Name: ______________________________ Date: __________

10.2 Measuring Temperature

How do you find the temperature of a substance?

There are many different kinds of thermometers used to measure temperature. Can you think of some you find at home? In your classroom you will use a glass immersion thermometer to find the temperature of a liquid. The thermometer contains alcohol with a red dye in it so you can see the alcohol level inside the thermometer. The alcohol level changes depending on the surrounding temperature. You will practice reading the scale on the thermometer and report your readings in degrees Celsius.

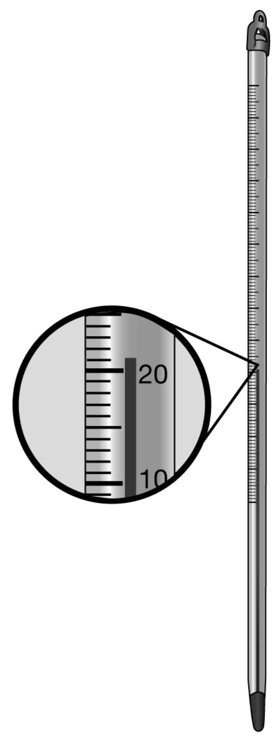
Materials

- Alcohol immersion thermometer
- Beakers
- Water at different temperatures
- Ice

Safety: Glass thermometers are breakable. Handle them carefully. Overheating the thermometer can cause the alcohol to separate and give incorrect readings. Glass thermometers should be stored horizontally or vertically (never upside down) to prevent alcohol from separating.

Reading the temperature scale correctly

Look at the picture at right. See the close-up of the line inside the thermometer on the scale. The tens scale numbers are given. The ones scale appears as lines. Each small line equals 1 degree Celsius. Practice reading the scale from the bottom to the top. One small line above 20 °C is read as 21 °C. When the level of the alcohol is between two small lines on the scale, report the number to the nearest 0.5 °C.



Stop and think

a. What number does the large line between 20 °C and 10 °C equal? Figure out by counting the number of small lines between 20 °C and 10 °C.

b. Give the temperature of the thermometer in the picture above.

c. Practice rounding the following temperature values to the nearest 0.5 °C: 23.1 °C, 29.8 °C, 30.0 °C, 31.6 °C, 31.4 °C.

d. Water at 0 °C and 100 °C has different properties. Describe what water looks like at these temperatures.

e. What will happen to the level of the alcohol if you hold the thermometer by the bulb?

Reading the temperature of water in a beaker

An immersion thermometer must be placed in liquid up to the solid line on the thermometer (at least 2 and one half inches of liquid). Wait about 3 minutes for the temperature of the thermometer to equal the temperature of the liquid. Record the temperature to the nearest 0.5 °C when the level stops moving.

1. Place the thermometer in the beaker. Check to make sure that the water level is above the solid line on the thermometer.

2. Wait until the alcohol level stops moving (about three minutes). Record the temperature to the nearest 0.5 °C.

Reading the temperature of warm water in a beaker

A warm liquid will cool to room temperature. For a warm liquid, record the warmest temperature you observe before the temperature begins to decrease.

1. Repeat the procedure above with a beaker of warm (not boiling) water.

2. Take temperature readings every 30 seconds. Record the warmest temperature you observe.

Reading the temperature of ice water in a beaker

When a large amount of ice is added to water, the temperature of the water will drop until the ice and water are the same temperature. After the ice has melted, the cold water will warm to room temperature.

1. Repeat the procedure above with a beaker of ice and water.

2. Take temperature readings every 30 seconds. Record the coldest temperature you observe.

Name: ____________________ Date: __________

10.2 Temperature Scales

READ

The Fahrenheit and Celsius temperature scales are commonly used scales for reporting temperature values. Scientists use the Celsius scale almost exclusively, as do many countries of the world. The United States relies on the Fahrenheit scale for reporting temperature information. You can convert information reported in degrees Celsius to degrees Fahrenheit or vice versa using conversion formulas.

Fahrenheit (°F) to Celsius (°C) conversion formula:

$$°C = \left(\frac{5}{9}\right)(°F - 32)$$

Celsius (°C) to Fahrenheit (°F) conversion formula:

$$°F = \left(\frac{9}{5} \times °C\right) + 32$$

EXAMPLES

- What is the Celsius value for 65° Fahrenheit?

Solution:

$$°C = \left(\frac{5}{9}\right)(65°F - 32)$$

$$°C = \left(\frac{5}{9}\right)(33) = (5 \times 33) \div 9$$

$$°C = 165 \div 9$$

$$°C = 18.3$$

- 200 °C is the same temperature as what value on the Fahrenheit scale?

Solution:

