All About Heat Energy

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Introduction:

There is an old saying that all roads lead to Rome. To paraphrase; with energy all roads lead to heat. An examination of the Second Law of Thermodynamics and the Carnot cycle shows that every energy event or exchange results in waste heat. One implication is the impossibility of constructing a perpetual motion machine. In other words any useful results of the expenditure of energy requires a constant input of new energy. At the same time energy is the magic genie by which people improve their lives and material well-being. In our society new and improved is the battle cry as energy-consuming appliances abound, motor vehicles grow more numerous and larger, and energy conservation is just a suggestion which is largely ignored. World-wide, people are demanding a piece of the energy pie for the same reasons as we in the U. S. and fossil fuel consumption is escalating, forests are being consumed, and water is being used in unprecedented amounts. Considering that the energy produced from every gallon of gasoline, lump of coal, and cubic foot of natural gas burned will eventually return to heat, the consequences for global warming and our very existence in this universe become a concern. It has been recorded, for example, that a pollution cloud the size of the United States is produced on the Indian subcontinent each year. It is blown out over the Indian Ocean in the winter and back onto India by the summer monsoon winds. The cloud is known to cause temperature drops due to blockage of the sun, acid rain, respiratory problems, and other deleterious effects to life. The cloud is caused by the burning of fossil fuels by two billion people inhabiting the Asian continent. Within the seeming limitless universe the exhaustion of every energy resource on this planet would not raise its total temperature significantly. For our planet, however, global warming and energy-cause pollution has consequences for all life. Since heat is an all pervasive energy outcome, I intend to explore some of its characteristics, suggest demonstrations and lab activities, and touch upon environmental consequences and effects of heat energy. The level of discussion and activities will be aimed at middle school students. and easily available materials will be used whenever possible**.** Much of the discussion will also involve heat's effect on water since water's interaction with heat and its part in the environment and life is so crucial.

Science and Technology Standards

The Pittsburgh Public Schools for whom I teach science has adopted a set of science and technology standards. I have written this curriculum unit with these standards in mind. The standards that my work most closely fit are as follows:

1. All students explain how scientific principles of chemical, physical, and biological phenomena have developed and relate them to real-world situations.
2. All students explain the relationships among science, technology, and society.
3. All students develop and apply skills of observation, data collection, analysis, pattern recognition, prediction, and scientific reasoning in designing and conducting experiments and solving technological problems.
4. All students evaluate advantages, disadvantages, and ethical implications associated with the impact of science and technology on current and future life.
5. All students evaluate the impact on current and future life of the development and use of varied energy forms, natural and synthetic materials.

The Nature of Heat

The early Greeks thought that heat was a substance that flowed from a hotter to colder object. This idea persisted into the 1700's when some scientists proposed that heat is a fluid (caloric) that flowed freely from one object to another. An atom of any substance was surrounded by caloric fluid and as the substance was heated the spaces around the atoms would be filled with the fluid. Objects with more spaces around its atoms would have more caloric fluid than objects with fewer spaces. At the time this theory explained observations existing about heat. It was not until Benjamin Thompson, later known as Count Rumford (1753-1814), using a sensitive balance, showed that there was no evidence that objects gained or lost mass when heated or cooled as is suggested by the caloric theory. His famous experiment with drilling cannons showed that nothing other than metal shavings entered water that was used to cool the cannons during the boring process. He proposed instead that heat is caused by the motion or kinetic energy of moving particles. As the object increased in temperature the kinetic energy of the molecules increased because of their increased velocity. Conversely, when cooled, the kinetic energy of the molecules decreased. The kinetic molecular theory of heat is accepted as being the most accurate in explaining heat energy today.

The terms heat and temperature are often used interchangeably and can be confusing at first glance. One way to make a distinction is to compare a lit match with a campfire of burning logs. Both are wood and burning at the same temperature but students intuitively sense that the campfire has more heat associated with it. Temperature, then is a measurement on a thermometer and heat refers to the energy a system contains.

