

Discovering Matter



UNIT

1

Lab Manual

Front Cover:

The front cover shows two marshmallows cooking over a fire. Why do the marshmallows begin to change when they are heated by the fire?

Unit 1: Discovering Matter

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Intro Section: The Science of Cooking

Why Does Food Change When Cooked?

Cooking is all about changing food. Think about the kinds of foods that are found in a kitchen. Many kitchens have “raw” foods that haven’t been cooked. Fruits and vegetables are raw foods until they’ve been cooked in some way. So is uncooked meat.

And kitchens usually have foods that have already been cooked. Bread has already been cooked. Some food cannot be eaten until it has been cooked. Raw meat is an example of this. So are pasta and rice.



These fruits, vegetables, and raw meats haven't yet been cooked. The bread has already been cooked.

The Relationship Between Cooking and Science

The changes that food undergoes in the kitchen are all caused by scientific phenomena. "Cooking is chemistry and physics, except you get to eat your lab work," said Jack Bishop, who works at America’s Test Kitchen. (It’s important not to eat anything in your science lab because those materials are not edible.)

Broadly, science is the search for explanations about the natural world, and scientists use evidence to form conclusions that support those explanations. All knowledge learned from experiments is part of **science**.

Using a Scientific Process

Science is part of a larger cycle that includes engineering, math, and technology. This cycle is called the STEM cycle. Engineers apply scientific knowledge to create new technologies that solve problems. Math is a tool that both scientists and engineers use to capture results and communicate those results to others.

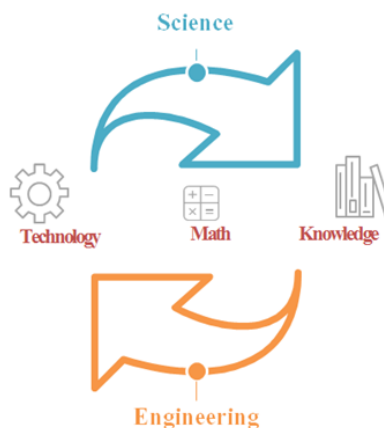
The STEM Cycle

Scientists: answer questions

Can the energy in algae power vehicles instead of fossil fuels?



biologist testing green algae to see if it can be used as a fuel source



Engineers: solve problems

Vehicles that run on fossil fuels pollute the environment.



biofuel engineers test a container ship powered by green algae

Science, technology, engineering, and math are connected in the STEM cycle.

Scientists use a scientific process to guide them in developing a replicable experiment as they seek out answers to questions about the world around them. A process is a series of steps designed to meet a goal.

There are eight steps that scientists often follow to answer questions using data from experiments. These steps give scientists a logical pathway to move from a question toward an evidence-based conclusion.

Step 1: Ask a question.

Asking questions is something that all scientists do. Scientists look for the causes of different phenomena they observe in the world around them.

The scientific process always begins with a question. For example, imagine that a scientist named Ana observed that her garden plants look shriveled after a week of no rain. Scientist Ana might then ask the question: “How does the amount of water a plant receives affect how tall it grows?”



A scientist might question whether a lack of water caused this plant to wilt.

Step 2: Research the question.

Every year the amount of scientific knowledge grows. Scientists use this existing knowledge to research their question. Scientist Ana might research what plants need to survive and grow. She might learn that plants use water to carry out different life functions.

Step 3: Form a hypothesis.

After scientists have researched their question, they form a hypothesis. A hypothesis is a statement that can be proved true or false. The hypothesis is the scientist’s prediction, based on what is known, about the answer to the question.

Scientist Ana might come up with one of the following hypotheses:

- “Plants grow taller when they don’t receive any water compared to when they receive water.”
- “Plants grow less tall when they don’t receive any water compared to when they receive water.”
- “The amount of water a plant receives has no effect on its height.”

Step 4: Write a summary of the experiment.

Scientists then write a summary of the experiment they will conduct to test their hypothesis. The summary should include the basics of the data to be collected, the variables that will be tested, and the parts of the experiment that will remain constant in each test or trial.

A variable is something you change. It can be a factor, trait, or condition that can exist in differing amounts or types. There are independent and dependent variables in an experiment. The independent variable is what the scientist changes. The dependent variable is what happens as a result of the independent variable.

In an experiment testing whether the amount of water a plant receives affects its height, the independent variable would be the different amounts of water the plants receive. The height the different plants grow would be the dependent variable.

Constants allow scientists to isolate one variable at a time to ensure the experiment results are valid. For example, the type of plant used and the amount of sunlight would need to stay the same in each test. If the type of plant or the amount of sunlight were different, it would be impossible to know whether the results were because of the amount of water or the other factors.

Step 5: List materials and procedure.

Scientists then list materials needed and the procedure they have created that they will follow. A procedure is like a recipe. Whenever you use a recipe, you are following a careful and precise procedure that someone else developed. Scientists write down their materials and procedure so anyone can use the same materials and follow the same steps to get similar results. They also want to create a record of their thinking.

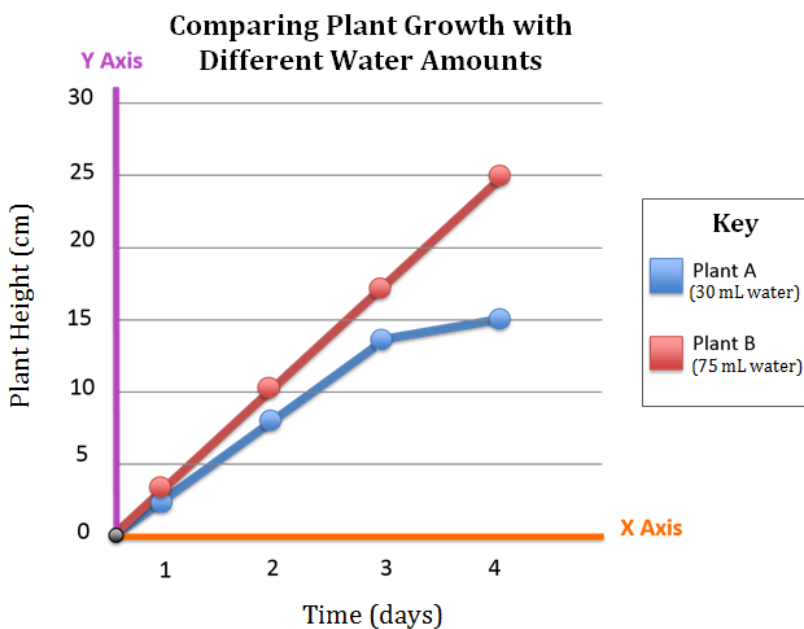
Step 6: Draw a scientific diagram.

They will also draw a scientific diagram. The diagram helps the scientists visualize how the different materials will interact in the experiment.

Step 7: Carry out experiment to collect data.

Scientists then conduct an experiment to test their hypothesis. An **experiment** is a specific procedure that tests if a hypothesis is true, false, or inconclusive. Scientists use experiments to look for patterns in data that suggest a **cause-and-effect** relationship, where one event or thing is the result of the other. A **pattern** is something that happens in a regular and repeated way.