$$°F = \left(\frac{9}{5}\right)(200°C) + 32$$

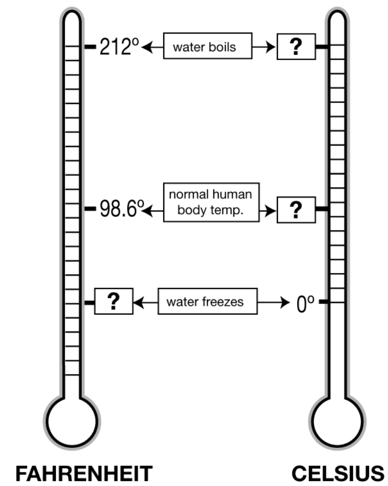
$$°F = [(9 \times 200°C) \div 5] + 32$$

$$°F = [1800 \div 5] + 32$$

$$°F = 360 + 32$$

$$°F = 392$$

PRACTICE



1. For each of the problems below, show your calculations. Follow the steps from the examples on the previous page.
   a. What is the Celsius value for 212 °F?
   b. What is the Celsius value for 98.6 °F?
   c. What is the Celsius value for 40 °F?
   d. What is the Celsius value for 10 °F?
   e. What is the Fahrenheit value for 0 °C?
   f. What is the Fahrenheit value for 25 °C?
   g. What is the Fahrenheit value for 75 °C?
2. The weatherman reports that today will reach a high of 45 °F. Your friend from Sweden asks what the temperature will be in degrees Celsius. What value would you report to your friend?
3. Your parents order an oven from England. The temperature dial on the new oven is calibrated in degrees Celsius. If you need to bake a cake at 350 °F in the new oven, at what temperature should you set the dial?
4. A German automobile's engine temperature gauge reads in Celsius, not Fahrenheit. The engine temperature should not rise above about 225 °F. What is the corresponding Celsius temperature on this car's gauge?
5. Your grandmother in Ireland sends you her favorite cookie recipe. Her instructions say to bake the cookies at 190 °C. To what Fahrenheit temperature would you set the oven to bake the cookies?
6. A scientist wishes to generate a chemical reaction in his laboratory. The temperature values in his laboratory manual are given in degrees Celsius. However, his lab thermometers are calibrated in degrees Fahrenheit. If he needs to heat his reactants to 232 °C, what temperature will he need to monitor on his lab thermometers?
7. You call a friend in Europe during the winter holidays and say that the temperature in Boston is 15 degrees. He replies that you must enjoy the warm weather. Explain his comment using your knowledge of the Fahrenheit and Celsius scales. To help you get started, fill in this table. What is 15 °F on the Celsius scale? What is 15°C on the Fahrenheit scale?

°F		°C
15 °F	=	
	=	15 °C

8. Challenge questions:
   a. A gas has a boiling point of –175 °C. At what Fahrenheit temperature would this gas boil?
   b. A chemist notices some silvery liquid on the floor in her lab. She wonders if someone accidentally broke a mercury thermometer, but did not thoroughly clean up the mess. She decides to find out if the silver stuff is really mercury. From her tests with the substance, she finds out that the melting point for the liquid is 35°F. A reference book says that the melting point for mercury is –38.87 °C. Is this substance mercury? Explain your answer and show all relevant calculations.

Extension: the Kelvin temperature scale

For some scientific applications, a third temperature scale is used: the Kelvin scale. The Kelvin scale is calibrated so that raising the temperature one degree Kelvin raises it by the same amount as one degree Celsius. The difference between the scales is that 0 °C is the freezing point of water, while 0 K is much, much colder. On the Kelvin scale, 0K (degree symbols are not used for Kelvin values) represents **absolute zero**. Absolute zero is the temperature when the average kinetic energy of a perfect gas is zero—the molecules display no energy of motion. Absolute zero is equal to –273 °C, or –459 °F. When scientists are conducting research, they often obtain or report their temperature values in Celsius, and other scientists must convert these values into Kelvin for their own use, or vice versa. To convert Celsius values to their Kelvin equivalents, use the formula:

$$K = {}^{\circ}C + 273$$

EXAMPLE ▶

Water boils at a temperature of 100 °C. What would be the corresponding temperature for the Kelvin scale?

$$K = {}^{\circ}C + 273$$

$$K = 100{}^{\circ}C + 273$$

$$K = 373$$

To convert Kelvin values to Celsius, you perform the opposite operation; subtract 273 from the Kelvin value to find the Celsius equivalent.

EXAMPLE ▶

A substance has a melting point of 625 K. At what Celsius temperature would this substance melt?

$${}^{\circ}C = K - 273$$

$${}^{\circ}C = 625\ K - 273$$

$${}^{\circ}C = 352$$

Although we rarely need to convert between Kelvin and Fahrenheit, use the following formulas to do so:

$${}^{\circ}F = \left(\frac{9}{5} \times K\right) - 460$$

$$K = \frac{5}{9}({}^{\circ}F + 460)$$

PRACTICE

1. Surface temperatures on the planet Mars range from –89 °C to –31 °C. Express this temperature range in Kelvin.
2. The average surface temperature on Jupiter is about 165K. Express this temperature in degrees Celsius.
3. The average surface temperature on Saturn is 134K. Express this temperature in degrees Celsius.
4. The average surface temperature on the dwarf planet Pluto is 50K. Express this temperature in degrees Celsius.
5. The Sun has several regions. The apparent surface that we can see from a distance is called the photosphere. Temperatures of the photosphere range from 5,000 °C to 8,000 °C. Express this temperature range in Kelvin.
6. The chromosphere is a hot layer of plasma just above the photosphere. Chromosphere temperatures can reach 10,000 °C. Express this temperature in Kelvin.
7. The outermost layer of the Sun's atmosphere is called the corona. Its temperatures can reach over 1,000,000 °C. Express this temperature in Kelvin.
8. Nuclear fusion takes place in the center, or core, of the Sun. Temperatures there can reach 15,000,000 °C. Express this temperature in Kelvin.
9. **Challenge!** Surface temperatures on Mercury can reach 660 °F. Express this temperature in Kelvin.
10. **Challenge!** Surface temperatures on Venus, the hottest planet in our solar system, can reach 755K. Express this temperature in degrees Fahrenheit.

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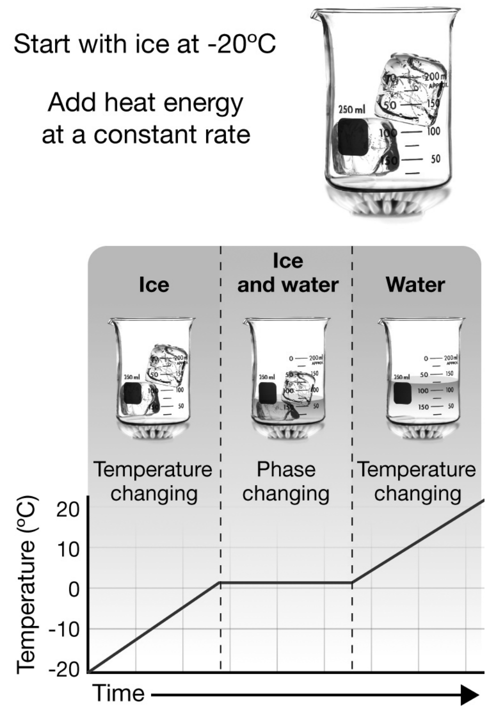
CONTENT 10.3

10.3 Reading a Heating/Cooling Curve

READ

A heating curve shows how the temperature of a substance changes as heat is added at a constant rate. The heating curve at right shows what happens when heat is added at a constant rate to a beaker of ice. The flat spot on the graph, at zero degrees, shows that although heat was being added, the temperature did not rise while the solid ice was changing to liquid water. The heat energy was used to break the intermolecular forces between water molecules. Once all the ice changed to water, the temperature began to rise again. In this skill sheet, you will practice reading heating and cooling curves.



