U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGY EDUCATION AND WORKFORCE DEVELOPMENT

Thermodynamics

Student Guide

(Six Activities)

Grades: 5-8, 9-12

Topic: Energy Basics

Owner: NEED

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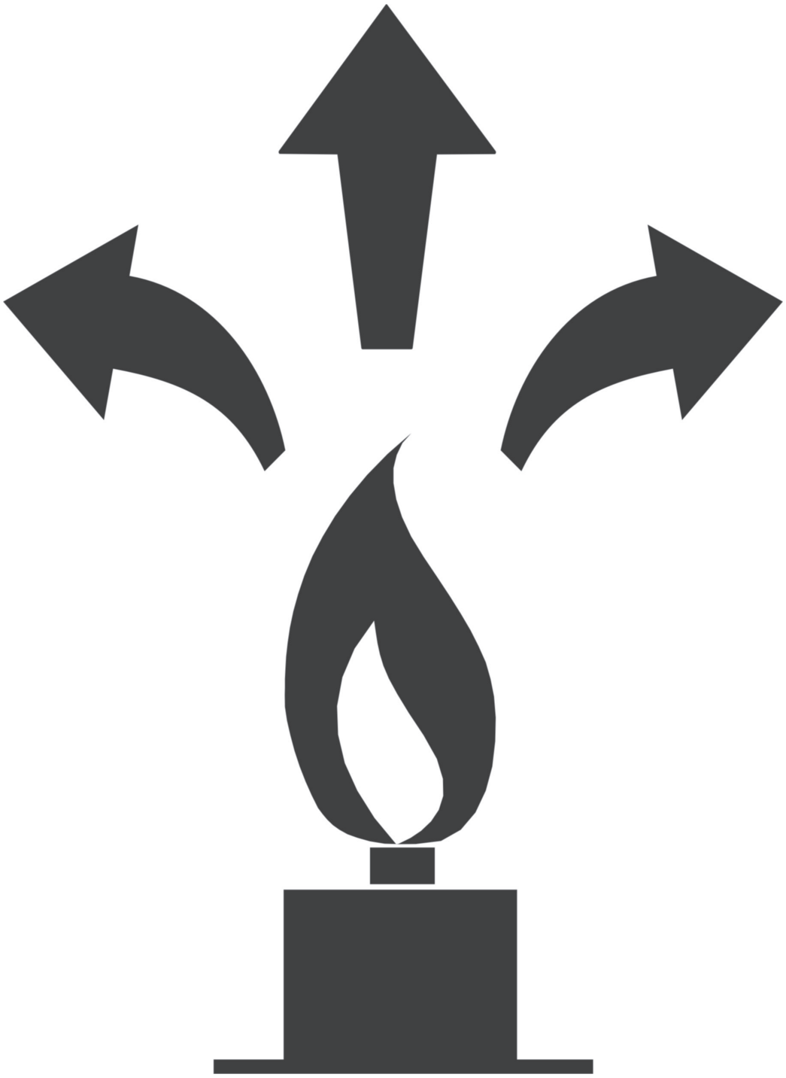
THERMODYNAMICS

Student Guide



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Student Introduction

Your teacher has introduced you to the mysteries of heat and how it affects matter. Now you will investigate and experiment with these concepts in the laboratory. You will visit six lab stations—one each day for the next six days. For you to complete the labs correctly and safely, follow these instructions:

1. Familiarize yourself with the lab guide. It includes:

♦ The **Scientific Concepts** covered in the labs
♦ **Metric Measurements & Conversions**
♦ **Lab Safety Rules**
♦ Six **Lab Station Guides**

2. Read the ***Learn About It*** sections from all of the labs before you begin.

3. Study and follow the **Lab Safety Rules**.

4. Study the **Metric Measurements and Conversions**.

5. Answer the ***Think About It*** questions in each Lab before performing the experiments.

6. Follow the instructions in the lab guides and record your data carefully. Use a calculator to help with the calculations.

7. Read your instructions and make sure you receive all of the materials you need from your teacher before you begin.

8. Share the load. Make sure that everyone in the group contributes to the process. Assign different tasks for each lab so that everyone has a chance to perform the experiments, record the data, and perform the calculations.

9. Make sure you clean up after the lab, dispose of the waste, and store the equipment properly. Remember, six groups of students must use the materials.

10. If a piece of equipment breaks, tell your teacher. He/she will give you instructions for cleaning the breakage and replacing the equipment.

11. Ask your teacher before proceeding if you have questions about the lab procedures.

12. Check off the concepts on the **Scientific Concepts** page as you investigate them. Ask your teacher if you aren't sure you understand a concept.

Scientific Concepts

☐ All matter is made of very small particles called atoms.

☐ Atoms consist of even smaller particles–protons, neutrons, and electrons.

☐ The number of protons in an atom determines the kind of atom–or element–it is.

☐ There are 109 different kinds of atoms or elements.

☐ Protons and neutrons make up the nucleus, which contains almost all the mass of the atom.

☐ Protons carry a positive electrical charge. Electrons carry a negative electrical charge equal to the positive charge of the protons. Neutrons carry no charge.

☐ Electrons have very little mass and travel in predictable orbits around the nucleus of the atom.

☐ The distances from the electrons to the nucleus are great.

☐ The distances between adjoining atoms in any substance are extremely great—matter is basically empty space.

☐ Substances are held together by the force of attraction between protons and electrons of adjoining atoms.

☐ Solids have very strong forces of attraction between their atoms, liquids less, and gases hardly any.

☐ The amount of internal energy that a substance contains determines how strong the force of attraction is between its atoms.

☐ Atoms are constantly in motion.

☐ Volume is the amount of space that a given number of atoms occupies.

☐ As the internal energy in a substance increases, so does the motion of the atoms, usually resulting in a decrease in the force of attraction and an increase in volume.

☐ Water is a unique substance; at 4°C, the volume of water will increase if energy is either added or removed.

☐ The amount of internal energy in a substance determines its state.

☐ When a given amount of heat energy is added or removed, the volume of solids changes the least and the volume of gases the most.

☐ Temperature is the measure of the average energy of the atoms in a substance.

☐ Thermal energy can be transferred by conduction— direct contact between two substances.

☐ Substances that transfer heat energy easily are called conductors. Substances that transfer heat energy poorly are called insulators.

☐ Thermal energy can be transferred by convection—the movement of atoms in liquids and gases in currents, caused by a temperature differential.

☐ Energy can be transferred through a vacuum—such as space—in the form of radiation.

☐ The specific heat of a substance is the amount of heat energy needed to raise the temperature of one gram of the substance 1°C.

☐ The heat of fusion of a substance is the amount of energy needed to change one gram of a substance at its melting point into a liquid without an increase in temperature.

☐ The heat of vaporization of a substance is the energy needed to change one gram of a substance at its boiling point into a gas without an increase in temperature.

Metric Measures & Conversions

LENGTH: THE DISTANCE FROM ONE POINT TO ANOTHER.

Measuring tool: Metric ruler

Meter	(m)	standard unit of measurement—a little more than a yard
Centimeter	(cm)	one hundredth of a meter—about 1/2 inch
Millimeter	(mm)	one thousandth of a meter—10 mm is about 1/2 inch
Kilometer	(km)	one thousand meters—almost 2/3 of a mile

1 m = 100 cm
1 m = 1000 mm
1 m = 1/1000 km
1 km = 1000 m

VOLUME: THE AMOUNT OF SPACE A SUBSTANCE OCCUPIES.

Measuring tool: Graduated cylinder

Liter	(L)	standard unit of measurement—a little more than a quart
Milliliter	(ml)	one-thousandth of a liter—about 22 drops

1 L = 1000 ml
1 L = 1000 cc
1 ml = 1 cc (cubic centimeter)

MASS: THE AMOUNT OF MATTER IN A SUBSTANCE.

Measuring tool: Triple beam balance

Gram	(g)	standard unit of measurement—a nickel is about 5 g
Kilogram	(kg)	1,000 grams—about 2.2 pounds

1 g = 1000 mg
1 kg = 1000 g

DENSITY: THE AMOUNT OF MASS IN A GIVEN VOLUME OF A SUBSTANCE.

Density = mass/volume

TEMPERATURE: THE MEASURE OF HOW HOT OR COLD A SUBSTANCE IS.

Measuring tool: Celsius thermometer

Freezing point of water = 0°C
Boiling point of water = 100°C
Normal body temperature = 37°C
Room Temperature = 21°C

HEAT: THE AMOUNT OF INTERNAL ENERGY IN A SUBSTANCE.

Measured in calories

One calorie is the amount of heat needed to raise the temperature of 1 g of water 1°C.

Lab Safety Rules

THERMODYNAMICS MEANS THE MOVEMENT OF HEAT. ALL OF THESE LABS INVOLVE THE USE OF HEAT. MOST OF THE LABS ALSO INVOLVE THE USE OF CHEMICALS, FIRE, AND GLASSWARE. ALL OF THESE CAN CAUSE INJURY IF MISHANDLED.

EYE SAFETY

Always wear safety glasses when performing experiments.

FIRE SAFETY

Do not heat any substance or piece of equipment unless specifically instructed to do so.

Be careful of loose clothing. Do not reach across or over a flame.

Keep long hair pulled back and secured.

Do not heat any substance in a closed container.

