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

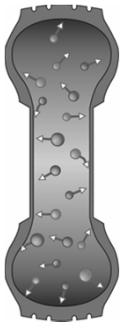
Q: How does air inflate a rubber balloon?

A: Its pressure pushes the balloon's skin outward

- Air is a gas: individual atoms and molecules
- Air has pressure: it exerts a force on a surface
- Pressure inside a balloon is greater than outside
  - Total pressure forces 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 area
  - The force per area is the air's pressure



Pressure Imbalances

- Balanced pressures exert no overall force
  - Pressure forces on two sides of a surface are balanced
  - Overall pressure force on that surface is zero
- Unbalanced pressures exert an overall force
  - Pressure forces on two sides of a surface don't balance
  - Overall pressure force on that surface is non-zero
  - Imbalance pushes surface toward the lower pressure
- Unbalanced pressures affect the air itself
  - The air is pushed toward lower pressure

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Question 2

Q: Why doesn't the atmosphere fall or collapse?
A: A gradient in its pressure supports its weight

- Air has a density: it has mass per volume
- Air's pressure is proportional to its density
- Air's density gives it a weight per volume
- The atmosphere is in equilibrium
  - Its density and pressure decrease with altitude
  - The resulting pressure imbalances support its weight

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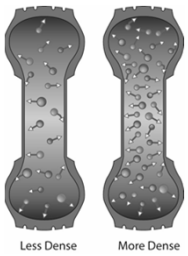
Air and Density

- Squeezing air particles more closely together
  - increases the air's density: its mass per volume
  - increases the air's pressure: its force per area
  - increases the air's weight per volume



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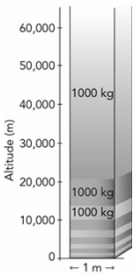
The Atmosphere

- Supporting its weight structures the atmosphere
  - A pressure imbalance supports each layer's weight
  - Air pressure decreases with altitude, a pressure gradient
  - Each layer supports all of the air above it
  - Net force on each layer is zero
  - The atmosphere is in stable equilibrium



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Question 3

Q: Why does the atmosphere push up on a balloon?
A: Its pressure gradient pushes the balloon upward

- Because of atmospheric structure, air pressure is
  - stronger near the bottom of a balloon,
  - weaker near the top of the balloon,
  - so the air pushes up harder than it pushes down,
  - and this imbalance yields an upward buoyant force
- The atmosphere pushes upward on the balloon!

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Archimedes' Principle

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

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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

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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

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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

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Pressure and Particle Density

- Particle density: particles per volume
- Particles in a gas contribute equally to pressure
  - 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

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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.

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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