Balloons

Turn off all electronic devices

Observations about Balloons

Balloons are held taut by the gases inside

Some balloon float in air while others don't

Hot-air balloons don't have to be sealed and most are not

Helium balloons leak even when they are sealed

5 Questions about Balloons

1. How does air inflate a rubber balloon?
2. Why doesn't the atmosphere fall or collapse?
3. Why does the atmosphere push up on a balloon?
4. Why does a hot air balloon float in cold air?
5. Why does a helium balloon float in air?

Question 1

Q: How does air inflate a rubber balloon?

A: Its pressure pushes the balloon's skin outward

Air is a gas—a fluid consisting of individual atoms and molecules

Air has pressure—a force that is extended over a surface

The pressure inside a balloon is greater than the pressure outside

- The net forces due to pressure on balloon skin are outward
- Balloon is held taut by those outward pressure forces

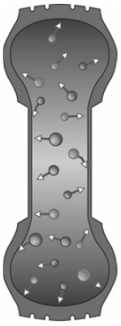
Air and Pressure

Air consists of individual atoms and molecules

- Thermal energy keeps them separate and in motion
- Air particles bounce around in free fall, like tiny balls

Air particles transfer momentum as they bounce

- Each momentum transfer involves tiny forces
- A surface exposed to air experiences a force
- The force on a surface is proportional to its surface area
- The force per unit of area is the air's pressure
- The SI unit of pressure is the pascal (or newton/meter^2)



Pressure Imbalances

Balanced pressures exert no net force on a surface

- The pressure forces on two sides of a surface are balanced
- The net pressure force on that surface is zero

Unbalanced pressures exert a net force

- The pressure forces on two sides of a surface don't balance
- The net pressure force on that surface is non-zero
- The unbalanced pressures push the surface toward the lower pressure

Unbalanced pressures affect the air itself

- The air is pushed toward lower pressure
- Unbalanced air pressure can support air's weight or cause it to accelerate

Question 2

Q: Why doesn't the atmosphere fall or collapse?

A: Its non-uniform pressure allows it support its own weight

Air has a density—mass per unit of volume

As air's density increases, its particles

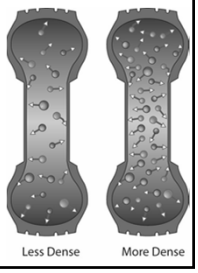
- bounce more often
- produce greater air pressure,
- so air's pressure is proportional to its density

Earth's gravity acts on air molecules

- gives air a weight per unit of volume
- so air's weight is proportional to its density

The atmosphere has a non-uniform density

- its non-uniform pressure supports its weight



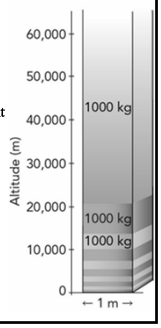
The Atmosphere

Supporting its weight structures the atmosphere

- Each layer of air has a weight
- That weight is supported by a pressure imbalance
- The net force on each layer is zero
- Each layer supports the weight of all of the air above it

The atmosphere is in stable equilibrium

- The air pressure decreases continuously with altitude
- The atmosphere has a downward pressure gradient



Question 3

Q: Why does the atmosphere push up on a balloon?

A: Its pressure gradient pushes the balloon upward

Because of atmospheric structure, the air pressure is

- larger near the bottom of a balloon,
- smaller near the top of the balloon,
- so the air pushes up on the balloon harder than it pushes down,
- The net upward pressure force is the buoyant force on the balloon

The atmosphere pushes upward on the balloon!

Archimedes' Principle

A balloon immersed in a fluid experience an upward buoyant force equal to the weight of the fluid it displaces

Question 4

Q: Why does a hot air balloon float in cold air?

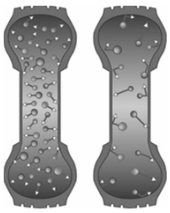
A: It weighs less than the air it displaces

As the temperature of air increases, its particles

- move faster, bounce harder, and bounce more often
- contribute more to air's pressure

A balloon filled with hot air at ordinary pressure

- contains fewer particles than the air it displaces
- weighs less than the air it displaces
- experiences a buoyant force that exceeds its weight



An Aside About Temperature

Air's temperature on a conventional scale is

- related to average thermal kinetic energy per particle

Air's temperature on an absolute scale is

- proportional to average thermal kinetic energy per part.

SI unit of absolute temperature: kelvins or K

- 0 K is absolute zero: no thermal energy available
- Step size: 1 K step same as 1 °C step
- Room temperature is approximately 300 K

Question 5

Q: Why does a helium balloon float in air?

A: It weighs less than the air it displaces

Compared with air, the particles in helium gas

- are lighter, but move faster and bounce more often
- contribute just as much to pressure

A balloon filled with helium at ordinary pressure

- contains as many particles as the air it displaces
- weighs less than the air it displaces
- experiences a buoyant force that exceeds its weight

Pressure and Particle Density

Particle density: particles per volume

Particles in a gas contribute equally to pressure, regardless of mass

- lower-mass particles move faster and bounce more,
- so all the effects of particle mass cancel out!

Gases with equal particle densities and equal temperatures have equal pressures

The Ideal Gas Law

is a summary relationship for gases:

$$\text{pressure} = \text{Boltzmann constant} \cdot \text{particle density} \cdot \text{absolute temperature}$$

- It assumes perfectly independent particles
- While real gas particles aren't perfectly independent, this law is a good approximation for real gases.

Summary about Balloons

A balloon will float if its average density is less than that of the surrounding air

A hot-air balloon has a lower particle density and a lower density than the surrounding air

A helium balloon has the same particle density but a lower density than the surrounding air