The results of the experiment are data. **Data** are the measurements and observations gathered from an experiment.



Step 8: Form a conclusion.

After data have been collected, scientists form a conclusion. The conclusion uses data from the experiment as evidence to support whether the hypothesis is true, false, or inconclusive.

The Scientific Process

1	Question	End with a question mark and do not include words such as “I” or “because.”
2	Research	Include a minimum of three facts relevant to the question.
3	Hypothesis	Write a concise statement that answers the question and can be proved true or false.
4	Summarize Experiment	Describe in 2-3 sentences the experiment you will do to test your hypothesis. Identify the independent and dependent variables, constants, and controls of the experiment. The independent variable is the variable changed. The dependent variable is what happens as a result of the independent variable. Constants of the experiment are conditions unchanged during each trial. A control in the experiment captures the effect of unknown variables.
5	Materials and Procedure	Vertically list all materials needed for your experiment with quantities. Next, vertically list the numbered steps of your procedure. Note safety precautions.
6	Scientific Diagram	Draw a diagram of the experiment set-up that is at least the size of your hand. Title it and include labels for all materials on the materials list.
7	Data	Follow your test procedure and gather data (both observations and numbers) to determine whether the hypothesis is true, false, or inconclusive. Use proper units, title data tables, and tape into lab notebooks.
8	Conclusion	Use the data collected in the experiment to explain why the hypothesis is true, false, or inconclusive. Every conclusion must contain a minimum of 3 elements: <ol style="list-style-type: none">1. Restate your hypothesis.2. Make a claim (true/false/inconclusive).3. Use key points of data as evidence to support and explain your claim.

Section 1: Using Energy to Change Food

Food is Matter

Today Mario Batali is a famous chef. But he remembers watching his Italian grandmother making her own pasta every Sunday. She would put her homemade ravioli or gnocchi into boiling water to cook it. He says that watching her do this played a major role in his becoming a chef.



Why is pasta a kind of matter?

Pasta is a kind of matter. **Matter** is anything that has mass and takes up space. **Mass** is a measure of the amount of matter that makes up an object or substance. It is measured in grams (g).

Properties of Matter

The mass of an object is one property of that object. A **property** is an observable or measurable characteristic of a substance. Physical properties include color, texture, mass, volume, and density. Volume is a measure of how much space an object or substance takes up. It is measured in cubic meters (m^3) for solids with a ruler, or liters (L) or milliliters (mL) for liquids.

Density is the amount of mass in a unit volume of a substance. Different elements have different densities. Density is a useful physical property for identifying an unknown substance because the amount or sample size of a material does not affect its density. Because most substances change volume when they are heated or cooled, densities are temperature dependent.

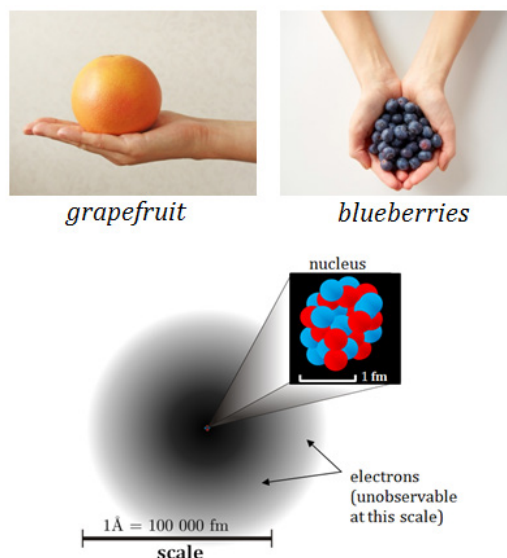
Each kind of matter has the properties it does because of the atoms that make it up. An **atom** is the smallest piece of matter that has the properties of an element. An element is a substance made up entirely of one kind of atom. All matter is made up of a specific combination of atoms.

To understand why matter has the properties it does, scientists begin with the structure of atoms that make it up. **Structure** is the way in which parts are put together to form a whole.

Atoms are so tiny that we cannot see them without special instruments. Because of this, scientists use scale to understand how the size of atoms relates to everyday objects. **Scale** is the size, extent, or importance (magnitude) of something relative to something else.

Scale of an Atom

For example, think about a grapefruit. If each atom in the grapefruit were the size of a blueberry, the grapefruit would have to be the size of Earth. There are so many atoms in just one grapefruit that they are impossible to count. Imagine having to fill up the entire planet with blueberries. That's about how many atoms are in one grapefruit.



Atoms themselves are made up of smaller particles called protons, neutrons, and electrons. These smaller particles are called subatomic particles. These smaller particles are much smaller than the atom itself. The protons and neutrons group together in the atom's core, called the nucleus. If the atom were the size of a blueberry and you opened the blueberry up, the nucleus would be too small to see.

All matter is made up of atoms. This scaled model of an atom shows the size of the atom compared to the particles that make it up.

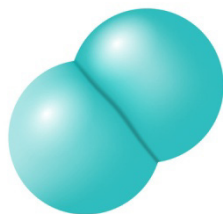
If you were to make the blueberry the size of a football field, you would just be able to see the nucleus. It would be the size of a small marble. The nucleus holds all of the atom's protons and neutrons. The electrons are smaller than the protons or neutrons. They are in constant motion around the nucleus. However, most of the atom is filled with empty space. There are vast regions of space between each of the electrons and between the electrons and the nucleus.

How Matter Forms

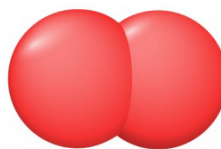
Atoms are like Lego blocks, fitting together with other atoms to form bigger pieces of matter. Whenever two or more atoms bond (join together), they form **molecules**. Each kind of matter has the properties it does because of the number and kind of atoms and molecules that make it up. Molecules can be small, made up of one or two atoms. Or they can be made up of thousands of atoms.

For example, oxygen (O_2) is a molecule made up of two oxygen atoms bonded together. It is a gas at room temperature. It is colorless and odorless. Hydrogen (H_2) is a molecule made up of two hydrogen atoms bonded together. Like oxygen, it is also a gas at room temperature. It is also colorless and odorless. It has the lowest density of all the elements.

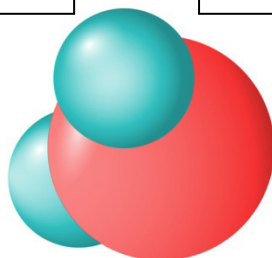
Water (H_2O) is a molecule that forms when two hydrogen atoms and one oxygen atom bond. It is a liquid at room temperature. It is odorless and almost colorless, except for a hint of blue.



This is a model of a molecule of hydrogen. It is made up of 2 hydrogen atoms.



This is a model of a molecule of oxygen. It is made up of 2 oxygen atoms.



This is a model of a water molecule. It is made up of 2 hydrogen atoms and 1 oxygen atom.

