THE BIG IDEA: Gas molecules are far apart and can move freely between collisions.

Gases are similar to liquids in that they flow; hence both are called *fluids*. In a gas, the molecules are far apart, allowing them to move freely between collisions. A gas expands to fill all space available to it and takes the shape of its container.

20.1 The Atmosphere

Earth's atmosphere consists of molecules that occupy space and extends many kilometers above Earth's surface.

20.1 The Atmosphere

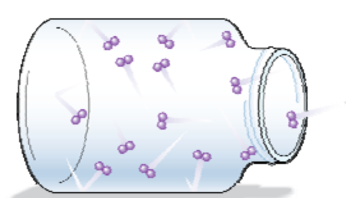
We live in an ocean of gas, our atmosphere.

- The molecules, energized by sunlight, are in continual motion.
- Without Earth's gravity, they would fly off into outer space.
- Without the sun's energy, the molecules would eventually cool and just end up as matter on the ground.

Unlike the ocean, which has a very definite surface, Earth's atmosphere has no definite surface.

20.1 The Atmosphere

Molecules in the gaseous state are in continuous motion.



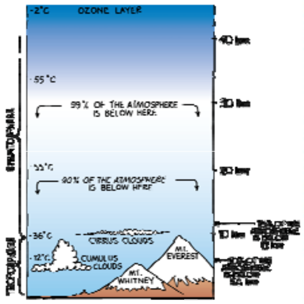
20.1 The Atmosphere

Unlike the ocean's uniform density at any depth, the density of the atmosphere decreases with altitude.

- Molecules in the atmosphere are closer together at sea level than at higher altitudes.
- The air gets thinner and thinner (less dense) the higher one goes; it eventually thins out into space.
- In the vacuous regions of interplanetary space there is a gas density of about one molecule per cubic centimeter. This is primarily hydrogen, the most plentiful element in the universe.

20.1 The Atmosphere

The temperature of the atmosphere drops as one goes higher (until it rises again at very high altitudes).



20.1 The Atmosphere

The “thickness” of the atmosphere relative to the size of the world is like the thickness of the skin of an apple relative to the size of the apple.

- 50% of the atmosphere is below 5.6 kilometers (18,000 ft).
- 75% of the atmosphere is below 11 kilometers (56,000 ft).
- 90% of the atmosphere is below 17.7 kilometers.
- 99% of the atmosphere is below an altitude of about 30 kilometers.

20.1 The Atmosphere

CONCEPT CHECK **What is the atmosphere?**

20.2 Atmospheric Pressure

Atmospheric pressure is caused by the weight of air, just as water pressure is caused by the weight of water.

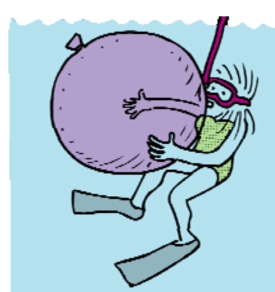
20.2 Atmospheric Pressure

The atmosphere, much like water in a lake, exerts pressure.

We are so accustomed to the invisible air around us that we sometimes forget it has weight.

20.2 Atmospheric Pressure

You don’t notice the weight of a bag of water while you’re submerged in water. Similarly, you don’t notice the weight of air as you walk around in it.



20.2 Atmospheric Pressure

Table 20.1 Densities of Various Gases

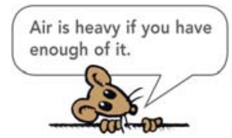
Gas	Density (kg/m³)*
Dry air	
0° C	1.29
10° C	1.25
20° C	1.21
30° C	1.16
Helium	0.178
Hydrogen	0.090
Oxygen	1.43

* At sea level atmospheric pressure and at 0° C (unless otherwise specified)

20.2 Atmospheric Pressure

The density of air changes with temperature.

- At sea level, 1 m^3 of air at 20°C has a mass of about 1.2 kg.
- Calculate the number of cubic meters in your room, multiply by 1.2 kg/m^3, and you'll have the mass of air in your room.



20.2 Atmospheric Pressure

Fully pressurizing a 777 jumbo jet adds 1000 kg to its mass.

