

# Clicker Question

# 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 rigid 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. Then it 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

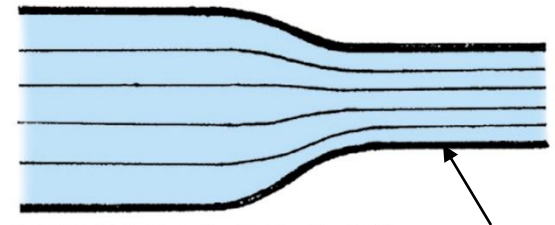
- So far, talked about stationary fluids (*hydrostatics*). When fluids are moving, (*hydrodynamics*), have additional effects.
- Consider water moving through pipe of varying thickness:

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

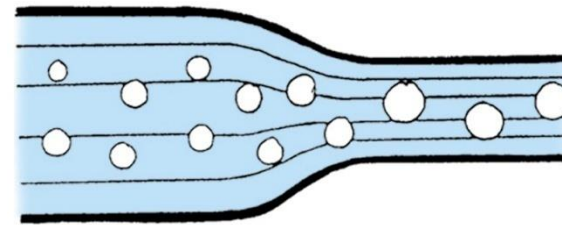
- Streamlines –(eg thin lines above) represent paths (trajectories) of parts of fluid. So are closer together in narrower regions where flow is faster.

# 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 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

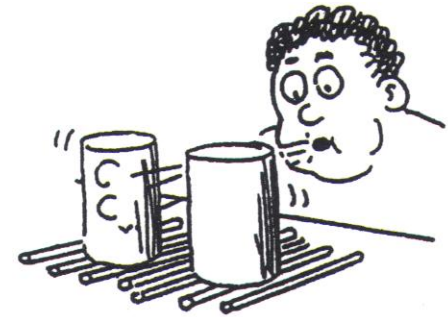
Eg. using high-speed water jets to cut steel – external pressure

# Examples

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

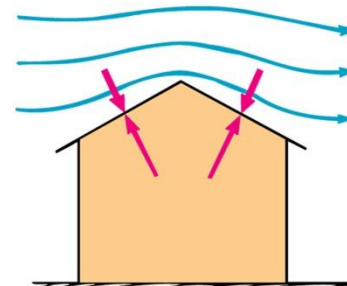
Paper rises! Blowing causes greater air speed above, so decreases internal pressure above c.f. below.

**ANOTHER DEMO:** (try also at home!)  
Balance two empty light bottles or cans on straws and blow between them – makes them move towards each other!



**Eg.** Messed up hair-dos 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.

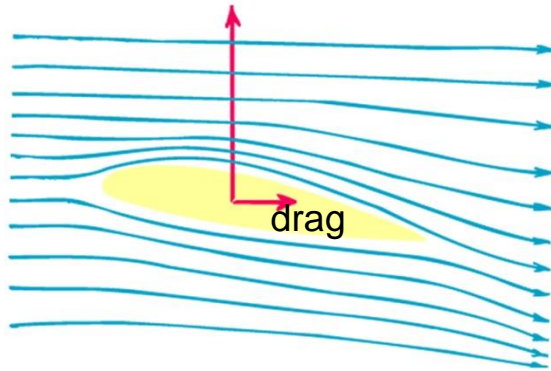
**Eg.** Why during storm, roof might blow off: fast moving air above (bunched up streamlines), so less air pressure above than inside.



# 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*.

net upward force (*lift*)

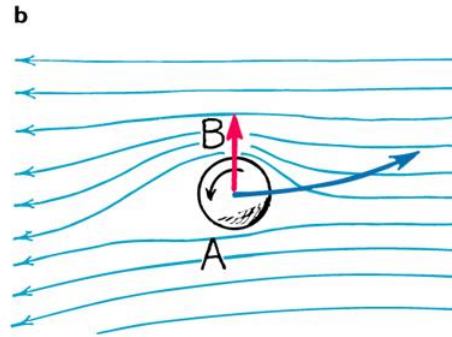
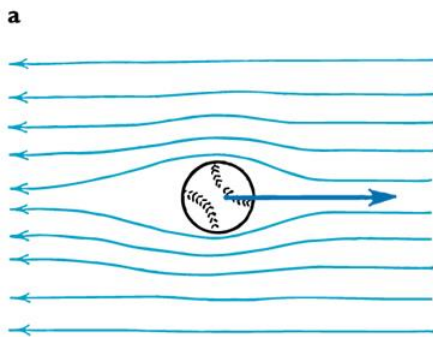


Increased lift for larger wing surface area and larger speeds.

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

non-spinning  
– symmetric  
streamlines



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...

## Clicker Question