** Note: The colors of the different molecules are not actually the colors of the atoms. They are used in these models to show the different kinds of atoms.*

The Relationship Between Matter and Energy

Matter cannot change without energy. This is why you need a pot of boiling water to cook pasta. **Energy** is the ability to do work. Work is any change in position, speed, or state of matter due to force (a push or pull that acts on an object, changing its speed, direction, or shape). Examples of work include heating an object or moving an object.

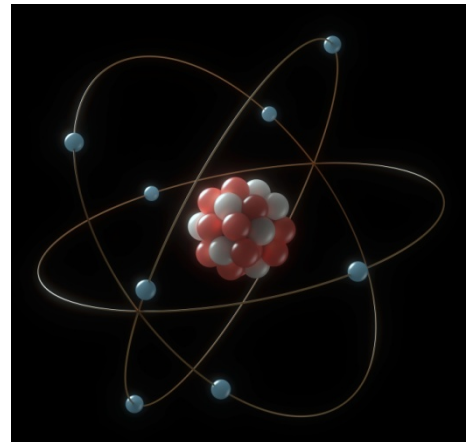
Energy can either be stored or in motion. Energy that is stored is called **potential energy**. The energy of motion is called **kinetic energy**.

Forms of Energy

Energy is never created or destroyed, but it can change from one form to another. For example, all matter has a form of chemical potential energy that is stored in the bonds holding together atoms and molecules. That chemical energy is what allows new molecules to form. We'll explore this idea more in the next section.

Chemical energy can also be transferred. For example, whenever we eat pasta and other food, we absorb some of the food's chemical energy.

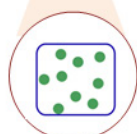
All matter also has a form of energy called thermal energy. **Thermal energy** is the motion of atoms and molecules in a substance or object as its temperature increases. **Temperature** is a measure of heat and is measured in Celsius with a thermometer. Heat is not the same as thermal energy. Heat refers to the thermal energy transferred from one object to another. The faster that atoms and molecules move, the more thermal energy they have and the warmer they become.



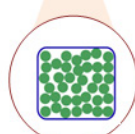
This is a 3D model of an atom. The bonds holding together this atom and all atoms and molecules store potential chemical energy.

Thermal Energy Changes Matter's State

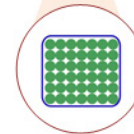
The amount of thermal energy present in a substance determines a substance's state of matter (whether a substance is a solid, liquid, or gas).



gas state



liquid state



solid state

Solids

Solids have the least amount of thermal energy of any state. As a result, the atoms in a solid are closely packed together. They are always moving, but because of how close they are, they can only vibrate in place. They cannot move past one another. As a result, solids keep their shape until something changes them.

When thermal energy is added to solids, the atoms or molecules begin to move more quickly. When enough energy is added, they will expand and become a liquid.

This is what happens when you leave ice cream out on a hot day. The ice cream absorbs thermal energy from the environment, causing the ice cream to melt. The temperature at which a substance changes from a solid to a liquid is called its melting point. Different substances have different melting points depending on how much energy is needed to change them from a solid to a liquid. This in turn depends on the kind of atoms that make them up.



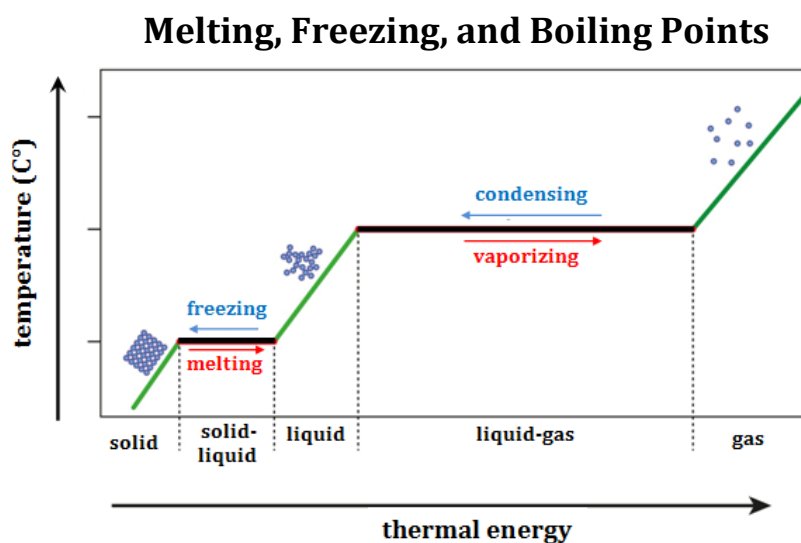
The addition of thermal energy causes this ice cream to melt.

Liquids and Gases

Water and milk are both examples of liquids. The atoms in a liquid are less tightly packed than in a solid. They are in constant contact with one another, but they have enough energy to slide past one another. Therefore, matter in a liquid state takes the shape of its container, but has no shape of its own.

When thermal energy is removed from a liquid, the kinetic energy of the atoms and molecules decreases. This causes them to slow down. When enough thermal energy is removed, the liquid will turn into a solid. This is called its freezing point. For example, water freezes when the temperature reaches 0 degrees Celsius (32 degrees Fahrenheit).

When enough thermal energy is added to a liquid, the atoms or molecules will move so quickly that the liquid will expand, becoming a gas. This is called a substance's boiling point. Water boils at 100 degrees Celsius (212 degrees Fahrenheit).



Different substances have different melting, freezing, and boiling points.

The molecules in a gas have so much energy that they move far apart and bounce around randomly. As a result, matter in a gas state has no shape and spreads out into space. If a certain amount of gas is taken out of one container and placed into a container that is twice as large, the gas will expand to fill the larger container.

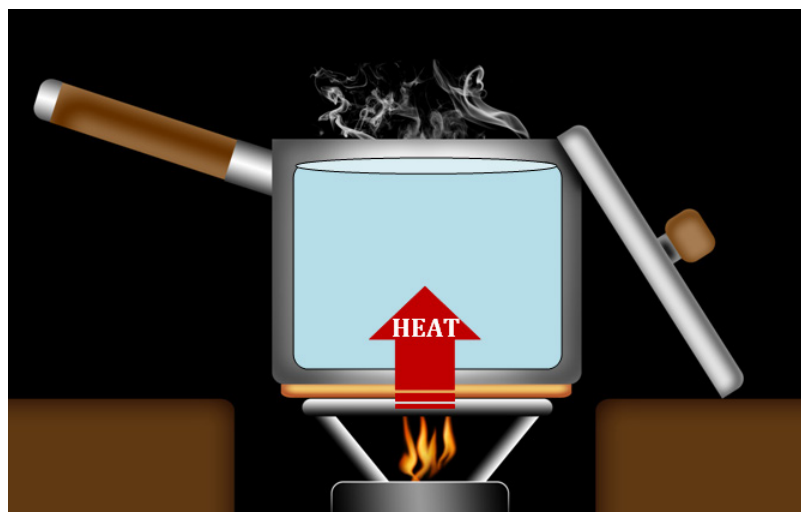
Energy Transfer

Cold water in a pot eventually heats up and starts to boil when enough thermal energy is added. This happens because energy can transfer into or out of systems or objects. A **system** is a set of connected, interacting parts that form a more complex whole. If pasta is cooking on the stove, the pot and the water/pasta in the pot form a system. Heat transfers into the system when the pot is on the stove and the stove is turned on.