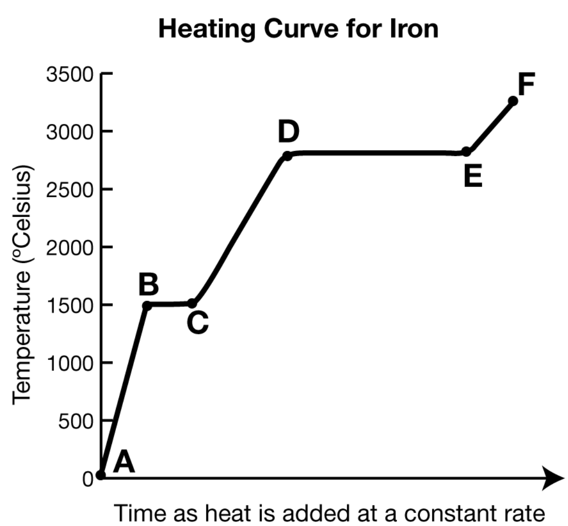
EXAMPLE

The heating curve at right shows the temperature change in a sample of iron as heat is added at a constant rate. The sample starts out as a solid and ends as a gas.

- Describe the phase change that occurred between points B and C on the graph.

Solution:

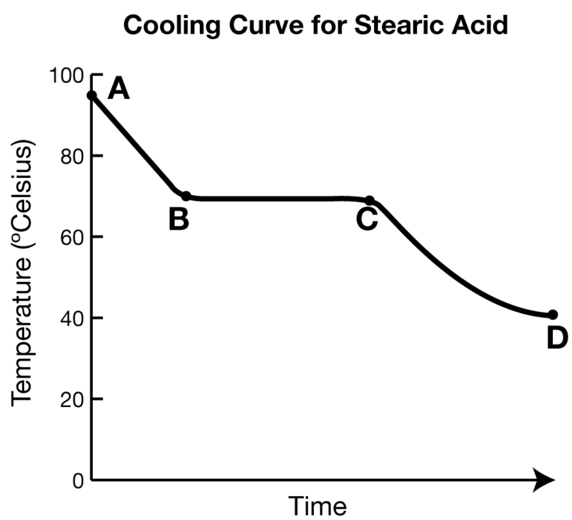
Between points B and C, the sample changed from solid to liquid.



PRACTICE

1. In the heating curve for iron, describe the phase change that occurred between points D and E on the graph.
2. Explain why the temperature stayed constant between points D and E.
3. What is the melting temperature of iron?
4. What is the freezing temperature of iron? How do you know?
5. What is the boiling temperature of iron?
6. Compare the boiling temperatures of iron and water (water boils at 100°C). Which substance has stronger intermolecular forces? How do you know?

The graph below shows a cooling curve for stearic acid. Stearic acid is a waxy solid at room temperature. It is derived from animal and vegetable fats and oils. It is used as an ingredient in soap, candles, and cosmetics. In this activity, a sample of stearic acid was placed in a heat-resistant test tube and heated to 95 °C, at which point the stearic acid was completely liquefied. The test tube was placed in a beaker of ice water, and the temperature monitored until it reached 40 °C. Answer the following questions about the cooling curve:



7. Between which two points on the graph did freezing occur?
8. What is the freezing temperature of stearic acid? What is its melting temperature?
9. Compare the melting temperature of stearic acid with the melting temperature of water. Which substance has stronger intermolecular forces? How do you know?
10. Can a substance be cooled to a temperature below its freezing point? Use evidence from any of the graphs in this skill sheet to defend your answer.

Name: ______________________________ Date: __________

CONTENT 11.1

11.1 Specific Heat

READ

Specific heat is the amount of thermal energy needed to raise the temperature of 1 gram of a substance 1 °C.

The higher the specific heat, the more energy is required to cause a change in temperature. Substances with higher specific heats must lose more thermal energy to lower their temperature than substances with a low specific heat. Some sample specific heat values are presented in the table below:

Material	Specific Heat (J/kg °C)
water (pure)	4,184
aluminum	897
silver	235
oil	1,900
concrete	880
gold	129
wood	1,700

Water has the highest specific heat of the listed types of matter. This means that water is slower to heat but is also slower to lose heat.

PRACTICE

Using the table above, solve the following heat problems.

1. If 100 joules of energy were applied to all of the substances listed in the table at the same time, which would have the greatest temperature change? Explain your answer.
2. Which of the substances listed in the table would you choose as the best thermal insulator? A thermal insulator is a substance that requires a lot of heat energy to change its temperature. Explain your answer.
3. Which substance—wood or silver—is the better thermal conductor? A thermal conductor is a material that requires very little heat energy to change its temperature. Explain your answer.
4. Which has more thermal energy, 1 kg of aluminum at 20 °C or 1 kg of gold at 20 °C?
5. How much heat in joules would you need to raise the temperature of 1 kg of water by 5 °C?
6. How does the thermal energy of a large container of water compare to a small container of water at the same temperature?