Always use the tongs or protective gloves when handling hot objects. Do not touch hot objects with your hands.

Keep all lab equipment, chemicals, papers, and personal effects away from the flame.

Extinguish the flame as soon as you are finished with the experiment and move it away from the immediate work area.

HEAT SAFETY

Always use tongs or protective gloves when handling hot objects and substances.

Keep hot objects away from the edge of the lab table—in a place where no one will accidentally come into contact with them.

Do not use the steam generator without the assistance of your teacher.

Remember that many objects will remain hot for a long time after the heat source is removed or turned off.

GLASS SAFETY

Never use a piece of glass equipment that appears cracked or broken.

Handle glass equipment carefully. If a piece of glassware breaks, do not attempt to clean it up yourself. Inform your teacher.

Glass equipment can become very hot. Use tongs if glass has been heated.

Clean glass equipment carefully before packing it away.

CHEMICAL SAFETY

Do not smell, touch, or taste chemicals unless instructed to do so.

Keep chemical containers closed except when using them.

Do not mix chemicals without specific instructions.

Do not shake or heat chemicals without specific instructions.

Dispose of used chemicals as instructed. Do not pour chemicals back into container without specific instructions to do so.

If a chemical accidentally touches your skin, immediately wash the area with water and inform your teacher.

Lab One: Matter & Forces of Attraction

LEARN ABOUT IT

Atoms are the building blocks of the universe—all matter is made of atoms. Atoms are made of even smaller particles. In the center of the atom is the nucleus, which is made of protons and neutrons. Spinning around the nucleus in predictable orbits are electrons.

The number of protons in an atom determines the kind of atom—or element—it is. Hydrogen, for example, has one proton, carbon has six, and oxygen has eight. The chart at the bottom of the page has the number of protons of some familiar elements.

Atoms contain the same number of protons and electrons. A carbon atom has six protons and six electrons. Atoms may contain a different number of neutrons, however. Uranium atoms, for example, always contain 92 protons and electrons, but contain 146 neutrons. The atomic number of an element is the number of protons in its nucleus.

Some Common Elements

Element	Symbol	Protons	Neutrons	Electrons	Atomic Mass
Hydrogen	H	1	0	1	1.008
Carbon	C	6	6	6	12.001
Oxygen	O	8	8	8	15.999
Aluminum	Al	13	14	13	26.980
Silver	Ag	47	51	47	107.868
Tin	Sn	50	69	50	118.710
Barium	Ba	56	81	56	137.330
Gold	Au	79	118	79	196.967
Radon	Rn	86	136	86	222.000
Uranium	U	92	146	92	238.029
Plutonium	Pu	94	150	94	244.000

The protons and neutrons in the nucleus contain almost all of the mass of an atom. The electrons orbiting the nucleus are very small and at a great distance from the nucleus. In a carbon atom, the nucleus contains 99.95% of the atom's mass.

The protons of atoms carry a positive electrical charge that is equal to the negative electrical charge carried by the electrons. The neutrons carry no charge. The opposing charges of protons and electrons produce a force of attraction between them, as well as between adjoining atoms.

Solids have very strong forces of attraction between adjoining atoms. The force of attraction in liquids is not so strong. And in gases, there is almost no force of attraction at all. There is a lot of empty space between the nucleus and the electrons, as well as between the adjoining atoms.

Adding heat energy to substances increases the motion of the atoms and decreases the force of attraction between the atoms. The empty space between the atoms increases as energy is added.

THINK ABOUT IT

Using the chart from the previous page, answer the following questions:

1. Helium (He) has an atomic mass of 4.003. How many protons, neutrons, and electrons does an atom of helium have?
2. Potassium (K) has an atomic mass of 39.098. How many protons, neutrons, and electrons does an atom of potassium have?
3. From the chart, estimate the atomic mass of a molecule of water (H_2O). A molecule of carbon dioxide (CO_2).
4. Will the mass of a sample of water change if it is heated? Will the volume?
5. Will a cylinder of hot water (90^{o}C) have more space between its molecules than a cylinder of cold water (10^{o}C)? Can you design an experiment to prove your hypothesis?

EXPERIMENT WITH IT

Let's investigate the emptiness of matter and the effect that adding heat energy has on the force of attraction in liquids.

Objectives: To investigate the empty spaces within and between molecules and atoms.

To investigate the force of attraction and the effect of adding heat energy.

SUPPLIES AND PREPARATION

Part I - Teacher Demonstration

Part II - Water & ethyl alcohol

- Two 250 ml graduated cylinders
- Ethyl alcohol
- Warm water (about 50^{o}C)
- Triple beam balance

Part III - Water & salt

- One 100 ml graduated cylinder
- One 25 ml graduated cylinder
- Container of table salt
- Warm water (about 50^{o}C)
- Triple beam balance

Part IV - Forces of attraction in liquids

- Waxed paper
- A few drops of water
- Two sealed test tubes of corn syrup
- Small container of ice

PROCEDURE

Part I - Teacher Demonstration: The beads and marbles represent atoms in the demonstration.

1. Record the data given to you by your teacher on the recording form.

Part II - Water & ethyl alcohol

1. Record the mass of one empty cylinder. Fill the cylinder with 140 ml of ethyl alcohol and record the mass.
2. Record the mass of second empty cylinder. Fill the cylinder with 60 ml of warm water (50°C) and record the mass.
3. Pour the water into the cylinder of ethyl alcohol. Record the resulting volume and mass of the cylinder.
4. Pour the mixture into the lab sink and rinse the cylinders.

Part III - Water & salt

1. Record the mass of the 25 ml cylinder. Fill the cylinder with 10 ml of salt and record the mass.
2. Record the mass of the 100 ml cylinder. Fill the cylinder with 50 ml of warm water and record the mass.
3. Pour the salt into the cylinder of water. Gently swirl the mixture. Record the volume and mass of the cylinder.
4. Pour the mixture into the sink and rinse the cylinders.

Part IV - Forces of attraction in liquids

1. Place one sealed test tube of corn syrup into container of ice. Place the other into warm water.
2. Sprinkle drops of water on the sheet of waxed paper as it is held as flat as possible by two partners. Gently tilt the paper. Observe the force of attraction between the drops of water.
3. Remove the test tube of corn syrup from the container of ice. Turn the test tube upside down. Observe the time it takes for the cold corn syrup to flow from one end of the test tube to the other.
4. Remove the test tube of corn syrup from the warm water. Turn the test tube upside down. Observe the time it takes for the warm corn syrup to flow from one end of the test tube to the other.

Record Data

Part I	Empty Mass	Full Mass	Mass of Substance	Volume of Substance
Cylinder One Marbles				
Cylinder Two Beads				
Cylinder Two Marbles & Beads				

Part II	Empty Mass	Full Mass	Mass of Substance	Volume of Substance
Cylinder One Alcohol				
Cylinder Two Water				
Cylinder One Alcohol & Water				

Part III	Empty Mass	Full Mass	Mass of Substance	Volume of Substance
Cylinder One Salt				
Cylinder Two Water				
Cylinder Two Salt & Water				

CALCULATING AND INTERPRETING

Part I - Demonstration - Marbles & Beads:

Let's look at the data. Remember, to find the mass of each substance, you must subtract the empty mass of the cylinder from the full mass. Would you expect the mass of the mixture to equal the mass of the marbles plus the mass of the beads? Do your results support your hypothesis?

Would you expect the volume of the marbles plus the volume of the beads to equal the volume of the mixture? No. Some of the beads filled in the empty spaces between the marbles. Let's calculate the amount of beads that did not add to the volume––the amount of beads that filled in the empty spaces.

Volume of beads in marbles = (volume of marbles + volume of beads) - volume of mixture

***Example*:**

A container with 500 ml of sand was poured into a container with 300 ml of marbles. The resulting mixture had a volume of 600 ml. How much of the sand filled in the empty spaces between the marbles?

Volume of sand in marbles = (volume of sand + volume of marbles) - volume of mixture
Volume of sand in marbles = (500 ml + 300 ml) - 600 ml
Volume of sand in marbles = 200 ml

NOW CALCULATE THE VOLUME OF BEADS THAT FILLED IN THE EMPTY SPACES BETWEEN THE MARBLES IN THE DEMONSTRATION.

Part II - Water & Ethyl Alcohol:

Let's look at your results. Remember, to find the mass of each substance, you must subtract the empty mass of the cylinder from the full mass. Would you expect the mass of the mixture to equal the mass of the ethyl alcohol plus the mass of the water? Do your results support your hypothesis?

Molecules of ethyl alcohol are very large. Molecules of water are very small. When molecules of ethyl alcohol and water are mixed together, some of the molecules of water fill in the empty spaces between the molecules of ethyl alcohol.

USING THE FORMULA ABOVE, CALCULATE THE VOLUME OF WATER THAT FILLED IN THE EMPTY SPACES BETWEEN THE ETHYL ALCOHOL MOLECULES.

Part III - Water & Salt:

Let's look at your results. Remember, to find the mass of each substance, you must subtract the empty mass of the cylinder from the full mass. Would you expect the mass of the mixture to equal the mass of the water plus the mass of the salt? Will the mass of the salt change when it is dissolved in water? Do your results support your hypothesis?