Heat is energy that has transferred whenever two substances are at different temperatures. Heat always flows from faster moving atoms (a higher temperature) to slower moving atoms (a cooler temperature) until both substances reach the same temperature. This point is called equilibrium.

Conduction

Conduction is heat transfer that occurs when molecules collide. When the stove is turned on, it heats up the surface of the pot. The warmer molecules of the pot collide with the cooler water molecules. This causes energy to transfer from the pot molecules to the water molecules.



Heat transfers from the stove to the pot and then the water.

Common Core Connection – ELA

Reading Informational Text – Key Ideas and Details

Read the following article: “The chemistry of cooking: Scientist meets chef,” and then answer the questions below.¹

On Monday and Wednesday nights, Lesa Tran and a small group of 14 undergraduate students gather in the kitchen for class. The class is called the Chemistry of Cooking. Together they put on aprons. They huddle around prep stations, stoves and fryers. They perform cooking demonstrations. These unconventional laboratory experiments have a specific purpose. They show the science involved in the composition, transformation and consumption of food.

Student groups get recipes to follow. They are asked to change different variables in the recipes. For example, the students observed that changing the type of flour or fat source when baking biscuits and cookies changes their overall texture and flavor. These experiences provide students the chance to taste, perceive and discuss the chemical changes caused by each component of the recipe, Tran said.

“To me, chemistry and food go hand in hand,” she said. “Food — like everything else in this world — is composed of atoms and molecules, which follow the same concepts and principles we learn in chemistry.”

Student Abby Halm signed up for the class after having taken a previous chemistry course with Tran. Halm said that the class has been beneficial on two levels. She was picking up cooking skills and dusting off her basic chemistry skills.

“Thinking back on the horrible mistakes I’ve made in the kitchen now I realize how and why I made those mistakes,” Halm said. “My cooking isn’t very good, but at least I’ll know why things have gone wrong.”

Questions:

1. What is the main point of this article?
2. How does chemistry influence cooking? Use specific details from the article.

¹ Adapted from a Rice University press release: <http://news.rice.edu/2014/12/04/the-chemistry-of-cooking-scientist-meets-chef/>

Section 1 Review

<u>Multiple Choice</u>	<u>Critical Thinking</u>
<p>MC1. Which of the following best explains why ice cream melts on a hot summer day?</p> <ul style="list-style-type: none">A. Thermal energy transfers into the ice cream, causing the ice cream molecules to gain mass.B. Thermal energy transfers out of the ice cream, causing the ice cream molecules to lose mass.C. Thermal energy transfers into the ice cream, causing the ice cream molecules to speed up.D. Thermal energy transfers out of the ice cream, causing the ice cream molecules to slow down. <p>MC2. Which of the following best describes how energy is transferred between substances?</p> <ul style="list-style-type: none">A. Thermal energy always moves from faster-moving molecules to slower-moving molecules.B. Thermal energy always moves from slower-moving molecules to faster-moving molecules.C. Energy cannot transfer between substances.D. It depends on the substances.	<p>CT1. How can independent and dependent variables show if there is a cause and effect relationship between the variables?</p> <p>CT2. How are molecules related to atoms?</p> <p>CT3. Why do scientists often use models of atoms that aren't to scale?</p> <p>CT4. Ice cube trays are usually filled with liquid water and then placed in the freezer. Over time, the liquid water becomes ice. How does the motion of water molecules change when the liquid water becomes ice?</p>

Section 2: Chemical Reactions

Baking Bread

Have you ever watched someone make bread? The baker takes a variety of different ingredients. They follow a recipe to combine the ingredients in a specific way. Then they add heat to the mixed ingredients. After some time, a loaf of bread is created.



When you bake a loaf of bread, chemical reactions occur. In a **chemical reaction**, the atoms of the original substances are rearranged into one or more new substances that have different properties from the original substances.

Chemical vs. Physical Changes

How is a loaf of bread different from the ingredients that make it up?

The changes that occur as a result of a chemical reaction are not the same as physical changes. Physical changes are changes that do not affect the chemical structure of a substance. For example, if you cut up a piece of paper, it is smaller but it is still paper. When you add enough thermal energy to an ice cube, it will turn into liquid water, but the molecules are still water molecules. The ingredients of salad dressing can be separated, and they will still have the same properties.

In contrast, a chemical change is a change that rearranges the chemical structure of the substances through a chemical reaction. When you bake bread, the ingredients are combined in such a way that the bread that is produced has different properties from the ingredients it came from. When you cook pasta, the noodles are chemically changed to become sticky and springy.

When you cook, it is good to know about the properties of the different ingredients. These properties are determined by the number and kind of atoms that make up the different ingredients.

But scientists often don't work with individual atoms because they are so small. Instead they work with elements (substances made up entirely of one kind of atom).

For example, salt is a staple of kitchens. It is made up of the elements sodium (Na) and a form of chlorine (Cl), so it is called sodium chloride.



Salt is made up of 2 elements: sodium and a form of chlorine.

Periodic Table of Elements

Scientists use a chart called the Periodic Table of Elements to organize all of the known elements according to their properties. There are currently 118 known elements. The last four were just added in 2016. Scientists are continuing to search for new elements.

Each element on the periodic table is assigned a symbol and a number. The symbol comes from the name of the element's atom (in English or Latin), and the atomic number comes from the number of protons found in the atom's nucleus.

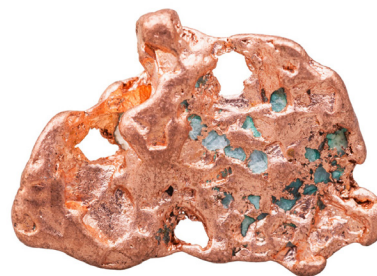
Atomic number	11	22.99	Atomic mass
Symbol	Na		
	Sodium		Element name

For example, sodium has 11 protons, while chlorine has 17. Neutrons and electrons don't define an element because the number of neutrons and electrons in an atom can fluctuate.

Organization of the Periodic Table

The periodic table is organized from top to bottom in groups by increasing atomic number. The periodic table indicates some patterns among elements. For example, an element's place on the periodic table tells us how reactive its atoms are and whether it is a metal, nonmetal, or metalloid.

- Metals are shiny, malleable, and good conductors of electricity and heat. Almost 75 percent of all elements are metals, including mercury, zinc, gold, copper, iron, and other elements in columns 1-12 of the periodic table.
- Nonmetals are brittle, dull, and poor conductors of electricity and heat. There are only 18 nonmetals on the periodic table. Gases and elements on the far right of the periodic table are nonmetals. Coal is an example of a nonmetal.
- Metalloids, also called semiconductors, have properties of both metals and nonmetals, such as being shiny and hard, but brittle. Boron, silicon, and arsenic are metalloids. Metalloids are found between metals and nonmetals on the periodic table. They are called semiconductors because depending on what other molecules are around, they can sometimes conduct electricity.