Name: ______________________________ Date: __________

CONTENT 11.1

11.1 Using the Heat Equation

READ

You can solve real-world heat and temperature problems using the following equation:

HEAT EQUATION

$$E = mC_p(T_2 - T_1)$$

- **Heat energy** (joules): E
- **Mass** (kg): m
- **Specific heat** ($\frac{\text{joule}}{\text{kg°C}}$): C_p
- **Change in temperature** (°C): $(T_2 - T_1)$

Below is a table that provides the specific heat of six everyday materials.

Material	Specific Heat (J/kg °C)	Material	Specific Heat (J/kg °C)
water (pure)	4,184	concrete	880
aluminum	897	gold	129
silver	235	wood	1,700

EXAMPLE

- How much heat does it take to raise the temperature of 10 kg of water by 10 °C?

  Solution:

  Find the specific heat of water from the table above: 4,184 J/kg °C. Plug the values into the equation.

$$\text{Thermal Energy (J)} = 10\text{ kg} \times 10\text{ °C} \times 4{,}184\text{ J/kg}\bullet\text{°C}$$
$$= 418{,}400\text{ joules}$$

PRACTICE

Use the specific heat table to answer the following questions. Don't forget to show your work.

1. How much heat does it take to raise the temperature of 0.10 kg of gold by 25 °C?
2. How much heat does it take to raise the temperature of 0.10 kg of silver by 25 °C?
3. How much heat does it take to raise the temperature of 0.10 kg of aluminum by 25 °C?
4. Which one of the three materials above would cool down fastest after the heat was applied? Explain.
5. A coffee maker heats 2 kg of water from 15 °C to 100 °C. How much thermal energy was required?
6. The Sun warms a 100-kg slab of concrete from 20 °C to 25 °C. How much thermal energy did it absorb?
7. 5,000 joules of thermal energy were applied to 1-kg aluminum bar. What was the temperature increase?
8. In the 1920's, many American homes did not have hot running water from the tap. Bath water was heated on the stove and poured into a basin. How much thermal energy would it take to heat 30 kg of water from 15 °C to a comfortable bath temperature of 50 °C?

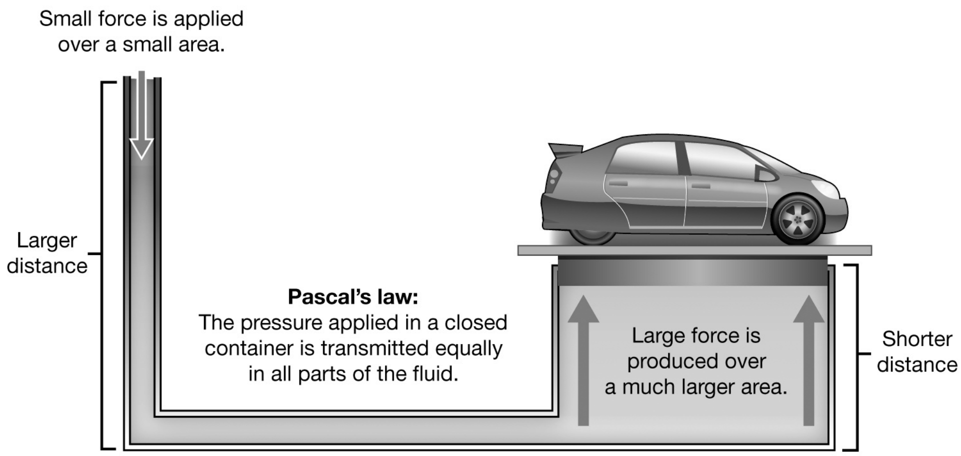
Name: ______________________ Date: __________

CONTENT 12.2

12.2 Pressure in Fluids

READ

Have you ever wondered how a 1,500-kilogram car is raised off the ground in a mechanic's shop? A hydraulic lift does the trick. All hydraulic machines operate on the basis of Pascal's principle, which states that the pressure applied to an incompressible fluid in a closed container is transmitted equally in all parts of the fluid.



A small force exerted over a large distance is traded for a large force over a small distance.

In the diagram above, a piston at the top of the small tube pushes down on the fluid. This input force generates a certain amount of pressure, which can be calculated using the formula:

$$Pressure = \frac{Force}{Area}$$

That pressure stays the same throughout the fluid, so it remains the same in the large cylinder. Since the large cylinder has more area, the output force generated by the large cylinder is greater. The output force exerted by the piston at the top of the large cylinder can be calculated using the formula:

$$Force = Pressure \times Area$$

You can see that the small input force created a large output force. But there's a price: The small piston must be pushed a greater distance than the large piston moves. Work output (output force × output distance) can never be greater than work input (input force × input distance).

EXAMPLE

- A 50.-newton force is applied to a small piston with an area of 0.0025 m^2. What pressure, in pascals, will be transmitted in the hydraulic system?

Solution:

$$Pressure = \frac{Force}{Area} = \frac{50.\text{ N}}{0.0025\text{ m}^2} = 20000\text{ Pa}$$

- The area of the large cylinder's piston in this hydraulic system is 2.5 m^2. What is the output force?

Solution:

$$Force = Pressure \times Area = 20000\text{ Pa} \times 2.5\text{ m}^2 = 50000\text{ N}$$

PRACTICE

1. In a hydraulic system, a 100.-newton force is applied to a small piston with an area of 0.0020 m^2. What pressure, in pascals, will be transmitted in the hydraulic system?
2. The area of the large cylinder's piston in this hydraulic system is 3.14 m^2. What is the output force?
3. An engineer wishes to design a hydraulic system that will transmit a pressure of 10,000 pascals using a force of 15 newtons. How large an area should the input piston have?
4. This hydraulic system should produce an output force of 50,000 newtons. How large an area should the output piston have?
5. Another engineer is running a series of experiments with hydraulic systems. If she doubles the area of the input piston, what happens to the amount of pressure transmitted by the system?
6. If all other variables remain unchanged, what happens to the output force when the area of the input piston is doubled?
7. If the small piston in the hydraulic system described in problems 1 and 2 is moved a distance of 2 meters, will the large piston also move 2 meters? Explain why or why not.
8. A 540-newton woman can make dents in a hardwood floor wearing high-heeled shoes, yet if she wears snowshoes, she can step effortlessly over soft snow without sinking in. Explain why, using what you know about pressure, force, and area.