20.2 Atmospheric Pressure

Consider a superlong hollow bamboo pole that reaches up through the atmosphere for 30 kilometers.

- If the inside cross-sectional area of the pole is 1 cm^2 and the density of air inside the pole matches the density of air outside, the enclosed mass of air would be about 1 kilogram.
- The weight of this much air is about 10 newtons.
- Air pressure at the bottom of the bamboo pole would be about 10 newtons per square centimeter (10 N/cm^2).

20.2 Atmospheric Pressure

The mass of air that would occupy a bamboo pole that extends to the "top" of the atmosphere is about 1 kg. This air has a weight of 10 N.

20.2 Atmospheric Pressure

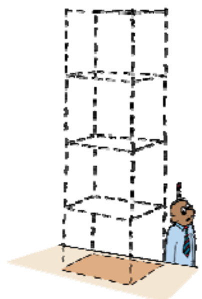
There are 10,000 square centimeters in 1 square meter.

A column of air 1 m^2 in cross section that extends up through the atmosphere has a mass of about 10,000 kilograms.

The weight of this air is about 100,000 newtons (10^5 N).

20.2 Atmospheric Pressure

The weight of air that bears down on a 1-square-meter surface at sea level is about 100,000 newtons.



20.2 Atmospheric Pressure

This weight produces a pressure of 100,000 newtons per square meter, or equivalently, 100,000 pascals, or 100 kilopascals.

- More exactly, the average atmospheric pressure at sea level is 101.3 kilopascals (101.3 kPa).

The pressure of the atmosphere is not uniform. There are variations in atmospheric pressure at any one locality due to moving air currents and storms.

20.2 Atmospheric Pressure

think!

About how many kilograms of air occupy a classroom that has a 200-square-meter floor area and a 4-meter-high ceiling?

20.2 Atmospheric Pressure

think!

About how many kilograms of air occupy a classroom that has a 200-square-meter floor area and a 4-meter-high ceiling?

Answer:

960 kg. The volume of air is $(200\ m^2) \times (4\ m) = 800\ m^3$. Each cubic meter of air has a mass of about 1.2 kg, so $(800\ m^3) \times (1.2\ kg/m^3) = 960$ kg (about a ton).

20.2 Atmospheric Pressure

CONCEPT CHECK **What causes atmospheric pressure?**

20.3 The Simple Barometer

The height of the mercury in the tube of a simple barometer is a measure of the atmospheric pressure.

20.3 The Simple Barometer

An instrument used for measuring the pressure of the atmosphere is called a **barometer.**

In a simple mercury barometer, a glass tube (longer than 76 cm) closed at one end, is filled with mercury and tipped upside down in a dish of mercury.

The mercury in the tube runs out of the submerged open bottom until the level falls to about 76 cm.

20.3 The Simple Barometer

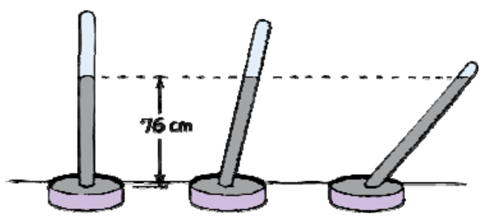
The empty space trapped above, except for some mercury vapor, is a vacuum.

The vertical height of the mercury column remains constant even when the tube is tilted.

If the top of the tube is less than 76 cm above the level in the dish, the mercury would completely fill the tube.

20.3 The Simple Barometer

In a simple mercury barometer, variations above and below the average column height of 76 cm are caused by variations in atmospheric pressure.



20.3 The Simple Barometer

The barometer "balances" when the weight of liquid in the tube exerts the same pressure as the atmosphere outside.

A 76-cm column of mercury weighs the same as the air that would fill a supertall 30-km tube of the same width.

If the atmospheric pressure increases, then it will push the mercury column higher than 76 cm.

20.3 The Simple Barometer

Water could be used to make a barometer but the glass tube would have to be much longer—13.6 times as long, to be exact.

A volume of water 13.6 times that of mercury is needed to provide the same weight as the mercury in the tube.