Copper is a metal.



Coal is a nonmetal.



Silicon is a metalloid.

Periodic Table of Elements

1 H HYDROGEN 1.00794																	2 He HELIUM 4.002602						
3 Li LITHIUM 6.941	4 Be BERYLLIUM 9.012182																	5 B BORON 10.811	6 C CARBON 12.0107	7 N NITROGEN 14.0067	8 O OXYGEN 15.9994	9 F FLUORINE 18.9984032	10 Ne NEON 20.1797
11 Na SODIUM 22.9903	12 Mg MAGNESIUM 24.305																	13 Al ALUMINUM 26.9815386	14 Si SILICON 28.0855	15 P PHOSPHORUS 30.973762	16 S SULFUR 32.065	17 Cl CHLORINE 35.453	18 Ar ARGON 39.948
19 K POTASSIUM 39.098	20 Ca CALCIUM 40.078	21 Sc SCANDIUM 44.955912	22 Ti TITANIUM 47.867	23 V VANADIUM 50.9415	24 Cr CHROMIUM 51.9961	25 Mn MANGANESE 54.938045	26 Fe IRON 55.845	27 Co COBALT 58.933195	28 Ni NICKEL 58.6934	29 Cu COPPER 63.546	30 Zn ZINC 65.39	31 Ga GALLIUM 69.723	32 Ge GERMANIUM 72.64	33 As ARSENIC 74.92160	34 Se SELENIUM 78.96	35 Br BROMINE 79.904	36 Kr KRYPTON 83.798						
37 Rb RUBIDIUM 85.468	38 Sr STRONTIUM 87.62	39 Y YTTORIUM 88.90585	40 Zr ZIRCONIUM 91.224	41 Nb NIOBIUM 92.90638	42 Mo MOLYBDENUM 95.94	43 Tc TECHNETIUM 97.9072	44 Ru RUTHENIUM 101.07	45 Rh RHODIUM 102.90550	46 Pd PALLADIUM 106.42	47 Ag SILVER 107.8682	48 Cd CADMIUM 112.411	49 In INDIUM 114.818	50 Sn TIN 118.710	51 Sb ANTIMONY 121.760	52 Te TELLURIUM 127.60	53 I IODINE 126.90447	54 Xe XENON 131.293						
55 Cs CESIUM 132.91	56 Ba BARIUM 137.33	57-71 Lanthanoids	72 Hf HAFNIUM 178.49	73 Ta TANTALUM 180.94788	74 W TUNGSTEN 183.84	75 Re RHENIUM 186.207	76 Os OSMIUM 190.23	77 Ir IRIDIUM 192.217	78 Pt PLATINUM 195.084	79 Au GOLD 196.966569	80 Hg MERCURY 200.59	81 Tl THALLIUM 204.3833	82 Pb LEAD 207.2	83 Bi BISMUTH 208.98040	84 Po POLONIUM 208.9824	85 At ASTATINE 209.9871	86 Rn RADON 222.0176						
87 Fr FRANCIUM 223.0197	88 Ra RADIUM 226.0254	89-103 Actinoids	104 Rf RUTHERFORDIUM 261.1088	105 Db DUBNIUM 262	106 Sg SEABORGIUM 266	107 Bh BOHRIUM 264	108 Hs HASSIUM 277	109 Mt MEITNERIUM 268	110 Ds DARMSTADTIUM 271	111 Rg ROENTGENIUM 272	112 Cn COPERNICIUM 285	113 Nh NIHONIUM 284	114 Fl FLEROVIUM 289	115 Mc MOSCOVIUM 288	116 Lv LIVERMORIUM 293	117 Ts TENNESSINE 294	118 Og OGANESSON 294						

Atomic Number → 7

Chemical Symbol → N

Chemical Name → NITROGEN

Relative Atomic Mass → 14.007

- alkali metals
- alkaline metals
- transition metals
- other metals
- metalloids
- nonmetals
- halogens
- noble gases
- lanthanoids
- actinoids

- Solid at room temperature
- 💧 Liquid at room temperature
- ☁️ Gas at room temperature
- 🧑 Artificially created
- ☢️ Radioactive

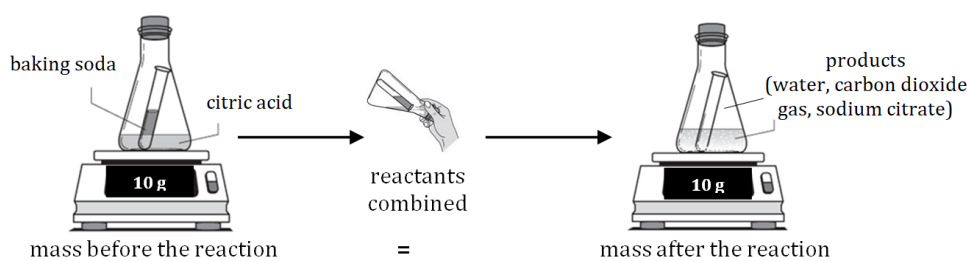
57 La LANTHANUM 138.90547	58 Ce CERIUM 140.116	59 Pr PRASEODYMIUM 140.90765	60 Nd NEODYMIUM 144.242	61 Pm PROMETHIUM 144.9127	62 Sm SAMARIUM 150.36	63 Eu EUROPIUM 151.964	64 Gd GADOLINIUM 157.25	65 Tb TERBIUM 158.92535	66 Dy DYSPROSIUM 162.500	67 Ho HOLMIUM 164.93032	68 Er ERBIUM 167.259	69 Tm THULIUM 168.93421	70 Yb YTTTRIUM 173.04	71 Lu LUTETIUM 174.967
89 Ac ACTINIUM 227.027	90 Th THORIUM 232.03806	91 Pa PROTACTINIUM 231.03588	92 U URANIUM 238.02891	93 Np NEPTUNIUM 237.0482	94 Pu PLUTONIUM 244.0642	95 Am AMERICIUM 243.0614	96 Cm CURIUM 247.0704	97 Bk BERKELIUM 247.0703	98 Cf CALIFORNIUM 251.0796	99 Es EINSTEINIUM 252.0830	100 Fm FERMIUM 257.0951	101 Md MENDELEVIUM 258.0984	102 No NOBELIUM 259.1010	103 Lr LAWRENCIUM 262.1097

Whenever two or more atoms bond together to form molecules or when bonded atoms are broken apart, a chemical reaction occurs. A result of this process is that the substance formed has different properties than the original substances. For example, at normal room temperature, both oxygen and hydrogen elements are gases. When hydrogen and oxygen bond in a molecule of water, they change into a liquid instead of a gas at room temperature.

In any chemical reaction, the atoms and molecules that interact together are called reactants. The atoms and molecules produced by the reaction are called products. Together, the reactants and products form a system. The environment is everything else, including the air or any substance mixed with the reactants.