Name: ____________________ Date: __________

12.3 Buoyancy

READ

When an object is placed in a fluid (liquid or gas), the fluid exerts an *upward force* upon the object. This force is called a **buoyant force**.

At the same time, there is an attractive force between the object and Earth—the force of gravity. It acts as a *downward force*. You can compare the two forces to determine whether the object floats or sinks in the fluid.

Buoyant force > Gravitational force	Buoyant force < Gravitational force
Object floats	Object sinks

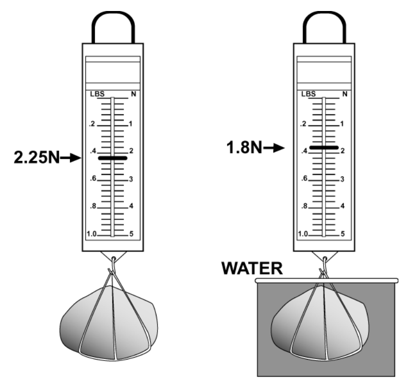
EXAMPLES

Example 1: A 13-N object is placed in a container of fluid. If the fluid exerts a 60-N buoyant (upward) force on the object, will the object float or sink?
Answer: Float. The upward buoyant force (60 N) is greater than the weight of the object (13 N).

Example 2: The rock weighs 2.25 N when suspended in air. In water, it appears to weigh only 1.8 N. Why?
Answer: The water exerts a buoyant force on the rock. This buoyant force equals the difference between the rock's weight in air and its apparent weight in water.

$$2.25 \text{ N} - 1.8 \text{ N} = 0.45 \text{ N}$$

The water exerts a buoyant force of 0.45 newtons on the rock.



PRACTICE

1. A 4.5-N object is placed in a tank of water. If the water exerts a force of 4.0 N on the object, will the object sink or float?

2. The same 4.5-N object is placed in a tank of glycerin. If the glycerin exerts a force of 5.0 N on the object, will the object sink or float?

3. You suspend a brass ring from a spring scale. Its weight is 0.83 N while it is suspended in air. Next, you immerse the ring in a container of light corn syrup. The ring appears to weigh 0.71 N. What is the buoyant force acting on the ring in the light corn syrup?

4. You wash the brass ring (from question 3) and then suspend it in a container of vegetable oil. The ring appears to weigh 0.73 N. What is the buoyant force acting on the ring?

5. Which has greater buoyant force, light corn syrup or the vegetable oil? Why do you think this is so?

6. A cube of gold weighs 1.89 N when suspended in air from a spring scale. When suspended in molasses, it appears to weigh 1.76 N. What is the buoyant force acting on the cube?

7. Do you think the buoyant force would be greater or smaller if the gold cube were suspended in water? Explain your answer.

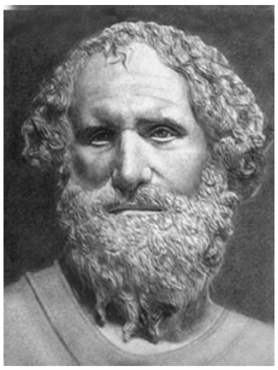
Name: ______________________________ Date: __________

BIOGRAPHY 12.3

12.3 Archimedes

Archimedes was a Greek mathematician who specialized in geometry. He figured out the value of pi and the volume of a sphere, and has been called "the father of integral calculus." During his lifetime, he was famous for using compound pulleys and levers to invent war machines that successfully held off an attack on his city for three years. Today he is best known for Archimedes' principle, which was the first explanation of how buoyancy works.

Archimedes' screw

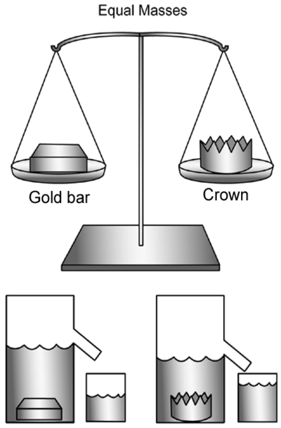


Archimedes was born in Syracuse, on Sicily (then an independent Greek city-state), in 287 B.C. His letters suggest he studied in Alexandria, Egypt, as a young man. Historians believe it was there that he invented a device for raising water by means of a rotating screw or spirally bent tube within an inclined hollow cylinder. The device known as Archimedes' screw is still used in many parts of the world.

"Eureka!"

A famous Greek legend says that King Hieron II of Syracuse asked Archimedes to figure out if his new crown was pure gold or if the craftsman had mixed some less expensive silver into it. Archimedes had to determine the answer without destroying the crown. He thought about it for days and then, as he lowered himself into a bath, the method for figuring it out struck him. The legend says Archimedes ran through the streets, shouting "Eureka!"—meaning "I have found it."

A massive problem



The crown displaced more water

Archimedes realized that if he had equal masses of gold and silver, the denser gold would have a smaller volume. Therefore, the gold would displace less water than the silver when submerged.

Archimedes found the mass of the crown and then made a bar of pure gold with the same mass. He submerged the gold bar and measured the volume of water it displaced. Next, he submerged the crown. He found the crown displaced more water than the gold bar had and, therefore, could not be pure gold. The gold had been mixed with a less dense material. Archimedes had confirmed the king's doubts.

Why do things float?