A water barometer would have to be at least 10.3 meters high.

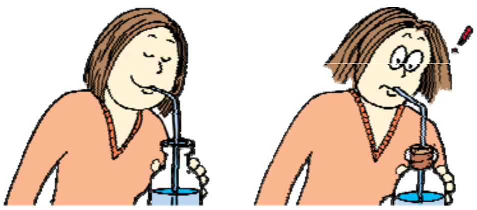
20.3 The Simple Barometer

The operation of a barometer is similar to the process of drinking through a straw.

- By sucking, you reduce the air pressure in the straw that is placed in a drink.
- Atmospheric pressure on the liquid's surface pushes liquid up into the reduced-pressure region.
- The liquid is *pushed* up into the straw by the pressure of the atmosphere.

20.3 The Simple Barometer

You cannot drink soda through the straw unless the atmosphere exerts a pressure on the surrounding liquid.



20.3 The Simple Barometer

There is a 10.3-meter limit on the height that water can be lifted with vacuum pumps.

In the case of an old-fashioned farm-type pump, atmospheric pressure exerted on the surface of the water pushes the water up into the region of reduced pressure inside the pipe.

Even with a perfect vacuum, the maximum height to which water can be lifted is 10.3 meters.

20.3 The Simple Barometer

The atmosphere pushes water from below up into a pipe that is evacuated of air by the pumping action.

20.3 The Simple Barometer

CONCEPT CHECK **How does a simple mercury barometer show pressure?**

20.4 The Aneroid Barometer

An aneroid barometer uses a small metal box that is partially exhausted of air. The box has a slightly flexible lid that bends in or out as atmospheric pressure changes.

20.4 The Aneroid Barometer

Atmospheric pressure is used to crush a can.

a. The can is heated until steam forms.

a

20.4 The Aneroid Barometer

Atmospheric pressure is used to crush a can.

a. The can is heated until steam forms.

b. The can is capped and removed from the heat.

a b

20.4 The Aneroid Barometer

Atmospheric pressure is used to crush a can.

a. The can is heated until steam forms.

b. The can is capped and removed from the heat.

c. When the can cools, the air pressure inside is reduced.

a b c

20.4 The Aneroid Barometer

A can containing a little water is heated until steam forms. There is now less air inside the can than before it was heated.

When the sealed can cools, the pressure inside is reduced because steam inside the can condenses to a liquid when it cools.

The pressure of the atmosphere crushes the can.

20.4 The Aneroid Barometer

Aneroid barometers work without liquids.

a. Variations in atmospheric pressure are indicated on the face of the instrument.

a

20.4 The Aneroid Barometer

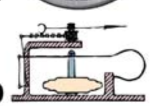
Aneroid barometers work without liquids.

a. Variations in atmospheric pressure are indicated on the face of the instrument.

b. The spring-and-lever system can be seen in this cross-sectional diagram.

a

b



20.4 The Aneroid Barometer

An **aneroid barometer** is an instrument that measures variations in atmospheric pressure without a liquid.

Since atmospheric pressure decreases with increasing altitude, a barometer can be used to determine elevation.

An aneroid barometer calibrated for altitude is called an *altimeter.*

20.4 The Aneroid Barometer

CONCEPT CHECK How does an aneroid barometer work?

20.5 Boyle's Law

Boyle's law states that the product of pressure and volume for a given mass of gas is a constant as long as the temperature does not change.

20.5 Boyle's Law

The air pressure inside the inflated tires of an automobile is considerably more than the atmospheric pressure outside.

The density of air inside the tire is also more than that of the air outside.

Inside the tire, the molecules of gas behave like tiny table tennis balls, moving helter-skelter and banging against the inner walls.

Their impacts on the inner surface of the tire produce a force that averaged over a unit of area provides the pressure of the enclosed air.

20.5 Boyle's Law

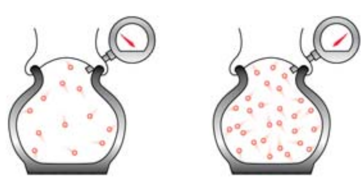
Suppose there are twice as many molecules in the same volume.