Conservation of Mass

The total number of atoms does not change in a chemical reaction. Because of this, the mass of any one element at the beginning of a reaction will equal the mass of that element at the end of the reaction. This is called the conservation of mass because matter is never created or destroyed. This means that the more reactants you add to the chemical reaction, the more products will form.



Mass is conserved in a chemical reaction.

It is always true that mass is conserved in a chemical reaction. However, this can be difficult to measure in the real world because the chemical reaction system can interact with the environment. Remember that if a gas is produced, it will fill whatever space it is in. This is impossible to measure. For this reason, scientists sometimes conduct closed-system experiments. These experiments are designed so that matter cannot be exchanged with the environment. This allows scientists to measure the effects of the reaction.

Energy in a Chemical Reaction

As the reactants combine and rearrange, energy is exchanged between the system and the environment. It's important to note here that reactants are sometimes dissolved in other substances, such as water. The dissolving substance (such as the water) is called the solvent. When this occurs, the solvent in which the reactants are dissolved is part of the environment.

Every chemical reaction needs energy to get started. This initial input of energy is called activation energy. For example, when someone strikes a match to light a candle, they provide the activation energy needed to start a fire, which is a chemical reaction.



When you strike a match, you provide the activation energy.

Once the reaction begins, some reactions absorb more energy from the environment than they release. Others release more energy into the environment than they absorb.

Endothermic Processes

Whenever a process occurs in which the system absorbs heat, it is called **endothermic**. “Endo-” means to draw in.

In an endothermic reaction, the environment's temperature decreases. This is because the reaction has absorbed energy from the environment.



Citric acid and baking soda combine in a chemical reaction. What evidence is there that this reaction is endothermic?

Exothermic Processes

Any process in which the system loses heat to the environment is called **exothermic**. “Exo-” means to give off. Because the energy is released as heat, the environment’s temperature will increase.

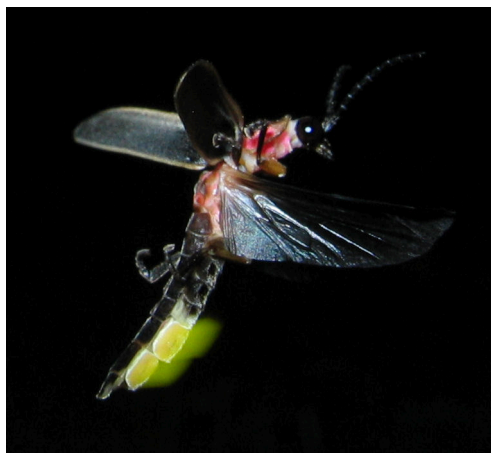
There are many examples of exothermic chemical reactions. When you light a match, an exothermic reaction takes place. The light and heat produced are evidence that energy is being released into the environment.

What evidence is there that this flame is the result of an exothermic chemical reaction?



Another common example of exothermic reactions occurs in certain animals that produce and release light. Called bioluminescence, this phenomenon occurs in animals that live in the ocean, as well as some land animals such as fireflies.

What evidence is there that this firefly's light is the result of an exothermic chemical reaction?



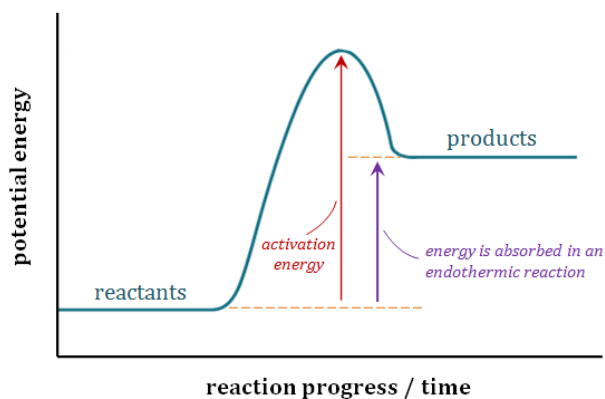
The strength of a chemical reaction can be measured by the amount of energy absorbed or released by the reaction. When more reactants are added, it increases the amount of energy that is absorbed or released.

In the Know: Endothermic vs. Exothermic

The difference between the different kinds of reactions can be understood by thinking about the amount of energy held in the products compared to the amount of energy held in the reactants.

Endothermic Reactions:

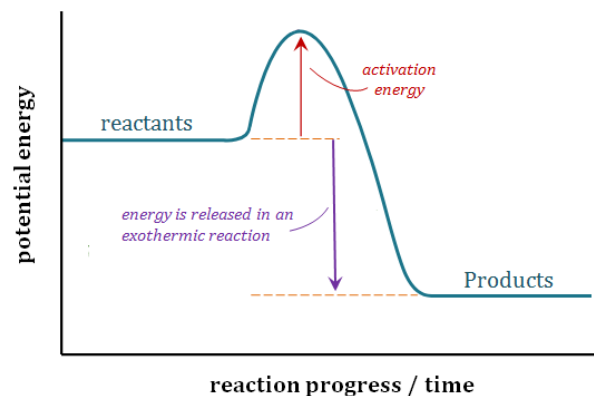
In an endothermic reaction, the reactants have less energy than the products. Because energy is never created or destroyed, the energy needed to form the products is absorbed from the environment into the system.



We can't observe these changes at the molecular level, but we can measure the temperature change that results. We see evidence of this transfer of energy when the environment's temperature decreases because it means that the reaction has absorbed energy from the environment.

Exothermic Reactions:

In an exothermic reaction, the reactants have more energy than the products. Because energy is never created or destroyed, energy is released by the reactants and transferred into the environment as heat.



Name: _____ Date: _____

Chemical Reactions Investigation

Part 1 Question: How do the masses of two substances change when they combine in a closed-system chemical reaction?

Write a hypothesis for the question in the spaces below:

Use the materials below to carry out the procedure. Record your data in Tables 1 and 2 as you carry out the procedure.

Materials

- 150 mL of water
- 2 effervescent tablets
- 1 graduated cup
- 1 funnel (optional)
- 1 digital scale
- 1 plastic bottle with cap

Safety

- Goggles must be worn at all times.

Procedure

1. Add 30 mL of water to the plastic bottle. Measure the mass of the bottle with water and the bottle cap.
2. Break the effervescent tablet into quarters. Find a piece or several small pieces together that total at least 1 gram (not more than 2 grams).
3. Put the effervescent tablet piece(s) into the plastic bottle with water and quickly seal the bottle with the cap to close the system. The bottle cap must be tightly sealed.
4. Measure the mass of the closed system when the chemical reaction is complete. Open the system and discard the water.
5. Repeat Steps 1-4 for four more tests, using fresh water and effervescent tablet piece(s) for each test.