Archimedes wrote a treatise titled *On Floating Bodies*, further exploring **density** and **buoyancy**. He explained that an object immersed in a fluid is pushed upward by a force equal to the weight of the fluid displaced by the object. Therefore, if an object weighs more than the fluid it displaces, it will sink. If it weighs less than the fluid it displaces, it will float. This statement is known as *Archimedes' principle*. Although we commonly assume the fluid is water, the statement holds true for any fluid, whether liquid or gas. A helium balloon floats because the air it displaces weighs more than the balloon filled with lightweight gas.

Cylinders, circles, and exponents

Archimedes wrote several other treatises, including "On the Sphere and the Cylinder," "On the Measurement of the Circle," "On Spirals," and "The Sand Reckoner." In this last treatise, he devised a system of exponents that allowed him to represent large numbers on paper—up to 8×10^{63} in modern scientific notation. This was large enough, he said, to count the grains of sand that would be needed to fill the universe. This paper is even more remarkable for its astronomical calculations than for its new mathematics. Archimedes first had to figure out the size of the universe in order to estimate the amount of sand needed to fill it. He based his size calculations on the writings of three astronomers (one of them was his father). While his estimate is considered too small by today's standard, it was much, much larger than anyone had previously suggested. Archimedes was the first to think on an "astronomical scale."

Archimedes was killed by a Roman soldier during an invasion of Syracuse in 212 B.C.

Reading reflection

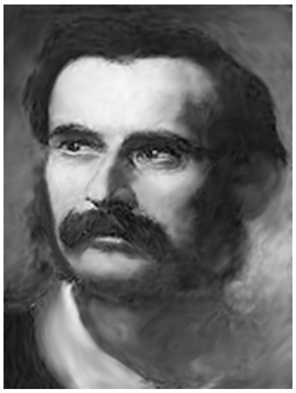
1. The boldface words in the article are defined in the glossary of your textbook. Look them up and then explain the meaning of each in your own words.
2. Imagine you are Archimedes and have to write your resume for a job. Describe yourself in a brief paragraph. Be sure to include in the paragraph your skills and the jobs you are capable of doing.
3. What was Archimedes' treatise "The Sand Reckoner" about?
4. Why does a balloon filled with helium float in air, but a balloon filled with air from your lungs sink?
5. **Research** one of Archimedes' inventions and create a poster that shows how the device worked.

Name: ______________________________ Date: __________

12.3 Narcís Monturiol

Monturiol, a visionary and peaceful revolutionary, wanted to improve the social and economic lives of his countrymen. Moved by the suffering of coral divers due to their extremely dangerous working conditions, Monturiol built a submarine to transport the divers to the reefs. He hoped that in time, his invention would also help people understand the ocean world.

Birth of a Spanish inventor



Narcís Monturiol was born on September 28, 1819, in Figueres, Catalonia, a region of northeastern Spain. Monturiol's father was a cooper—which means that he handcrafted wooden barrels that held wine, oil, and milk. Narcís was one of five children. At an early age he showed an interest in design and invention. When he was ten, he created a realistic model of a wooden clock.

His mother wanted Narcís to become a priest, but he earned a law degree instead. He never practiced law, however. Instead, he became a self-taught engineer.

Monturiol was active politically. He supported socialism, communism, and the ideal of a utopia where everyone lived together in harmony. He turned to science with the hope of creating that utopia.

The perils of coral diving

Monturiol was concerned about the danger involved in the work of Spanish coral fishermen. A diver, holding his breath for several minutes, dove nearly 20 meters beneath the ocean surface to retrieve valuable pieces of coral. The divers risked drowning, injuries from rocks and coral, and possible shark attacks.

In 1857, Monturiol formed a company to design and build a submarine. His goal was to develop a vessel to help coral divers with their physical work and to lessen the risk involved.

Monturiol was not the first to build a submarine. Historical records show that Aristotle, Renaissance period inventors, and others had attempted to build submarines. These models were often created for warfare. Most early submarines were unsuccessful and dangerous.

Ictineo I

Monturiol's first submarine, *Ictineo I*, made its first dive in 1859. The name *Ictineo* is derived from Greek, and is translated "fish ship." During its initial dive, *Ictineo I* hit underwater pilings. Repairing what he could, Monturiol sent *Ictineo I* on its second dive within a few hours.

Monturiol's seven-meter submarine had a spherical inner hull built to withstand water pressure, and an elliptical (egg-shaped) outer hull for ease of movement. Between the two hulls were tanks that stored and released water to control the submarine's depth. Oxygen tanks were also stored in this space. The submarine was powered by four men turning the propeller by hand.

Ictineo I was equipped with a ventilator, two sets of propellers, and several portholes. The submarine had the ability to retrieve objects and was equipped with a back-up system to raise it to the surface in an emergency.

Ictineo I made nearly 20 dives that first year, to a depth of 20 meters. The submarine eventually stayed underwater for nearly two hours.

Ictineo II

Monturiol created a second and improved model called *Ictineo II*. Rather than relying on manpower, the *Ictineo II* had a steam engine. These engines were traditionally powered by an open flame. Monturiol created a submarine-safe alternative to power the engine using a chemical reaction. The open flame would have removed oxygen, but the chemical reaction added oxygen to the cabin instead.

The *Ictineo II* was 17 meters long, had two engines, dove to depths of nearly 30 meters, had many portholes, and remained underwater for almost seven hours.

Unfortunately, Monturiol ran out of funds and was forced to sell his submarine for scrap. Although he didn't receive much credit for his inventions during his lifetime, he is now recognized as an important contributor to submarine development. Monturiol died in 1885.

BIOGRAPHY 12.3

Reading reflection

1. What moved Monturiol to create a submarine?
2. Identify key features of the *Ictineo I* and II.
3. **Research:** Where are model replicas of *Ictineo I* and *II* located?
4. **Research**: What happed to Monturiol's *Ictineo I*?
5. **Research:** Name three things Monturiol invented in addition to the submarine.
6. **Research:** How did Spain honor Monturiol in 1987?
7. **Research:** What is the Narcís Monturiol medal?