- The air density is then doubled.
- If the molecules move at the same average speed, the number of collisions will double.
- This means the pressure is doubled.

So pressure is proportional to density.

20.5 Boyle's Law

When the density of the air in the tire is increased, the pressure is increased.



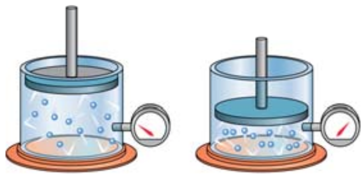
20.5 Boyle's Law

The density of the air can also be doubled by compressing the air to half its volume.

- We increase the density of air in a balloon when we squeeze it.
- We increase air density in the cylinder of a tire pump when we push the piston downward.

20.5 Boyle's Law

When the volume of gas is decreased, the density—and therefore pressure—is increased.



20.5 Boyle's Law

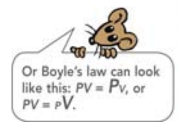
The product of pressure and volume is the same for any given quantity of a gas.

Boyle's law describes the relationship between the pressure and volume of a gas.

$$P_1V_1 = P_2V_2$$

P_1 and V_1 represent the original pressure and volume

P_2 and V_2 represent the second, or final, pressure and volume



20.5 Boyle's Law

Scuba divers must be aware of Boyle's law when ascending.

As the diver returns to the surface, pressure decreases and thus the volume of air in the diver's lungs increases.

A diver must not hold his or her breath while ascending—the expansion of the diver's lungs can be very dangerous or even fatal.

20.5 Boyle's Law

A scuba diver must be aware of Boyle's law when ascending to the surface.

20.5 Boyle's Law

think!

If you squeeze a balloon to one third its volume, by how much will the pressure inside increase?

20.5 Boyle's Law

think!

If you squeeze a balloon to one third its volume, by how much will the pressure inside increase?

Answer:

The pressure in the balloon is increased three times. No wonder balloons break when you squeeze them!

20.5 Boyle's Law

think!

A scuba diver 10.3 m deep breathes compressed air. If she holds her breath while returning to the surface, by how much does the volume of her lungs tend to increase?

20.5 Boyle's Law

think!

A scuba diver 10.3 m deep breathes compressed air. If she holds her breath while returning to the surface, by how much does the volume of her lungs tend to increase?

Answer:

Atmospheric pressure can support a column of water 10.3 m high, so the pressure in water due to the weight of the water alone equals atmospheric pressure at a depth of 10.3 m. Taking into account the pressure of the atmosphere at the water's surface, the total pressure at this depth is twice atmospheric pressure. Her lungs will tend to inflate to twice their normal size if she holds her breath while rising to the surface.

20.5 Boyle's Law

CONCEPT CHECK **What does Boyle's law state?**

20.6 Buoyancy of Air

Any object less dense than the air around it will rise.

20.6 Buoyancy of Air

In the last chapter, all the rules for buoyancy were stated in terms of *fluids* rather than liquids.

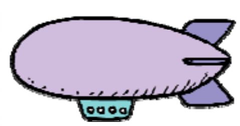
The rules hold for gases as well as liquids.

The physical laws that explain a dirigible aloft in the air are the same that explain a fish "aloft" in water.

Archimedes' principle for air states that an object surrounded by air is buoyed up by a force equal to the weight of the air displaced.

20.6 Buoyancy of Air

The dirigible and the fish both hover at a given level for the same reason.



20.6 Buoyancy of Air

A cubic meter of air at ordinary atmospheric pressure and room temperature has a mass of about 1.2 kg.

- Its weight is about 12 N.
- Any 1-m^3 object in air is buoyed up with a force of 12 N.
- If the mass of the object is greater than 1.2 kg, it will fall to the ground when released.
- If the object has a mass less than 1.2 kg, it will rise in the air.

20.6 Buoyancy of Air

A gas-filled balloon rises in the air because it is less dense than the surrounding air. Everything is buoyed up by a force equal to the weight of the air it displaces.

20.6 Buoyancy of Air

think!

Two rubber balloons are inflated to the same size, one with air and the other with helium. Which balloon experiences the greater buoyant force? Why does the air-filled balloon sink and the helium-filled balloon float?