When the salt is poured into the water, the salt dissolves—the molecules of salt are spread throughout the water. Some of the molecules of salt fill in the empty spaces between the molecules of water.

USING THE FORMULA ON PAGE 12, CALCULATE THE VOLUME OF SALT THAT FILLED IN THE EMPTY SPACES BETWEEN THE WATER MOLECULES.

What do you think would happen if equal amounts of salt and water were mixed together? What if 50 ml of water were poured into 200 ml of salt?

Would the results be different if sugar were used? What about pepper?

Part IV - Forces of Attraction in Liquids:

How does the demonstration with the water droplets on the waxed paper demonstrate the molecular force of attraction between water molecules? How did the addition of heat energy affect the forces of attraction between the molecules of corn syrup? Could you design an experiment to measure the change in the forces of attraction as heat energy is added?

MAKE SURE YOU UNDERSTAND IT

1. An atom of mercury (Hg) has 80 protons and an atomic mass of 200.59. How many electrons and neutrons does it have?

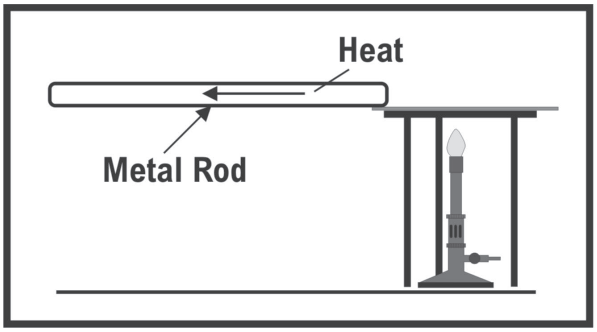
2. The formula for carbonic acid is H_2CO_3. What would the atomic mass of a molecule of carbonic acid be?

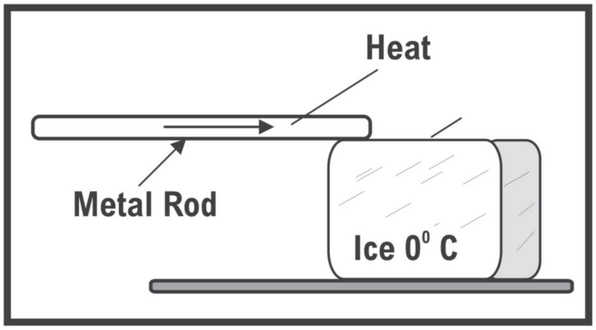
3. A cylinder with 200 ml of water was poured into a cylinder with 200 ml of ethyl alcohol. Five percent of the water filled in the empty spaces between the alcohol molecules. What was the volume of the mixture?

Lab Two: Heat Transfer by Conduction

LEARN ABOUT IT

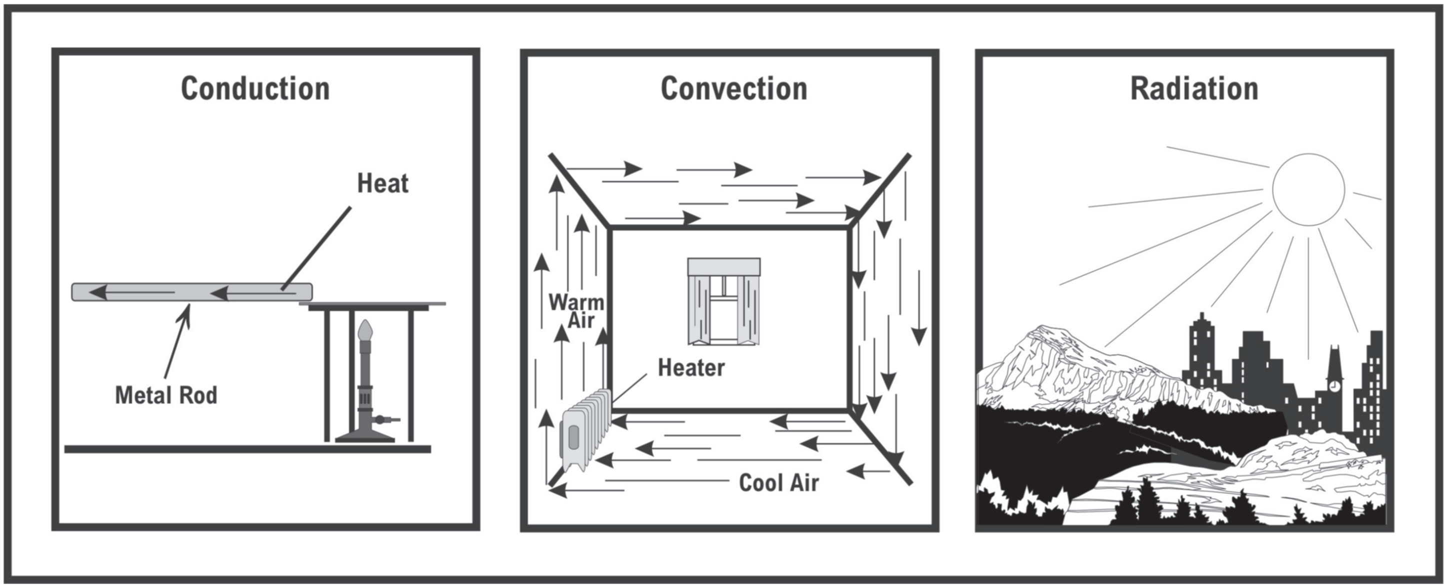
Heat can be transferred three ways—by conduction, convection and radiation. **Conduction** is heat transfer by direct contact between objects. If you place a metal rod against a heated object, the vibrating atoms in the heated object will strike the atoms in the rod and cause them to vibrate with more motion. The atoms at the end of the rod will then strike other atoms in the rod and they too will start to vibrate with more motion. Eventually, the entire rod will heat up.





If the same rod is placed on an ice cube, the low-energy molecules of the ice will absorb some energy from the rod and slow down the vibration of the atoms that are touching the ice. The atoms in the warmer section of the rod will then supply some of their energy to the less energetic atoms at the end touching the ice. The atoms supplying the energy to the colder end will become less energetic. This process of supplying energy from the warmer section of the rod to the cooler section will continue until the entire rod cools.

The atomic mass and structure of a substance affect its ability to transfer energy between adjoining atoms. Substances that transfer heat energy quickly are called **conductors**. Substances that transfer heat energy slowly are called **insulators**. The chart on page 15 lists the rates at which different materials transfer heat. The higher the number, the better the substance conducts heat.



Conductivity of Selected Materials

Substance	Conductivity (cal/secXmeter°C)
Diamond	10,255
Copper	1,633
Aluminum	1,005
Brass	460
Lead	147
Steel	57
Nickel	33
Concrete	5
Glass	3
Water	3
Wood (oak)	0.6
Wool	0.2
Goose Down	0.1
Air & Most Gases	0.1
Foam Polystyrene	0.04

THINK ABOUT IT

Using the chart above, answer the following questions:

1. Which substance is the best at transferring heat and would be the best conductor?
2. Which substance is the poorest at transferring heat and would be the best insulator?
3. Why does a concrete wall feel cooler than a wood wall in the same room?
4. Of the metals listed on the top of the chart, which would be the best to use when making a frying pan?
5. How are substances with low conductivity rates used in our daily lives?

EXPERIMENT WITH IT

Let's investigate conduction and insulation.

Objectives**:** To investigate the insulating qualities of different materials.

To investigate the conductivity of different metals.

SUPPLIES AND PREPARATION

Part I - Insulation

- Foam polystyrene cup with lid
- Iron crucible with lid
- Porcelain crucible with lid
- Thermometer
- Shallow pan with 1/2 inch of ice water
- Hot water (about 50°C) in beaker

Part II - Conductivity

- Conductometer
- Paraffin balls
- Candle
- Safety pin
- Matches
- Ring stand with clamp
- Watch with second hand

PROCEDURE

Part I - Insulation

1. Fill the foam cup and crucibles with about 30 ml of hot water, cover with lid, and record the temperature of the water. Place containers in the pan of ice water.
2. Wait five minutes, then record the temperature of the water in each container. Proceed to Part II of the lab while you are waiting.

PROCEDURE CONTINUED

Part II - Conductivity

1. Examine the conductometer. Note the notched sides of the rod ends. Note that the five rods are labeled with letters.
2. Make a sketch of the conductometer with the letters so that you will know which metal each rod is made of while you are performing the experiment.

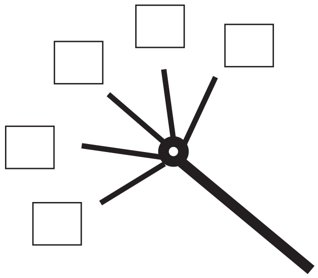
A––Aluminum

B––Brass

C––Copper

N—Nickel Silver

S––Steel



3. Barely push the point of the safety pin about 2 mm into one of the paraffin balls.
4. Carefully light the candle.
5. Gently heat the paraffin ball about 3 cm above the flame for two or three seconds to soften one side.
6. Quickly attach the melted portion of the ball to the notched end of one of the rods on the conductometer.
7. Allow to cool for a few seconds, then carefully remove the safety pin by placing your finger on the paraffin ball.
8. Attach the other paraffin balls to the ends of the rods in the same way. Turn the conductometer over to make sure that all the balls are securely attached.
9. Clamp the conductometer to the ring stand with the balls located underneath the rods.
10. Place the candle directly under the center disc of the conductometer with the top of the flame 1–2 cm below the disc. It is important to heat the exact center of the disc.
11. Begin recording the time as soon as the candle is placed under the disc.
12. Record the time and the metal rod as each ball falls. Don't stop timing until all the balls have fallen.
13. Extinguish the candle.