Name: ______________________ Date: __________

CHALLENGE! 12.3

12.3 Archimedes' Principle

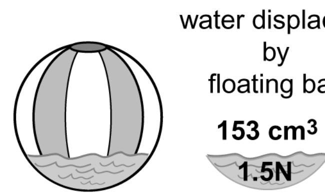
READ

More than 2,000 years ago, Archimedes discovered the relationship between buoyant force and how much fluid is displaced by an object. **Archimedes' principle** states:

The buoyant force acting on an object in a fluid is equal to the weight of the fluid displaced by the object.

We can practice figuring out the buoyant force using a beach ball and a big tub of water. Our beach ball has a volume of 14,130 cm^3. The weight of the beach ball in air is 1.5 N.

If you put the beach ball into the water and don't push down on it, you'll see that the beach ball floats on top of the water by itself. Only a small part of the beach ball is underwater. Measuring the volume of the beach ball that is under water, we find it is 153 cm^3. Knowing that 1 cm^3 of water has a mass of 1 g, you can calculate the weight of the water displaced by the beach ball.

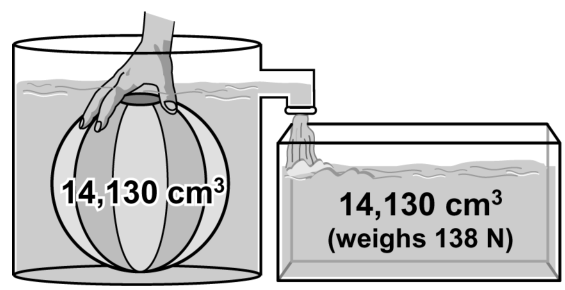


153 cm^3 of water = 153 grams = 0.153 kg

weight = mass × force of gravity per kg = (0.153 kg) × 9.8 N/kg = 1.5 N

According to Archimedes principle, the buoyant force acting on the beach ball equals the weight of the water displaced by the beach ball. Since the beach ball is floating in equilibrium, the weight of the ball pushing down must equal the buoyant force pushing up on the ball. We just showed this to be true for our beach ball.

Have you ever tried to hold a beach ball underwater? It takes a lot of effort! That is because as you submerge more of the beach ball, the more the buoyant force acting on the ball pushes it up. Let's calculate the buoyant force on our beach ball if we push it all the way under the water. Completely submerged, the beach ball displaces 14,130 cm^3 of water. Archimedes principle tells us that the buoyant force on the ball is equal to the weight of that water:



14,130 cm^3 of water = 14,130 grams = 14.13 kg

weight = mass × force of gravity per kg = (14.13 kg) × 9.8 N/kg = 138 N

If the buoyant force is pushing up with 138 N, and the weight of the ball is only 1.5 N, your hand pushing down on the ball supplies the rest of the force, 136.5 N.

EXAMPLE

- A 10-cm^3 block of lead weighs 1.1 N. The lead is placed in a tank of water. One cm^3 of water weighs 0.0098 N. What is the buoyant force on the block of lead?

  Solution:

  The lead displaces 10 cm^3 of water.
  buoyant force = weight of water displaced
  10 cm^3 of water × 0.0098 N/cm^3 = 0.098 N

PRACTICE

1. A block of gold and a block of wood both have the same volume. If they are both submerged in water, which has the greater buoyant force acting on it?

2. A 100-cm^3 block of lead that weighs 11 N is carefully submerged in water. One cm^3 of water weighs 0.0098 N.
   a. What volume of water does the lead displace?
   b. How much does that volume of water weigh?
   c. What is the buoyant force on the lead?
   d. Will the lead block sink or float in the water?

3. The same 100-cm^3 lead block is carefully submerged in a container of mercury. One cm^3 of mercury weighs 0.13 N.
   a. What volume of mercury is displaced?
   b. How much does that volume of mercury weigh?
   c. What is the buoyant force on the lead?
   d. Will the lead block sink or float in the mercury?

4. According to problems 2 and 3, does an object's density have anything to do with whether or not it will float in a particular liquid? Justify your answer.

5. Based on the table of densities, explain whether the object would float or sink in the following situations:

material	density (g/ cm^3)
gasoline	0.7
gold	19.3
lead	11.3
mercury	13.6
molasses	1.37
paraffin	0.87
platinum	21.4

   a. A block of solid paraffin (wax) in molasses.
   b. A bar of gold in mercury.
   c. A piece of platinum in gasoline.
   d. A block of paraffin in gasoline.

Name: ______________________________ Date: __________

CONTENT 13.2

13.2 Boyle's Law

READ

The relationship between the volume of a gas and the pressure of a gas, at a constant temperature, is known as Boyle's law. The equation for Boyle's law is shown at right.

Units for pressure include: atmospheres (atm), pascals (Pa), or kilopascals (kPa). Units for volume include: cubic centimeters (cm^3), cubic meters (m^3), or liters.

BOYLE'S LAW

Initial volume → V_1; *Initial pressure* → P_1; *New pressure* → P_2; *New volume* → V_2

$$P_1 V_1 = P_2 V_2$$

Mass and temperature constant

EXAMPLE

A kit used to fix flat tires consists of an aerosol can containing compressed air and a patch to seal the hole in the tire. Suppose 10.0 L of air at atmospheric pressure (101.3 kilopascals, or kPa) is compressed into a 1.0-L aerosol can. What is the pressure of the compressed air in the can?