20.6 Buoyancy of Air

think!

Two rubber balloons are inflated to the same size, one with air and the other with helium. Which balloon experiences the greater buoyant force? Why does the air-filled balloon sink and the helium-filled balloon float?

Answer:

Both balloons are buoyed upward with the same buoyant force because they displace the same weight of air. The air-filled balloon sinks in air because it is heavier than the buoyant force that acts on it. The helium-filled balloon is lighter than the buoyant force that acts on it.

20.6 Buoyancy of Air

CONCEPT CHECK **What causes an object to rise?**

20.7 Bernoulli's Principle

Bernoulli's principle in its simplest form states that when the speed of a fluid increases, pressure in the fluid decreases.

20.7 Bernoulli's Principle

The discussion of fluid pressure thus far has been confined to stationary fluids.

Motion produces an additional influence.

20.7 Bernoulli's Principle

Relationship Between Fluid Pressure and Speed

Most people think that atmospheric pressure increases in a gale, tornado, or hurricane. Actually, the opposite is true.

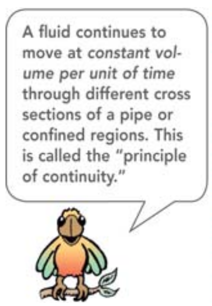
The pressure within air that gains speed is actually less than for still air of the same density.

When the speed of a fluid increases, its pressure decreases.

20.7 Bernoulli's Principle

Consider a continuous flow of water through a pipe.

- The amount of water that flows past any given section of the pipe is the same as the amount that flows past any other section of the same pipe.
- This is true whether the pipe widens or narrows.
- The water in the wide parts will slow down, and in the narrow parts, it will speed up.



20.7 Bernoulli's Principle

Because the flow is continuous, water speeds up when it flows through the narrow or shallow part of the brook.

20.7 Bernoulli's Principle

Daniel Bernoulli, a Swiss scientist of the eighteenth century, advanced the theory of water flowing through pipes.

Bernoulli's principle describes the relationship between the speed of a fluid and the pressure in the fluid.

20.7 Bernoulli's Principle

The greater the speed of flow, the less is the force of the water at right angles (sideways) to the direction of flow.

The pressure at the walls of the pipes decreases when the speed of the water increases.

Bernoulli found this to be a principle of both liquids and gases.

20.7 Bernoulli's Principle

Bernoulli's principle is a consequence of the conservation of energy.

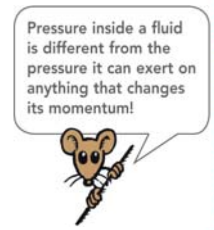
Simply stated, higher speed means lower pressure, and lower speed means higher pressure.

20.7 Bernoulli's Principle

We must distinguish between the pressure within the fluid and the pressure exerted by the fluid on something that interferes with its flow.

The pressure within the fast-moving water in a fire hose is relatively low.

The pressure that the water can exert on anything in its path to slow it down may be huge.



20.7 Bernoulli's Principle

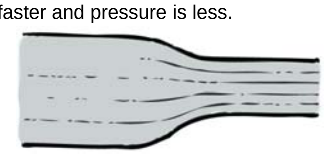
Streamlines

In steady flow, one small bit of fluid follows along the same path as a bit of fluid in front of it.

The motion of a fluid in steady flow follows streamlines.

Streamlines are the smooth paths of the bits of fluid.

The lines are closer together in the narrower regions, where the flow is faster and pressure is less.



20.7 Bernoulli's Principle

Pressure differences are evident when liquid contains air bubbles.

The volume of an air bubble depends on the pressure of the surrounding liquid.

- Where the liquid gains speed, pressure is lowered and bubbles are bigger.
- Bubbles are squeezed smaller in slower higher-pressure liquid.

20.7 Bernoulli's Principle

Water speeds up when it flows into the narrower pipe.

a. The close-together streamlines indicate increased speed and decreased internal pressure.

a

20.7 Bernoulli's Principle

Water speeds up when it flows into the narrower pipe.

a. The close-together streamlines indicate increased speed and decreased internal pressure.

b. The bubbles are bigger in the narrow part because internal pressure there is less.

a b

20.7 Bernoulli's Principle

Bernoulli's principle holds only for steady flow.