Record Data

Part I	**Initial Temperature**	**Final Temperature**	**Difference in Temperature**
Foam Cup			
Iron Crucible			
Porcelain Crucible			

Part II	**Aluminum**	**Brass**	**Steel**	**Nickel Silver**	**Copper**
Time					

CALCULATING AND INTERPRETING

Part I - Insulation:

Using the chart on the first page of the lab, compare your results with similar materials in the chart. Are your results consistent with the conductivity rates that you hypothesize? What variables in your experiment might have affected your results?

From the chart:

Best insulator **Poorest insulator**

From the experiment:

Best insulator **Poorest insulator**

Part II - Conductivity:

Let's use the formulas below to determine the relative conductivity of the five metals on the conductometer from the chart and then from your results.

Relative conductivity Conductivity of metal / Conductivity of copper
Relative conductivity = Time for copper / Time for metal

CALCULATING AND INTERPRETING CONTINUED

From the chart, you can see that the least conductive metal on the conductometer is nickel silver. We will use nickel silver as the standard for comparison.

Example:

Nickel silver has a conductivity rating of 33. What is the relative conductivity of nickel silver? Of copper?

Nickel silver:

Relative conductivity   Conductivity of metal / Conductivity of nickel silver
Relative conductivity   33/33   1.0

Copper:

Relative conductivity   1633/33   49.48

NOW CALCULATE THE RELATIVE CONDUCTIVITY OF ALUMINUM, STEEL, AND BRASS.

Nickel silver = 1.0   Aluminum =   Steel =   Brass =   Copper = 49.5

The results of your experiment are recorded as time––the time it took for heat energy to be transferred by conduction along the length of the metal rods. Let's use your results to determine the relative conductivity of the metals, again using nickel silver as the standard. The relative conductivity for nickel silver will again be 1.0.

Example:

The following times were recorded when using a conductometer: copper—10 seconds; aluminum—15 seconds; and nickel silver—7 minutes. What are the relative conductivities of the metals using the formula above?

Aluminum:

Relative conductivity = Time for nickel silver/Time for metal
Relative conductivity   420 (7 min.   420 sec)/15   28   (Actual relative conductivity is 30.45)

Copper:

Relative conductivity = Time for nickel silver / Time for metal
Relative conductivity   420/10   42   (Actual relative conductivity is 49.48)

NOW CALCULATE THE RELATIVE CONDUCTIVITIES OF THE METALS USING YOUR DATA. USE THE LEAST CONDUCTIVE METAL—THE LAST BALL TO FALL—AS YOUR STANDARD.

Nickel Silver =   Aluminum =   Steel =   Brass =   Copper =

Compare your results to the relative conductivity rates you calculated above. Are your results consistent with the actual rates? What variables in your experiment might have affected your results?

MAKE SURE YOU UNDERSTAND IT

Using the chart on the second page of the lab and the formulas in the calculation section, answer the following problems:

1. How many times more conductive is aluminum than brass?

2. Two identical sized rods—one glass and one nickel silver—were heated. The glass object transferred heat at a rate of 1000 calories per second through the rod. How many calories per second were transferred by the nickel silver rod?

3. Using a conductometer in a perfect environment, the paraffin ball on the nickel silver rod fell in 8 minutes 15 seconds. Calculate the time that it took for the other paraffin balls to fall.

Lab Three: Convection & Radiation

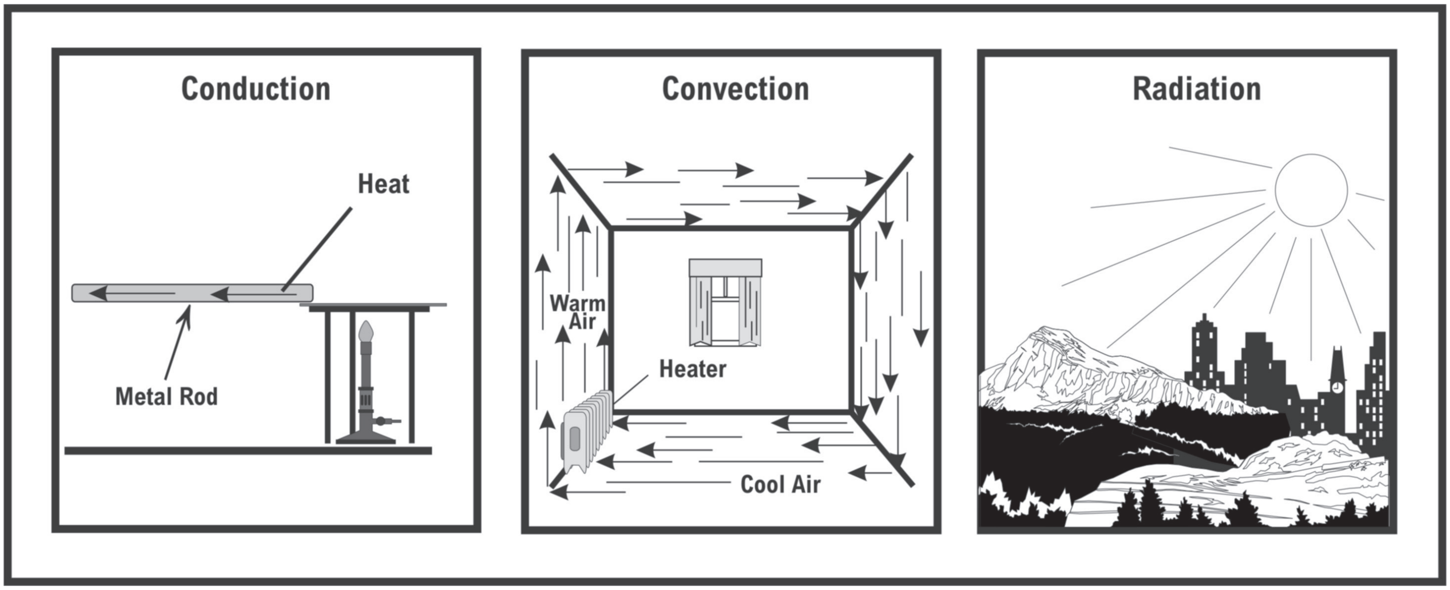
LEARN ABOUT IT

Heat can be transferred three ways—by conduction, convection and radiation. Conduction is heat transfer by direct contact between objects. Conduction occurs when two substances with different temperatures come in contact with each other. The warmer, faster-moving molecules collide with the cooler, slower-moving molecules and give up some of their energy. Conduction can occur in solids, liquids, and gases.

Convection is heat transfer by the motion of molecules in currents. Convection can only occur in liquids and gases––in substances in which the molecules are free to move. In solids, the molecules are held in fixed positions, so there can be no flow of molecules. In solids, the motion is through vibration of the molecules.

In liquids and gases, the molecules can move freely. When one part of a substance is heated, the motion of the molecules in that part increases. As the motion increases, the molecules begin to spread out and become less dense. The molecules in the cooler part of the substance are more closely packed together. Since the heated molecules are less dense, they rise, while the cooler, denser molecules sink. This motion produces currents that carry heat energy.

Radiation is the transfer of energy through space in the form of rays. Energy from the sun reaches the earth through radiation. When objects give off heat, they can also give off radiant energy in the form of light and invisible rays. These rays transfer energy that produces heat upon contact with the molecules in a substance.



THINK ABOUT IT

1. Why do you feel warmer in the sun than in the shade, when the temperature of the air is the same?
2. If you could only heat one floor of a two-story house in the winter, which floor would you heat? Why?
3. If you burn toast in the kitchen, why can you smell it all over the house?
4. Why do workers in the tropics wear long-sleeved, light-colored clothing?
5. Why does the wind seem to blow inland from the ocean during daylight hours?

EXPERIMENT WITH IT

Let's investigate radiation and convection.

Objectives*:* To investigate the transfer of energy by radiation.

To investigate the transfer of heat energy by convection in liquids and gases.

SUPPLIES AND PREPARATION:

Part I - Radiation

- Black and silver containers
- Thermoconductivity strip
- Two thermometers
- Radiation source (infrared lamp)
- Index card
- Tape
- Timer or clock

Part II - Convection in gases

- Thermoconductivity strip
- Candle or alcohol lamp
- Matches

Part III - Convection in liquids

- U-tube
- Candle
- Food Coloring
- Matches
- Water
- Ring stand with clamp

PROCEDURE

Part I - Radiation

1. Observe the color of the crystals. Fold an index card tightly around the middle of the crystal strip. Fasten the card with tape.
2. Turn on your source of radiation, following your teacher's instructions.
3. Hold the crystal strip about 25 cm away from the radiation source until the color begins to change. Remove the index card and observe the color of the crystals under the card.
4. Place the thermometers in the silver and black containers and record the temperature of the air inside the containers.
5. Direct the radiation source onto the containers from a distance of 18-24 inches. Record the temperature of the containers every five minutes for 20 minutes. Proceed to Parts II and III of the lab during the timing.