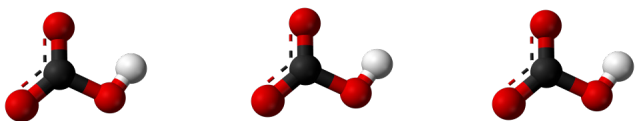

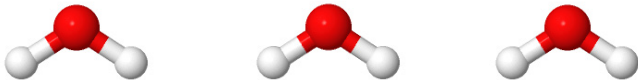

Data

Table 1: Comparing Mass Before and After a Chemical Reaction					
	Before the Reaction			After the Reaction	
	Bottle + Cap + Water (g)	Effervescent Tablet Piece(s) (g)	Initial Mass (g)	Final Mass (g)	Change in Mass (final-initial) (g)
Test 1					
Test 2					
Test 3					
Test 4					
Test 5					

Table 2: Observations – Water + Effervescent Tablet			
	Observations of Substances Before Mixing	Observations of Substances During the Reaction	Observations of Substances After the Reaction
Test 1			
Test 2			
Test 3			
Test 4			
Test 5			

Part 1 Conclusion: Use the data you recorded in Tables 1 and 2 to write a conclusion for the investigation. The conclusion should summarize your findings and explain how the data did or did not support your hypothesis.

Develop and use a model: When the ingredients that make up the effervescent tablet (reactants) dissolve in water, products form. The chart below shows a simplified version of the reactants and products for the reaction.

Table 3: Reactants and Products	
Reactants	
3 bicarbonate molecules (HCO_3^-)	
3 hydrogen (H^+)	
Products	
3 water molecules (H_2O)	
3 carbon dioxide molecules (CO_2)	
Key: H (white) = hydrogen atom; C (black) = carbon atom; O (red) = oxygen atom.	

Use information from Table 3 on the previous page and the Periodic Table of Elements in your lab manual to:

- a) Develop a visual model that describes how mass is conserved in a chemical reaction. Use the empty space on the page to develop your model.
- b) Label any relationships you notice between the different parts of your model.

Part 2 Question: How are endothermic and exothermic chemical reactions different? Use the materials and procedure below to observe and analyze two chemical reactions.

Materials

- 30 mL of vinegar
- 30 mL of hydrogen peroxide
- 3 grams of yeast
- 3 grams of baking soda
- 2 foam cups
- 2 measuring cups (30-mL)
- 1 digital scale
- 1 digital thermometer

Safety

- Goggles and disposable gloves must be worn at all times.

Procedure

1. Pour 30 mL of vinegar into one foam cup. Measure the initial temperature of the vinegar. (You may need to wait for a minute until the thermometer gives a steady value.) Leave the thermometer in the vinegar.
2. Add 3 grams of baking soda to the vinegar. (Do not stir the mixture.)
3. Record the final temperature of the solution when the reaction is complete (the highest or lowest value the thermometer reads) and any observations you notice during the reaction. Rinse the thermometer with water and dry.
4. Repeat Steps 1-3 in a new foam cup for the second chemical reaction, this time using the hydrogen peroxide in place of the vinegar and yeast in place of the baking soda.

Data

Record your data in Tables 1 and 2.

Table 1: Reaction 1				
Combined Substances		Final Temperature of Solution (°C)	Initial Temperature of Vinegar (°C)	Temperature Change (final-initial) (°C)
Vinegar (mL)	Baking Soda (g)			
30	3			
Observations:				
Table 2: Reaction 2				
Combined Substances		Final Temperature of Solution (°C)	Initial Temperature of Hydrogen Peroxide (°C)	Temperature Change (final-initial) (°C)
Hydrogen Peroxide (mL)	Yeast (g)			
30	3			
Observations:				

Analyze the reactions:

1. Is the vinegar and baking soda reaction endothermic or exothermic? Use the data you collected and any observations you made as evidence to support your reasoning.

2. Is the hydrogen peroxide and yeast reaction endothermic or exothermic? Use the data you collected and any observations you made as evidence to support your reasoning.

Part 3 Question: How does increasing the concentration of one reactant in an endothermic chemical reaction affect the temperature change of the reaction? Write a hypothesis for the question in the spaces below:

Use the materials below to carry out the procedure.

Materials

- 150 mL of vinegar
- 60 grams of baking soda
- 1 foam cup
- 1 measuring cup (30-mL)
- 1 digital scale
- 1 digital thermometer

Safety

- Goggles and disposable gloves must be worn at all times.

Procedure

1. Copy the temperature data you collected in Part 2 Table 1 for Test 1: 30 mL of vinegar combined with 3 grams baking soda.
2. Pour 30 mL of vinegar into one foam cup. Measure the initial temperature of the vinegar. (You may need to wait for a minute until the thermometer gives a steady value.) Leave the thermometer in the vinegar.
3. Add 6 grams of baking soda to the vinegar. Record the final temperature of the solution when the reaction is complete (the lowest value the thermometer reads). Discard the solution and rinse the thermometer and foam cup with water.
4. Repeat Steps 2-3 for four more tests, increasing the amount of baking soda in the cup by 3 grams for each additional test.

Data

Record your data in Table 1 as you carry out the procedure.

Test	Combined Substances		Final Temperature of Solution (°C)	Initial Temperature of Vinegar (°C)	Temperature Change (final-initial) (°C)
	Vinegar (mL)	Baking Soda (g)			
1	30	3			
2	30	6			
3	30	9			
4	30	12			
5	30	15			
6	30	18			

Section 2 Review

<u>Multiple Choice</u>	<u>Critical Thinking</u>
<p>MC3. Which of the following describes a chemical reaction?</p> <ul style="list-style-type: none">A. a sugar cube dissolving in waterB. ice cubes forming in a freezerC. ice cream melting in a bowlD. a cake baking in the oven <p>MC4. A campfire can be a welcome addition to a campsite when it is cold outside. The campfire warms people who are near it. What can you conclude about how the campfire warms the air?</p> <ul style="list-style-type: none">A. It warms the air through an endothermic process that absorbs thermal energy from the environment.B. It warms the air through an exothermic process that releases thermal energy into the environment.C. It causes a change of state that turns a solid into a liquid.D. It causes a change of state that turns a liquid into a gas.	<p>CT5. Why do chemical reactions result in products that have different properties from the reactants?</p> <p>CT6. Why is changing a substance's state of matter a physical change, not a chemical change?</p>

Section 3: Design Challenge – Ice Packs

Preserving Food

No food will last forever. In time, all foods decay. When this happens, we can no longer eat them. Before people had refrigerators and freezers, they used blocks of ice in a container to keep foods cold. The cold slowed down decay. When refrigerators and freezers were invented, they helped solve the problem of food spoiling by keeping foods fresh for longer periods of time.

However, it was still difficult to keep foods cold for extended periods of time when you didn't have access to a refrigerator.



Refrigerators are technologies designed by people to solve a problem.

Engineering Solutions

In the 1950s, engineers began using what they know about heat transfer and chemical reactions to design instant cold packs. Engineering is different from science, although science and engineering are connected. Remember the STEM cycle. Scientists use experiments to gain knowledge. **Engineers** use that scientific knowledge and mathematics to create new technologies that solve problems. A technology is anything that people have modified from the natural world to meet their needs and wants.

Similar to how scientists follow a scientific process to answer a question, engineers also follow a process. Engineers often follow a process with eight steps that guides them as they create new technologies to solve problems. The engineering process is similar to the scientific process but it differs because each has a different goal. Scientists are trying to answer a question, while engineers are trying to solve a problem.