If the flow speed is too great, the flow may become turbulent and follow a changing, curling path known as an **eddy.**

In that case, Bernoulli's principle does not hold.

20 Gases
Conceptual Physics

20.7 Bernoulli's Principle

CONCEPT CHECK **What does Bernoulli's principle state?**

20 Gases
Conceptual Physics

20.8 Applications of Bernoulli's Principle

When lift equals weight, horizontal flight is possible.

20 Gases
Conceptual Physics

20.8 Applications of Bernoulli's Principle

Bernoulli's principle partly accounts for the flight of birds and aircraft.

Try blowing air across the top of a sheet of paper. The paper rises because air passes faster over the top of the sheet than below it.

20 Gases
Conceptual Physics

20.8 Applications of Bernoulli's Principle

The paper rises when you blow air across the top of it.

20 Gases
Conceptual Physics

20.8 Applications of Bernoulli's Principle

Lift

Due to the shape and orientation of airplane wings, air passes somewhat faster over the top surface of the wing than beneath the lower surface.

Pressure above the wing is less than pressure below the wing.

Lift is the upward force created by the difference between the air pressure above and below the wing.

20.8 Applications of Bernoulli's Principle

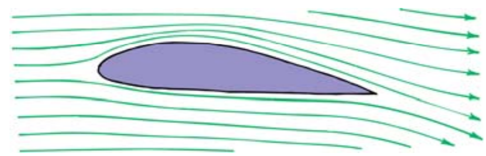
Even a small pressure difference multiplied by a large wing area can produce a considerable force.

The lift is greater for higher speeds and larger wing areas.

Low-speed gliders have very large wings relative to the size of the fuselage. The wings of faster-moving aircraft are relatively small.

20.8 Applications of Bernoulli's Principle

Air pressure above the wing is less than the pressure below the wing.



20.8 Applications of Bernoulli's Principle

Atmospheric pressure decreases in a strong wind.

Air pressure above a roof is less than air pressure inside the building when a wind is blowing.

This produces a lift that may result in the roof being blown off.

Unless the building is well vented, the stagnant air inside can push the roof off.

20.8 Applications of Bernoulli's Principle

In high winds, air pressure above a roof can drastically decrease.

20.8 Applications of Bernoulli's Principle

Curve Balls

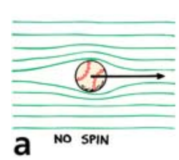
Bernoulli's principle is partly involved in the curved path of spinning balls.

When a moving baseball spins, unequal air pressures are produced on opposite sides of the ball.

20.8 Applications of Bernoulli's Principle

Bernoulli's principle is partly involved in the curved path of a spinning ball.

a. Streamlines are the same on either side of a nonspinning ball.

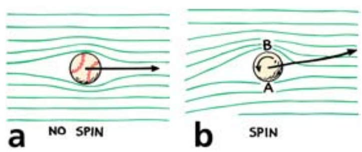


20.8 Applications of Bernoulli's Principle

Bernoulli's principle is partly involved in the curved path of a spinning ball.

a. Streamlines are the same on either side of a nonspinning ball.

b. A spinning ball produces a crowding of streamlines.



20.8 Applications of Bernoulli's Principle

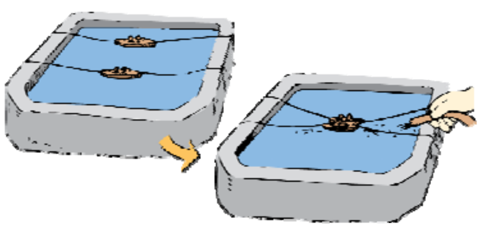
Boat Collisions

Passing ships run the risk of a sideways collision.

- Water flowing between the ships travels faster than water flowing past the outer sides.
- Streamlines are closer together between the ships than outside.
- Water pressure acting against the hulls is reduced between the ships.
- The greater pressure against the outer sides of the ships forces them together.