Part II - Convection in gases

1. Carefully light the candle or alcohol lamp.
2. Make a note of the color of the crystals.
3. Using the handles, hold the crystal strip to the side of the candle, about 30 cm away for 15 seconds. Observe and make a note of any color change.
4. Now move the crystal strip directly over the candle about 30 cm above the top of the flame for 15 seconds. Observe and make note of any color change.
5. Extinguish the candle and set aside for the next demonstration.

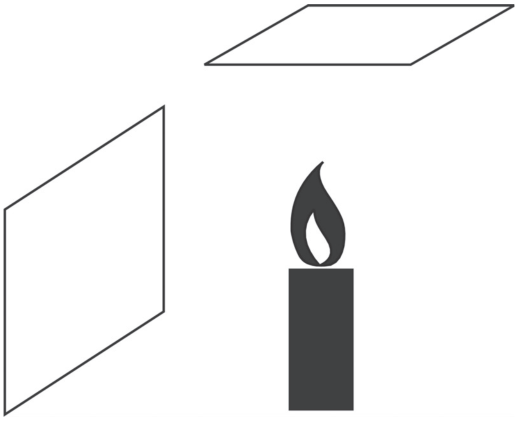
Part III - Convection in liquids

1. Fill the U-tube with water to the base of the opening.
2. Carefully attach the U-tube to the lab stand with a clamp as shown in the diagram on page 24. The bottom of the U-tube should be about four inches above the lab table. Allow the apparatus to stand undisturbed for a minute before proceeding, so that any motion of the water will cease.
3. Place the candle under one corner of the U-tube and carefully light it.
4. Place one drop of food coloring into the water through the opening at the top of the U-tube and observe its movement. Draw arrows to show the movement of the food coloring in the diagram in the recording section on page 24.

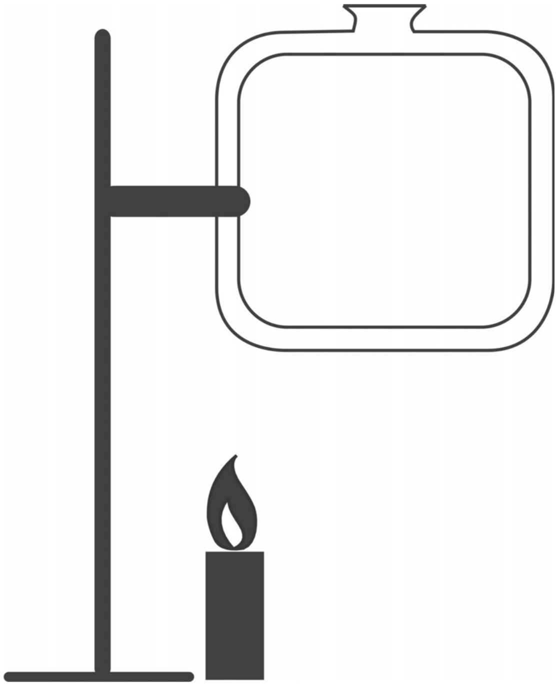
Record Data

Part I	Initial Temperature	Temperature 5 minutes	Temperature 10 minutes	Temperature 15 minutes	Temperature 20 minutes
Black Can					
Silver Can					

Part II	Use colored pencils to record the crystal’s colors in the different positions.



Part III	Use arrows to show the movement of the food coloring.



Part I - Radiation

Crystals:

1. From your observation of the crystals, did the radiation cause an increase in the thermal energy of the crystals?
2. Did the radiation penetrate the index card?
3. Make a list of the colors the crystals produced, from the color with the least amount of heat energy to the color with the most amount of heat energy.
4. Why do you think the crystals change color as heat energy is added?
5. Can you think of a practical use for the crystals?

Black and silver containers:

1. From your data, did radiation cause an increase in the temperature of the air in both containers?
2. Did the color of the containers make a difference?
3. What do you think caused the difference?

Part II - Convection in gases

1. Does your data demonstrate a pattern or current caused by the heat from the candle?
2. How would you design an experiment using perfume to demonstrate convection currents?

Part III - Convection in liquids

1. Does your data demonstrate a convection current?
2. What do you think would happen if you placed the candle in the middle of the bottom tube instead of at one corner?
3. What would happen if you placed the candle right below the opening?

MAKE SURE YOU UNDERSTAND IT

On a hot summer day, the sun shone down on the concrete at the end of the pool, which was shaded by a big oak tree. All day long, the temperature in the pool increased, though it remained in the shade. Explain how radiation, convection and conduction contributed to the heating of the pool. Where in the pool was the water warmest? When the sun went down, the temperature of the air dropped way below the temperature of the water in the pool. What happened then? Describe the energy flows.

Lab Four: Expansion & Contraction

LEARN ABOUT IT

Atoms and molecules are held together by electrostatic forces of attraction. Their positively charged nuclei are attracted to the negatively charged electrons of adjoining atoms. These forces of attraction are strongest in solids. The forces are strong enough to hold the molecules in fixed positions. The molecules vibrate, but they cannot escape from their positions.

In liquids, the forces of attraction are much weaker. The molecules move freely about within the substance. The forces of attraction in gases are almost zero, because the molecules are so far apart from each other.

When heat is added to a substance, the motion of the molecules increases. When heat is taken away, the molecular motion decreases. An increase in motion weakens the forces of attraction and the substance expands in volume. The volume decreases as the molecular motion decreases. Water is the exception to this rule. At 4^{o}C, water expands when energy is either added or removed. That is why ice floats.

Solids, because of their strong forces of attraction, expand the least when heated. Liquids expand more, and gases expand the most, because the forces of attraction are almost zero.

The rate at which a substance expands or contracts when heated or cooled depends on the forces of attraction between the atomic and molecular structure of the substance. Some substances expand very little when heated, while others expand at much greater rates.

The chart on the next page lists some common substances and the rates that their volumes change when heated––their cubic expansion. The higher the number, the more the substance expands when heated and contracts when cooled.

THINK ABOUT IT

Using the chart on the next page, answer the following questions.

1. Which substance expands or contracts the most with temperature change? Which substance expands or contracts the least with temperature change?

2. Why are steel, rather than aluminum, rods used to reinforce concrete?

3. Does the metal used to fill cavities in teeth have a high or low expansion rate? Why?

4. Why is Pyrex cookware better than regular glass for cooking? Why does regular glass break more easily when it is used for cooking?

5. If you were building a bridge in an area where the summers are hot and the winters are cold, what would you need to take into account in your construction plans?

6. If you were making a thermometer to measure very slight changes in temperature, which liquid from the chart would you use? Why?

Cubic Expansion of Some Solids and Liquids

Substance	Cubic Expansion per °C	
Aluminum	69×10^{-6}	(0.000069)
Steel	36×10^{-6}	(0.000036)
Copper	51×10^{-6}	(0.000051)
Lead	87×10^{-6}	(0.000087)
Nickel	39×10^{-6}	(0.000039)
Concrete	36×10^{-6}	(0.000036)
Glass	26×10^{-6}	(0.000026)
Pyrex Glass	10×10^{-6}	(0.000010)
Ethyl Alcohol	1120×10^{-6}	(0.001120)
Glycerin	505×10^{-6}	(0.000505)
Water	207×10^{-6}	(0.000207)
Mercury	182×10^{-6}	(0.000182)
Air & Most Gases	3400×10^{-6}	(0.003400)

EXPERIMENT WITH IT

Let's investigate expansion and contraction in the laboratory.

Objectives: To determine the rates of expansion of water and glycerin.

To confirm that water at 4°C expands when heat energy is added or removed.

To observe expansion in metals and gases.

SUPPLIES AND PREPARATION

Part I - Rates of expansion of water and glycerin

- Sealed volumetric flask with 40 ml of water
- Sealed volumetric flask with 40 ml of glycerin
- 1,000 ml beaker of room temperature water (about 22°C)
- 1,000 ml beaker of hot water (about 70°C)
- Thermometer

SUPPLIES AND PREPARATION CONTINUED

Part II - Expansion of water at 4°C

- 250 ml graduated cylinder filled with warm water (50°C)
- 250 ml graduated cylinder filled with ice water
- 2—250 ml graduated cylinders—sealed with stopper—with isopropyl alcohol
- Thermometer
- 1,000 ml beaker of ice water
- 1,000 ml beaker of hot water (50°C)

Part III - Expansion and contraction of solids and gases

- Compound bi-metal bar
- Gas expansion tube
- Balloon
- Candle flame
- Beaker of ice water

PROCEDURE

Part I - Rates of expansion of water and glycerin

1. Place volumetric flasks in beaker of room temperature water and carefully remove the tops. Save the tops to reapply after the experiment. Allow flasks to remain in beaker for five minutes, then record the temperature of the water in the beaker and the exact volumes of the water and glycerin in the flasks. The temperature of the water in the beaker will be the temperature of the water and glycerin in the flasks.
2. Place the flasks into the beaker of hot water. Wait five minutes, then record the temperature of the water in the beaker. The temperature of the liquids in the flasks should be the same temperature as that of the water in the beaker.
3. Do not remove the flasks from the beaker. Hold the flasks upright in the beaker and record the volumes of water and glycerin in the flasks.
4. Allow the flasks to cool, then put the tops back on tightly.