Looking for	Solution
Pressure of compressed air in a can ($\mathbf{P_2}$)	$P_2 = \frac{101.3\ \text{kPa} \times 10.0\ \text{L}}{1.0\ \text{L}} = 1{,}013\ \text{kPa}$
Given	
P_1 = 101.3 kPa; V_1 = 10.0 liters; V_2 = 1.0 liters	The pressure inside the aerosol can is 1,013 kPa.
Relationship	
Use Boyle's Law to solve for $\mathbf{P_2}$. Divide each side by $\mathbf{V_2}$ to isolate $\mathbf{P_2}$ on one side of the equation. $P_2 = \frac{P_1 V_1}{V_2}$	

PRACTICE

1. The air inside a tire pump occupies a volume of 130. cm^3 at a pressure of one atmosphere. If the volume decreases to 40.0 cm^3, what is the pressure, in atmospheres, inside the pump?

2. A gas occupies a volume of 20. m^3 at 9,000. Pa. If the pressure is lowered to 5,000. Pa, what volume will the gas occupy?

3. You pump 25.0 L of air at atmospheric pressure (101.3 kPa) into a soccer ball that has a volume of 4.50 L. What is the pressure inside the soccer ball if the temperature does not change?

4. Hyperbaric oxygen chambers (HBO) are used to treat divers with decompression sickness. As pressure increases inside the HBO, more oxygen is forced into the bloodstream of the patient inside the chamber. To work properly, the pressure inside the chamber should be three times greater than atmospheric pressure (101.3 kPa). What volume of oxygen, held at atmospheric pressure, will need to be pumped into a 190.-L HBO chamber to make the pressure inside three times greater than atmospheric pressure?

5. A 12.5-liter scuba tank holds of oxygen at a pressure of 202.6 kPa. What is the original volume of oxygen at 101.3 kPa that is required to fill the scuba tank?

Name: ______________________________ Date: __________

CONTENT 13.2

13.2 Gay-Lussac Law

READ

The pressure-temperature relationship shows a direct relationship between the pressure of a gas and its temperature when the temperature is given in the Kelvin scale. Another name for this relationship is the Gay-Lussac Law. The pressure-temperature equation is below.

Converting from degrees Celsius to Kelvin is easy—you *add* 273 to the Celsius temperature. To convert from Kelvins to degrees Celsius, you *subtract* 273 from the Kelvin temperature.

PRESSURE-TEMPERATURE RELATIONSHIP

Initial pressure (atm) → P_1; *Initial temperature* (K) → T_1; *New pressure* → P_2; *New temperature* → T_2

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Volume and mass constant

EXAMPLE

A constant volume of gas is heated from 25.0°C to 100°C. If the gas pressure starts at 1.00 atmosphere, what is the final pressure of this gas?

<table>
<tr><td>Looking for
The new pressure of the gas (P_2)</td><td rowspan="3">Solution
T_1 = 25 °C + 273 = 298
T_2 = 100 °C + 373 = 313
$P_2 = \frac{1 \text{ atm} \times 373}{298} = 1.25 \text{ atm}$
The new pressure of the volume of gas is 1.25 atmospheres.</td></tr>
<tr><td>Given
T_1 = 25 °C; P_1 = 1 atm; T_2 = 100 °C</td></tr>
<tr><td>Relationships
Use pressure-temperature relation to solve for P_2. Multiply each side by T_2 to isolate P_2 on one side of the equation.
$P_2 = \frac{P_1 T_2}{T_1}$
Convert temperature values in Celsius degrees to Kelvin:
$T_{Kelvin} = T_{Celsius} + 273$</td></tr>
</table>

PRACTICE

1. At 400. K, a volume of gas has a pressure of 0.40 atmospheres. What is the pressure of this gas at 273 K?

2. What is the temperature of the volume of gas (starting at 400. K with a pressure of 0.4 atmospheres), when the pressure increases to 1 atmosphere?

3. Use the pressure-temperature relationship to fill in the following table with the correct values. Pay attention to the temperature units.

	P_1	T_1	P_2	T_2
a.	30.0 atm	–100 °C		500 °C
b.	15.0 atm	25.0 °C	18.0 atm	
c.	5.00 atm		3.00 atm	293 K

Name: ______________________ Date: __________

CONTENT 13.2

13.2 Charles' Law

READ

Charles' law shows a direct relationship between the volume of a gas and the temperature of a gas when the temperature is given in the **Kelvin scale**. The Charles' law equation is below.

CHARLES' LAW

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Initial volume (m³) → V_1; *Initial temperature* (K) → T_1; V_2 ← *New volume* (m³); T_2 ← *New temperature* (K)

Pressure and mass constant

Converting from degrees Celsius to Kelvin is easy—you *add* 273 to the Celsius temperature. To convert from Kelvins to degrees Celsius, you *subtract* 273 from the Kelvin temperature.

EXAMPLE

A truck tire holds 25.0 liters of air at 25 °C. If the temperature drops to 0 °C, and the pressure remains constant, what will be the new volume of the tire?

	Solution
Looking for The new volume of the tire (V_2)	$T_1 = 25\ °C + 273 = 298$ $T_2 = 0\ °C + 273 = 273$
Given $V_1 = 25.0$ liters; $T_1 = 25\ °C$; $T_2 = 0\ °C$	
Relationships Use Charles' Law to solve for V_2. Multiply each side by T_2 to isolate V_2 on one side of the equation. $V_2 = \frac{V_1 T_2}{T_1}$ Convert temperature values in Celsius degrees to Kelvin: $T_{Kelvin} = T_{Celsius} + 273$	$V_2 = \frac{25.0\ L \times 273}{298} = 23.0\ L$ The new volume inside the tire is 23.0 liters.

PRACTICE

1. If a truck tire holds 25.0 liters of air at 25.0 °C, what is the new volume of air in the tire if the temperature increases to 30.0 °C?

2. A balloon holds 20.0 liters of helium at 10.0 °C. If the temperature increases to 50.0 °C, and the pressure does not change, what is the new volume of the balloon?

3. Use Charles' Law to fill in the following table with the correct values. Pay attention to the temperature units.

	V_1	T_1	V_2	T_2
a.		840 K	1,070 mL	147 K
b.	3250 mL	475 °C		50 °C
c.	10 L		15 L	50 °C