20.8 Applications of Bernoulli's Principle

Try this experiment in your sink and watch Bernoulli in action!



20.8 Applications of Bernoulli's Principle

Shower Curtains

What happens to a bathroom shower curtain when the shower water is turned on full blast?

Air near the water stream flows into the lower-pressure stream and is swept downward with the falling water.

Air pressure inside the curtain is thus reduced, and the atmospheric pressure outside pushes the curtain inward.

20.8 Applications of Bernoulli's Principle

CONCEPT CHECK How is horizontal flight possible?

Assessment Questions

1. Compared to the height of the tallest mountains, the height of Earth's atmosphere is
   a. enormously high, with enough volume to cause no concern.
   b. higher than mountains, but not by much.
   c. less than the tallest mountains.
   d. about the height of Mt. Everest.

Assessment Questions

1. Compared to the height of the tallest mountains, the height of Earth's atmosphere is
   a. enormously high, with enough volume to cause no concern.
   b. higher than mountains, but not by much.
   c. less than the tallest mountains.
   d. about the height of Mt. Everest.

Answer: B

Assessment Questions

2. Atmospheric pressure is due to the
   a. weight of the atmosphere.
   b. weight and volume of the atmosphere.
   c. density and volume of the atmosphere.
   d. weight of planet Earth itself.

Assessment Questions

2. Atmospheric pressure is due to the
   a. weight of the atmosphere.
   b. weight and volume of the atmosphere.
   c. density and volume of the atmosphere.
   d. weight of planet Earth itself.

Answer: A

Assessment Questions

3. Compared to the weight of a column of air to the top of the atmosphere, the weight of fluid in a barometer having the same column area is
   a. negligible.
   b. the same.
   c. much more.
   d. actually less.

Assessment Questions

3. Compared to the weight of a column of air to the top of the atmosphere, the weight of fluid in a barometer having the same column area is
   a. negligible.
   b. the same.
   c. much more.
   d. actually less.

Answer: B

Assessment Questions

4. An aneroid barometer makes use of the fact that atmospheric pressure
   a. remains relatively constant day after day.
   b. decreases with altitude.
   c. increases with altitude.
   d. depends on climatic factors such as wind.

Assessment Questions

4. An aneroid barometer makes use of the fact that atmospheric pressure
   a. remains relatively constant day after day.
   b. decreases with altitude.
   c. increases with altitude.
   d. depends on climatic factors such as wind.

Answer: B

Assessment Questions

5. When you squeeze an air-filled party balloon, you increase its
   a. volume.
   b. mass.
   c. weight.
   d. density.

Assessment Questions

5. When you squeeze an air-filled party balloon, you increase its
   a. volume.
   b. mass.
   c. weight.
   d. density.

Answer: D

Assessment Questions

6. A helium-filled balloon hovers in air. The pressure of the atmosphere against the bottom of the balloon must be
   a. greater than pressure against the top.
   b. equal to the pressure on top.
   c. less than the pressure on top.
   d. greater than the density of the material of which the balloon is made.

Assessment Questions

6. A helium-filled balloon hovers in air. The pressure of the atmosphere against the bottom of the balloon must be
   a. greater than pressure against the top.
   b. equal to the pressure on top.
   c. less than the pressure on top.
   d. greater than the density of the material of which the balloon is made.

Answer: A

Assessment Questions

7. Compared with the pressure within the water coming from a fire hose, the water pressure that knocks over a shed is
   a. less.
   b. the same.
   c. more.
   d. nonexistent.

Assessment Questions

7. Compared with the pressure within the water coming from a fire hose, the water pressure that knocks over a shed is
   a. less.
   b. the same.
   c. more.
   d. nonexistent.

Answer: C

Assessment Questions

8. If air speed is greater along the top surface of a bird's wings, pressure of the moving air there is
   a. unaffected.
   b. less.
   c. more.
   d. turbulent.

Assessment Questions

8. If air speed is greater along the top surface of a bird's wings, pressure of the moving air there is
   a. unaffected.
   b. less.
   c. more.
   d. turbulent.

Answer: B