Record Data

Part I	**Initial & Final Temperatures**		**Change in Temperature**	**Initial & Final Volumes**		**Change in Volume**
Water						
Glycerin						

Part II - Expansion of water at 4^{o}C

1. Warm one cylinder of isopropyl alcohol and one cylinder of water by placing them in a beaker of water at approximately 50^{o}C before beginning the experiment. Place the other cylinders of isopropyl alcohol and water in a beaker filled with ice water.
2. In five minutes, remove the stoppers from the cylinders. With the cylinders remaining in the beakers, record the temperature of the liquids for all four vials at the bottom, then the top of the cylinders, taking care not to stir up the liquids.

Record Data

Part II	Bottom Temperature	Top Temperature	Difference in Temperature
Cylinder One Warm Water			
Cylinder Two Cold Water			
Cylinder Three Warm Alcohol			
Cylinder Four Cold Alcohol			

Part III - Expansion and contraction of solids and gases

Compound bi-metal bar

1. Examine the compound bi-metal bar. The bar is made of thin strips of two metals—nickel and steel—bonded together. The bar has been labeled N for nickel and S for steel. Look at the expansion rates of these two metals on the chart on page 27. In which direction will the bar bend when heated? When cooled?
2. Carefully light the candle. Place the middle part of the bar into the candle flame for 10 seconds, then into the cold water. Were your hypotheses correct?
3. Extinguish the candle.

Gas expansion tube

1. Place the bulb of the expansion tube into a beaker of hot water for a moment. Now place the bulb in a beaker of cold water. Observe how quickly the gas expands and contracts by watching the balloon.

CALCULATING AND INTERPRETING

Part I - Expansion of water and glycerin

Let's use the formula below to calculate the expansion rates of water and glycerin.

Expansion rate = (change in volume)/(change in temperature)x(original volume)

***Example**:*

A container with 100 ml of ethyl alcohol at 0°C was heated to 100°C. The volume of the ethyl alcohol at 100°C was 111 ml. What is the expansion rate of ethyl alcohol?

Expansion rate = (change in volume)/(change in temperature)x(original volume)
Expansion rate = (11 ml)/(100°C x 100 ml)
Expansion rate = 0.0011 = 1100×10^{-6}

(Actual expansion rate of ethyl alcohol = 1120×10^{-6}*)*

NOW CALCULATE THE EXPANSION RATES OF WATER AND GLYCERIN WITH YOUR DATA.

Expansion rate of water =

Expansion rate of glycerin =

Compare your results to the actual expansion rates of water and glycerin from the chart above. Are your results consistent with the actual rates? What variables in your experiment might have affected your results?

Part II - Expansion of water at 4 C

Most liquids contract when cooled and expand when heated—no matter what the original temperature. This means that the cooler molecules in a liquid will be denser and will flow to the bottom of a container, while the warmer molecules will flow to the top. In a tall cylinder of cold liquid, one would expect to find a two to four degree temperature differential between the warmer molecules at the top of the cylinder and the cooler molecules at the bottom of the cylinder.

Similarly, in a tall container of warm liquid that is releasing some of its heat energy to its surroundings, one would expect to find a two to four degree temperature difference between the warmer molecules at the top and the cooler molecules at the bottom.

Water is the exception to this rule. At 4°C, water molecules expand when they are either heated or cooled. Therefore, a cylinder of warm water that is releasing its heat energy to its surroundings will demonstrate the differential explained above, but a cold cylinder of water will not. A cylinder of ice water will demonstrate the opposite—the temperature of the water at the bottom of the cylinder will be two to four degrees warmer than the temperature of the water at the top. The molecules at 0°C are not as dense as the molecules at 4°C, so the colder molecules rise to the top of the cylinder of water.

Do the results of your data confirm this phenomenon? If not, what variables in your experiment might have affected your results?

Part III - Expansion and contraction of solids and gases

Bi-metal bar: In your experiment with the bi-metal bar, you observed that some metals expand more than others when the same amount of heat energy is added. The metal that expands more when heated also contracts more when cooled. How could a bi-metal strip be used in a thermostat?

Gas expansion tube: In your experiment with the gas expansion tube, you observed that gases expand and contract quickly. Look at the expansion rates for air and other gases on the chart. Before shipping a car in the winter from Alaska to the Caribbean, how would you prepare the tires? What might happen if you did nothing?

MAKE SURE YOU UNDERSTAND IT

Using the formulas for calculating change in volume and resulting volume, as shown in the example, solve the problems that follow.

Cubic expansion rate = (change in volume) / (change in temperature)x(original volume)

Change in volume = (original volume)x(temperature change)x(cubic expansion rate)

Resulting volume = original volume + change in volume

Example:

A container with two liters of mercury experiences a 50°C increase in temperature. How much will the mercury expand because of this temperature change? What is the resulting volume?

Step One: Calculate the change in volume of the mercury using the formula. Remember the following conversions:

1 liter = 1,000 milliliters **$1 \times 10^{-6} = 0.000001$**

Change in volume = (original volume)x(temperature change)x(cubic expansion rate)
$\text{Change in volume} = (2\ L)\times(50^{0}C)\times(182 \times 10^{-6})$
$\text{Change in volume} = (2)\times(50)\times(182 \times 10^{-6}) = 18{,}200 \times 10^{-6} = 0.0182\ L$
Change in volume = 0.0182 L

Step Two: Calculate the resulting volume using the formula.

Resulting volume = original volume + change in volume
Resulting volume = (2 L) + (0.0182 L)
Resulting volume = 2.0182 L

PROBLEMS TO SOLVE:

1. What would be the volume of a 10 cubic meter block of aluminum if its temperature increased from 10^{0}C to 510^{0}C?

2. A beaker with 500 ml of a mystery liquid at 20^{o}C was heated to 120^{o}C. Its volume at that temperature had increased to 510 ml. What is the rate of expansion of the mystery liquid?

3. A container of 100 L of ethyl alcohol was heated until the volume increased to 101.1 L. How many degrees Celsius did the temperature of the ethyl alcohol increase?

Lab Five: Specific Heat

LEARN ABOUT IT

The **specific heat** of a substance is the amount of heat energy needed to raise the temperature of one gram of that substance 1°C.

The chart on the following page shows the specific heat of several substances. The specific heat of water is 1.00. It requires one calorie to raise the temperature of one gram of water 1°C. Water is the standard used to determine the specific heats of other substances.

Liquid mercury is 13.6 times denser than water. It requires only 0.033 calories of heat to raise the temperature of one gram of mercury 1°C.

Adding one calorie of heat energy to one gram of water will increase its temperature 1°C. That same amount of heat energy—one calorie—will raise the temperature of one gram of mercury 30°C.

The atomic mass and structure of some substances are such that only a small amount of energy is needed to increase the motion of their atoms. They have low specific heats. Substances with high specific heats require more energy to produce the same increase in molecular motion.

The converse is also true. A small loss of energy in some substances causes a large decrease in molecular motion—a large decrease in temperature. Water—with its high specific heat—retains its heat, its molecular motion. A small loss of energy causes a small loss of temperature.

THINK ABOUT IT

Using the chart on the next page, answer the following questions.

1. Generally, what effect does density have on the specific heat of a substance?

2. What is the relationship between the atomic mass of a substance and its specific heat? Why do you think this is?

3. Which substance requires the most amount of heat energy to cause a one degree increase in its temperature?

4. Which substance requires the least amount of heat energy to cause a one degree increase in its temperature?

5. Why do you think the human body has such a high specific heat? How do you think a detective could utilize this information in a murder case?

Specific Heat Capacities and Densities of Some Substances

Substances	Specific Heat (cal/g°C)	Density (g/cc)	Atomic Mass (neutrons & protons)
Aluminum	0.215	2.7	27
Tin	0.054	7.3	50
Copper	0.092	8.9	63
Ice @ -15°C	0.478	0.9	18
Gold	0.030	19.3	197
Iron	0.107	7.8	56
Lead	0.030	11.3	207
Silver	0.056	10.5	108
Human Body @ 37°C	0.830	--	--
Zinc	0.0915	7.14	30
Ethyl Alcohol	0.586	0.81	46
Mercury	0.033	13.6	200
Water	1.000	1.0	18
Air*	0.240	0.0013	14.4

** average 79% nitrogen & 20% oxygen*

EXPERIMENT WITH IT

Let's investigate specific heat in the laboratory.

Objective: To determine the specific heats of several metals.

SUPPLIES AND PREPARATION

- 5––Metal samples
- 5—Foam cups with lids
- 5—Thermometers
- Tongs and safety gloves
- Triple beam balance
- Beaker
- Hot plate or Bunsen burner and ring stand or tripod
- Water

PROCEDURE

1. Determine and record the mass of the metal samples.
2. Place the metal samples in a beaker of boiling water for two minutes. Keep the water boiling. The metals will increase in temperature until all are the temperature of boiling water at 100°C.
3. Mark each foam cup with the name of one of the metal samples. Fill the cups with an amount of room temperature water equal to the mass of the metal samples and record the temperature. (For example, if the samples weigh 50 g, place 50 ml of water in the foam cups.)
4. Using the safety gloves and tongs, remove each sample from the boiling water and place into a marked foam cup. Cover each foam cup with a lid. After 30 seconds, gently shake the foam cups for three seconds.
5. Wait an additional 30 seconds. Record the final temperature of the water in each cup.