Step 1: Identify a problem.

The engineering process begins with a problem. When engineers are defining a problem, they include the criteria (the needs the solution must meet) and constraints (ways the solution is limited). Available materials and cost are two common engineering constraints.

For example, the first instant cold pack was designed to solve the problem of keeping food and drinks temporarily cold when ice wasn't available.

Step 2: Research the problem.

Once they have identified the problem, engineers need to research it to find out what is known about the problem. For example, engineers designing an instant cold pack would need to know the following scientific information:

- Thermal energy can transfer into or out of objects or systems.
- Certain substances can combine in an endothermic chemical reaction. Because thermal energy is absorbed, the environment becomes colder.
- Adding more reactants increases the amount of energy that is absorbed. Reducing the amount of reactants decreases the amount of energy that is absorbed.

Step 3: Survey available materials.

After engineers have researched their problem, they survey the available materials. This survey includes a sketch of the material, as well as how much of the material they have available and the properties of that material.

Step 4: Come up with possible solutions.

Engineers then come up with possible solutions for how the problem can be solved with the available materials. For example, one possible solution is to combine two substances, such as water and ammonium nitrate (NH_4NO_3), that will combine in an endothermic reaction. The two substances will have to be separated by a barrier that can be broken so the two substances can combine and react when the pack needs to become cold.

Step 5: Diagram and build a prototype of the solution.

Once engineers come up with a possible solution, they diagram and build a prototype. A **prototype** is a scaled-down first draft of a technology.

Step 6: Test the prototype.

Once built, engineers test the prototype. They want to see how well it works and whether it meets the criteria of the problem within the constraints.

Step 7: Collect data.

They use the tests to gather data about how well the prototype solves the problem during testing.

Step 8: Refine or replicate.

Finally, engineers use their data to decide whether to refine or replicate. If the prototype doesn't work in some way, engineers know they need to refine their design. They need to look at what didn't work and come up with ways to improve it.

If the prototype solved the problem, meeting the criteria within the constraints, the engineers will replicate their design. This means they will use their design and scale it up to create a full-sized version of their technology.

Designing New Materials

New technologies can then be used to solve other problems or help scientists investigate further scientific questions, continuing the STEM cycle. For example, instant cold packs have evolved so they can be used on people to reduce swelling and ease muscle pains. This is useful in situations when natural ice is not available or not practical.



Instant ice packs solve different problems.

The kind of material to wrap the reacting substances is one challenge for the instant cold pack. It has to be flexible enough to fit the natural curves of the human body. It also has to be insulated so that it doesn't become so cold that it burns the person using it.

Synthetic Materials

Engineers have designed various synthetic materials. A **synthetic** substance is one that is formed through a chemical process developed by humans, as opposed to those of natural origin. Remember that all matter, both naturally occurring and synthetic, is formed from combinations of the 118 known elements. Synthetic materials are created from those naturally occurring elements that combine in chemical reactions to produce new and different kinds of matter.

In order to make synthetic materials, engineers need to know about the properties of different substances, and how those properties will change in chemical reactions between different substances. They use that scientific knowledge to evaluate how well the proposed synthetic materials will meet the needs of the problem at hand.

Using an Engineering Process

1	Problem	Identify the problem, including the criteria and constraints of the problem, and summarize in two or three sentences.
2	Research	Use what you know to help solve the problem. Record a minimum of three facts relevant to the problem.
3	Survey Available Materials	List the available materials that can be used to solve the problem and include for each material a sketch, quantity, description, and properties.
4	Possible Solutions	List three ways the problem can be solved with the available materials.
5	Diagram and Build Prototype	Draw a hand-sized scientific diagram of the prototype solution you will then build from your materials. A scaled-down version of a technology is called a prototype. Title the diagram and include labels for each material or part of your prototype.
6	Test	Test your prototype to see how well it solves the problem.
7	Data	Collect data (measurements and observations) as evidence for how well the prototype solves the problem.
8	Refine or Replicate	Use your data to evaluate the success of the prototype and recommend if it should be refined or replicated. You may redesign your prototype to better solve the problem. Every conclusion must contain a minimum of three elements: <ol style="list-style-type: none">1. Restate the problem and describe the prototype technology.2. Make a claim about whether the technology should be refined or replicated.3. Use key points of data gathered from testing to support the recommendation to refine or replicate.

Section 3 Review

<u>Multiple Choice</u>	<u>Critical Thinking</u>
<p>MC5. Which of the following best describes the difference between a scientist and an engineer?</p> <ul style="list-style-type: none">A. Scientists solve problems and engineers answer questions.B. Scientists answer questions and engineers solve problems.C. Scientists gather data and engineers do not.D. Engineers follow a process and scientists do not. <p>MC6. How is a synthetic material similar to a naturally occurring material?</p> <ul style="list-style-type: none">A. Both are made up of atoms and molecules.B. Neither is made up of atoms or molecules.C. Neither is created as a result of a chemical reaction.D. A synthetic material has no similarities with a naturally occurring material.	<p>CT7. How are synthetic materials different from naturally occurring substances?</p> <p>CT8. Why is the development of a synthetic material for a specific purpose an example of engineering?</p> <p>CT9. Plastic is a synthetic material. Ask your teacher for the video link and then answer the following questions:</p> <ul style="list-style-type: none">▪ Why is plastic a synthetic material?▪ Briefly, how are the properties of plastic different from the resources it comes from?▪ How do the properties of plastic make it beneficial to society?▪ Are there any negative consequences to using so much plastic?

Science Words to Know

atom – the smallest piece of matter that has the properties of an element; a combination of three subatomic particles: protons, neutrons, and electrons

cause and effect – a relationship between events or things, where one is the result of the other

chemical reaction – a process that rearranges the atoms of the original substances into a new substance that has different properties from the original substances

conduction – heat transfer that occurs when molecules collide

data – the measurements and observations gathered from an experiment

energy – the ability to do work

endothermic – a process in which energy is absorbed from the environment

engineer – anyone who uses scientific knowledge and mathematics to solve problems by creating new technologies

exothermic – a process in which energy is released into the environment

experiment – a specific procedure that tests if a hypothesis is true, false, or inconclusive

kinetic energy – the energy of motion

mass – a measure of the amount of matter that makes up an object or substance; measured in grams (g)

matter – everything that has mass and takes up space

molecule – a combination of two or more atoms bonded together

pattern – something that happens in a regular and repeated way

potential energy – energy that is stored

property – an observable or measurable characteristic of a substance

prototype – a scaled-down first draft of a technology

scale – the size, extent, or importance (magnitude) of something relative to something else

science – all knowledge gained from experiments

scientist – a person who uses a scientific process to discover new knowledge

structure – the way in which parts are put together to form a whole

synthetic – substances formed through a chemical process developed by humans, as opposed to those of natural origin

system – a set of connected, interacting parts that form a more complex whole

temperature – a measure of heat; measured in Celsius with a thermometer

thermal energy – the motion of atoms and molecules in a substance or object as its temperature increases