Record Data

Substance	Mass	Initial Temperature	Final Temperature	Temperature Change	Specific Heat
Aluminum					
Copper					
Lead					
Tin					
Zinc					

CALCULATING

Let's use the formulas below to calculate the specific heat of the metal samples.

Heat gained/lost = (temperature change of water)x(mass)x(specific heat)

Specific heat = (heat gained/lost) / (mass)x(temperature change of metal)

Example:

A sample of iron with a mass of 55 g is taken from a container of boiling water (100°C) and placed into a foam container with 55 ml (g) of water at 20°C. After two minutes, the temperature of the water and iron sample is 27.7°C. Calculate the specific heat of iron.

Step One: Calculate the heat energy gained by the water using the formula above.

Heat gained by water = (temperature change)x(mass)x(specific heat)
Heat gained by water= (7.7°C)x(55 g)x(1.00 cal/g°C) = 424 cal

CALCULATING CONTINUED

Step Two: Calculate the specific heat of the iron using the formula below. Remember the heat lost by the iron is equal to the heat gained by the water.

Specific heat = (heat gained) / (mass)x(temperature change of metal)
Specific heat = (424 cal) / (55 g)x(72.3°C) = 0.105 cal/g°C

(Actual specific heat of iron from chart above = 0.107 cal/g°C)

NOW CALCULATE THE SPECIFIC HEAT OF YOUR SAMPLES.

Aluminum: **Copper:** **Lead:** **Tin:** **Zinc:**

Compare your results with the specific heat values in the chart above. Are your results similar? What variables in your procedure may have affected your results?

MAKE SURE YOU UNDERSTAND IT

Using the chart and the formulas for calculating heat lost/gained and specific heat, solve the problems below.

1. A 10 g copper sample at 150°C is placed in a foam cup of water containing 50 ml of water at 30°C. After two minutes, the copper has given off some of its heat energy and the copper and water are at the same temperature. What is that temperature?

2. An unknown metal at 125°C with a mass of 10 g is placed in a foam cup with 40 ml of water at 20°C. After two minutes, the metal and water reach 22.75°C. What is the metal?

3. Three 20 g samples of iron, lead, and aluminum are placed on a concrete sidewalk on a sunny 38°C day. Before being placed in the sun, the samples were stored in a container at 20°C. What happens to the temperature of the metals over a one-hour period? What would happen to the same 20°C samples if they were put in a freezer at 0°C for a one-hour period?

Lab Six: Heat of Fusion & Vaporization

LEARN ABOUT IT

It requires energy to overcome the forces of attraction between atoms and molecules. To change a substance from a solid into a liquid requires energy to break the forces of attraction that keep the atoms or molecules in fixed positions.

The **heat of fusion** is the energy needed to change one gram of a substance, at its melting point, from a solid into a liquid without an increase in temperature.

To change from a liquid into a gas requires even more energy per gram to overcome the forces of attraction. The forces of attraction between atoms and molecules in gases are almost zero.

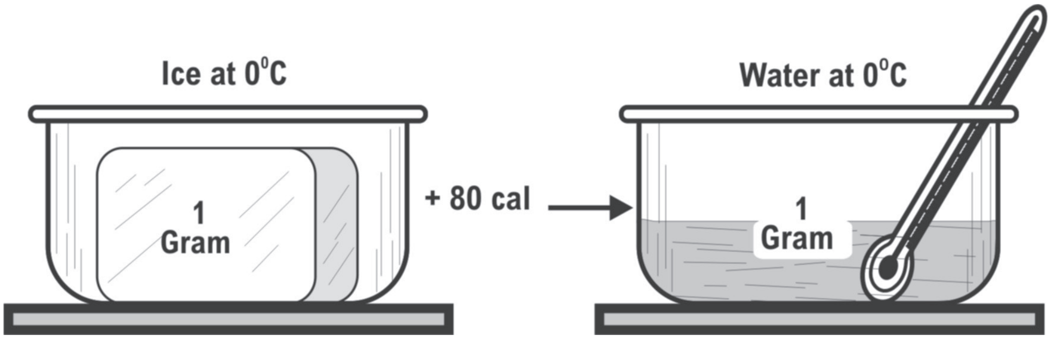


Figure 1. The heat of fusion of water is 80 cal/g.

The **heat of vaporization** is the energy needed to change one gram of a substance, at its boiling point, from a liquid into a gas without an increase in temperature. The chart on the next page lists the melting and boiling points of several substances, and their heats of fusion and vaporization. Notice how much greater the heat of vaporization is than the heat of fusion for the substances listed.

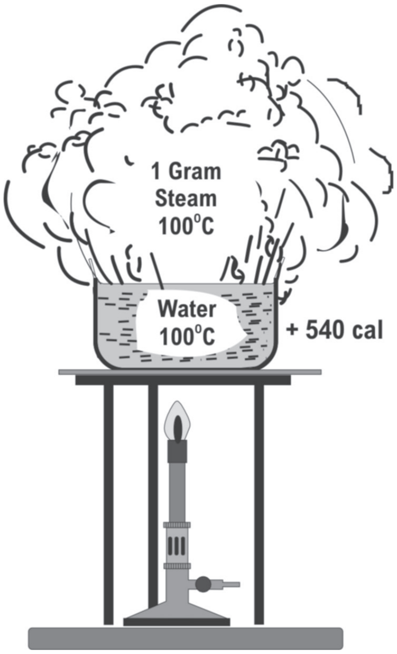


Figure 2. The heat of vaporization of water is 540 cal/g.

Heats of Fusion and Vaporization

Substance	Melting Point (°C)	Heat of Fusion (cal/g)	Boiling Point (°C)	Heat of Vaporization (cal/g)
Copper	1,083	49.5	2,566	1,130
Ethyl Alcohol	-114	25.8	78	204
Gold	1,063	15.0	2,808	411
Lead	327	5.5	1,750	205
Mercury	- 39	2.7	357	71
Oxygen	- 218	3.3	- 183	51
Water	0	80.0	100	540

Let's look at one familiar substance from the chart—water. What happens as thermal energy is added to ice at -20°C? Look at the graph on page 38. As energy is added to the ice, its temperature rises from -20°C to 0°C.

At 0°C, H_2O molecules can exist as either a solid or a liquid—the only difference is the amount of energy holding the molecules together. In a solid state, the molecules are in fixed positions—they do not have enough energy to break the bonds that hold them together. The forces of attraction between the molecules are great—you can stand on a frozen lake.

In a liquid state, however, the H_2O molecules are free to move about. As energy is added to the ice at 0°C, it changes into a liquid—water—at 0°C. All the added energy is used to change the water from a solid into a liquid—to break the bonds holding the molecules in a fixed position—not to increase the temperature. Notice how the line on the graph remains horizontal during this phase. This energy is the **heat of fusion.**

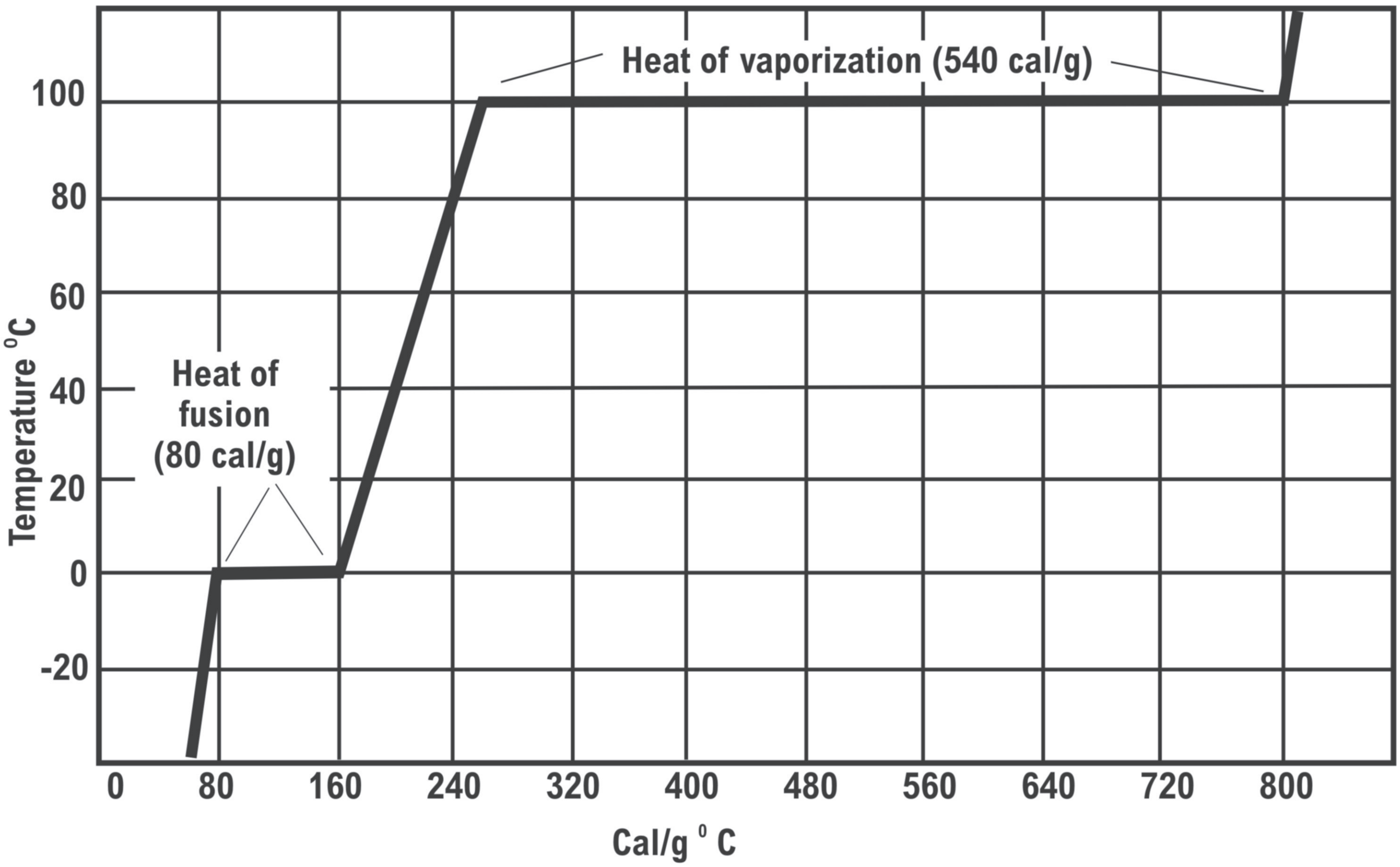
If we continue to add energy to the water, its temperature increases to 100°C. At this temperature, the H_2O molecules can exist either as a liquid or as a gas. As additional heat is added to the sample, the energy is used to reduce the forces of attraction between the water molecules. Eventually, all the H_2O molecules have the energy to escape from the bonds of the other molecules. The additional energy changes the liquid into gas—vapor or steam––without producing an increase in temperature. This energy is the **heat of vaporization**.

Again, notice that the line on the graph is horizontal during this phase. Once all the water has been changed into steam, additional energy will increase the temperature of the steam.

The converse is true when going from a gas to a liquid, or liquid to a solid. The same amounts of energy must be removed from a substance to change a gas to a liquid as were added to change the liquid to a gas.

The heat of fusion for water is 80 calories per gram (cal/g). It takes 80 calories to change one gram of ice at 0°C into water at 0°C. Conversely, 80 calories must be removed to change one gram of water at 0°C to ice at 0°C. The heat of vaporization for water is 540 cal/g. This amount of energy must be added or removed from one gram of steam or water to change its state.

Heating Curve of H_2O



THINK ABOUT IT

Using the Heats of Fusion and Vaporization chart on page 37, answer the following questions.

1. Is the melting point of a substance related to its heat of fusion?
2. Does it take more energy to change a solid into a liquid or a liquid into a gas? Why?
3. Which substance requires the most amount of heat energy to change from a liquid into a gas?
4. Which substance requires the least amount of heat energy to change from a solid into a liquid?
5. Do the heats of fusion and vaporization for substances seem to be related in any way?

EXPERIMENT WITH IT

Let's investigate changes of state in the laboratory.

Objectives: To determine the heat of fusion of water.

To determine the heat of vaporization of water.

SUPPLIES AND PREPARATION

Part I - Heat of Vaporization

- Steam generator with hose—to be operated by teacher
- Foam cup with 100 ml (g) of water at room temperature (about 22°C) & lid
- Thermometer
- Graduated cylinder
- Bunsen burner or hot plate with ring stand to operate steam generator

Part II - Heat of Fusion

- Ice cube
- Foam cup with 100 ml (g) of warm water (about 50°C) & lid
- Thermometer
- Graduated cylinder

PROCEDURE

Part I - Heat of Vaporization

1. Record the temperature of the 100 ml of water in the cup.
2. With your teacher's supervision, insert the hose from the steam generator into the foam cup through the slit in the lid.
3. Wait approximately 8 minutes. (While you are waiting, proceed to Part II)
4. Remove hose and immediately record the temperature of the water in the cup.
5. Carefully pour the water from the cup into the graduated cylinder and record the volume of the water.

Part II - Heat of Fusion

1. Record the temperature of the 100 ml of warm water.
2. Place the ice cube in the cup of water and cover the cup with the lid.
3. After 30 seconds gently shake the cup.
4. Within one minute, the ice cube should be completely melted. If not, wait until the ice is melted and record the final temperature of the water.
5. Carefully pour the water from the cup into the graduated cylinder and record the final volume of the water.

Record Data

	Initial Volume	Final Volume	Change in Volume	Initial Temperature	Final Temperature	Change in Temperature
Part I						
Part II						

CALCULATING

Let's use the formulas below to calculate the heats of fusion and vaporization of water. Remember, one milliliter of water has a mass of one gram. (1 ml H_2O = 1 g H_2O)

Heat gained/lost = (mass)x(temperature change)x(specific heat)
Heat of Vaporization = (heat gained/lost) / (mass of steam)
Heat of Fusion = (heat gained/lost) / (mass of ice)

Part I: Heat of Vaporization

Example:

A cup with 100 ml of water at 22°C was attached to a steam generator. After five minutes, the volume of water in the cup had increased 106 ml. The temperature of the water had increased to 52°C. Calculate the heat of vaporization of water.

Step One: Calculate the volume of the steam changed into water by subtracting 100 ml–the initial volume–from the final volume of water. Change the volume into mass (1 ml H_2O = 1 g H_2O).

Step Two: Calculate the amount of heat energy gained by the water using the equation below.

Heat gained = (mass)x(temperature change)x(specific heat)
Heat gained = (100 g)x(52° C - 22° C)x(1.00 cal/g°C)
Heat gained = (100 g)x(30°C)x(1.00 cal/g°C) = 3,000 cal

Step Three: Using the same formula, calculate the heat lost by the steam to the water.

Heat lost = (mass)x(temperature change)x(specific heat)
Heat lost = (6 g)x(100°C - 52°C)x(1.00 cal/g°C)
Heat lost = (6 g)x(48°C)x(1.00 cal/g°C) = 288 cal

Step Four*:* The amount of heat gained by the water is much more than the heat lost by the steam. This difference is the heat required to change the steam from a gas at 100°C into water at 100°C. This is the heat of vaporization. Now, let's use the formula below to calculate the heat of vaporization.

Heat of Vaporization = (heat gained/lost) / (mass of the steam)
Heat of Vaporization = (3,000 cal - 288 cal) / (6 g)
Heat of Vaporization = (2,712 cal) / (6 g) = 452 cal/g

(The actual heat of vaporization of water is 540 cal/g.)

NOW CALCULATE THE HEAT OF VAPORIZATION WITH YOUR FIGURES.

Compare your results to the actual heat of vaporization. What variables in your procedure may have affected your results?

Part II: Heat of Fusion

Example:

An ice cube at 0°C was placed into a cup with 100 ml of water at 50°C. In one minute, the ice cube had melted. The volume of water in the cup was 120 ml and temperature of the water was 30°C. Calculate the heat of fusion of water.

Step One: Calculate the volume of the ice that changed into water by subtracting 100 ml–the initial volume–from the final volume of water. Change the volume into mass (1 ml H_2O = 1 g H_2O).

Step Two: Calculate the energy lost by the warm water using the equation above.

Heat lost = (mass)x(temperature change)x(specific heat)
Heat lost = (100 g)x(50°C - 30°C)x(1.00 cal/g°C)
Heat lost = (100 g)x(20°C x 1.00 cal/g°C) = 2,000 cal

Step Three: Calculate the heat gained by the ice using the same equation.

Heat gained = (mass)x(temperature change)x(specific heat)
Heat gained = (20 g)x(30°C - 0°C)x(1.00 cal/g°C)
Heat gained = (20 g)x(30°C)x(1.00 cal/g°C) = 600 cal

Step Four: Compare the amount of heat gained by the ice to the heat lost by the water. More is lost by the warm water than gained by the ice water. The difference is the heat needed to change the ice at 0°C into water at 0°C. This is the heat of fusion.

Let's use the formula below to calculate the heat of fusion.

Heat of Fusion = (heat gained/lost) / (mass of the ice)
Heat of Fusion = (2,000 cal - 600 cal) / 20 g
Heat of Fusion = 1,400 cal / 20 gm = 70 cal/g

(The actual heat of fusion for water is 80 cal/ g)

NOW CALCULATE THE HEAT OF FUSION WITH YOUR FIGURES.

Compare your results to the actual heat of fusion. What variables in your procedure may have affected your results?

MAKE SURE YOU UNDERSTAND IT

Using the formulas for calculating heat lost/gained and the heats of vaporization and fusion, solve the problems below.

1. A 20 g piece of ice at 0°C is placed in a foam container with 50 g of water at 100°C. After two minutes the ice has completely melted. What is the temperature of the water?

2. Two grams of steam at 100°C are put into a foam container with 50 g of water at 20°C. What is the final temperature of the water?

3. An unknown amount of steam is added to 90 g of water at 20°C. The final temperature of the water is 82°C. What is the mass of the steam added to the water?

4. A 100 g piece of ice at 0°C is placed into a foam container. A total of 20 g of steam at 100°C is introduced into the container. In three minutes, the ice has melted and all the steam has condensed into water. What is the temperature of the water in the container?

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