Another definition is that temperature is a measure of the ***average kinetic energy*** of the molecules of a substance. Heat content is the ***total kinetic energy*** of the molecules in the same substance. The formula for kinetic energy is $1/2\ mv^2$ which shows that mass and velocity of the atoms or molecules are both important in heat content. It follows that two different materials such as water and iron could have the same temperature but differ significantly in their heat energy because of their differing atomic weights (masses). The gram atomic weight of any substance contains the same number of atoms known as Avogadro's number or $6.02 \text{ X } 10^{23}$. The standard for Avogadro's number is hydrogen. **One gram** of hydrogen with an atomic weight of one contains Avogadro's number of atoms. **One gram** of water with an atomic weight of 18 has 1/18th the number of atoms as one gram of hydrogen because it has eighteen times the mass of hydrogen. Iron has an atomic weight of approximately 56. One gram of iron contains 1/56th the atoms of one gram of hydrogen . One gram of water, then, has approximately 3 times the number of atoms as one gram of iron . Three times the number of atoms translates into more heat retaining ability (heat capacity) for water than for and equal mass of iron.

The idea for determining temperatures of substances using statistical methods based on averages comes from Ludwig Boltzmann, an Austrian physicist who lived from 1844 to 1906. Since the gram-molecular weight of any substance contains Avogadro's number of atoms or molecule (6.02×10^{23}), it becomes apparent that a supercomputer the likes of which the world has never seen would be required to trace the path of every atom or molecule on a substance whose temperature one might want to analyze. In 1859, when Boltzmann formulated his theory, computers were just fanciful ideas and Boltzmann, in a brilliant mathematical tour de force, set forth his famous value for the kinetic energy of molecules. Boltzmann's constant has a value of 1.38×10^{-23} Joules per degree Kelvin. In other words for every one degree Kelvin increase in temperature the kinetic energy of a molecule increases by the stated amount. Today the Boltzmann constant is a fundamental unit in many statistical analyses used in physics. Boltzmann extended his statistical theories to propose that properties of matter can be understood by observing the cumulative properties of the atoms within. This theory led to a branch of science called statistical mechanics. Boltzmann was also a strong advocate of the theory that all matter is made up of atoms and in the 1890's he engaged in heated, sometimes bitter debates with an opposing group who espoused an energetic view of matter. Boltzmann committed suicide in 1906 and shortly after his death Brownian motion was discovered which proved the existence of atoms and supported his views.

Measuring Heat Capacity

Different objects differ in their ability to gain or lose heat energy. A quantitative measure of the heat capacity of an object can be done easily in the lab using simple materials. Various metal cylinders of equal mass are available from science supply companies. Common test cylinders are aluminum, copper, lead, and zinc. These cylinders can be placed in a beaker of boiling water for five minutes. They should be all at equal temperature at this point. Using a pair of tongs, quickly place the cylinders lengthwise on a paraffin block. Paraffin blocks are available in the canning section of the supermarket. The cylinder with the greatest heat capacity will melt the most paraffin. In the experiment above the order from least to greater heat capacity is lead, zinc, copper, iron, and aluminum. Students can see on the periodic table that heat capacity is inversely proportional to atomic weight. The greater the atomic weight the lower the heat capacity. Since heat capacity is related to the total kinetic energy of the atoms in a given mass of a substance, the fewer atoms the lower the heat capacity. Quantitatively, heat capacity is defined as the amount of heat energy required to raise the entire quantity of material in question one degree Celsius.

The instructor can point out that heat capacity is important in the environment. Coastal areas experience land and sea breezes in part because of the differing heat capacities of land and water. During the day land heats faster than water because of its lower heat capacity and breezes tend to blow in from the ocean (a sea breeze). At night water retains the heat gained during the day while the land becomes cooler and the wind direction is reversed. The sea and land breezes that result will be further explored in the section on convection currents. The high heat capacity of water also affects climate near large bodies of water. A large lake such as Lake Erie slowly gains heat energy. The heat it retains in the fall moderates the temperature in surrounding farmlands by delaying early killing frosts thus extending the growing season for grape vineyards that surround the lake. The oceans are important heat sinks for the entire earth and their role in climate could be a discussion or research topic for students. Later the high latent heat of fusion of water will be discussed. The continent-sized ice shelves at both poles are important temperature regulators because of the high latent heat of fusion of water. The recent El Nino and La Nina events are also related to heat capacity of water and their effects on weather fuel the controversy surrounding global warming effecting every person alive today.

Demonstration: The Miracle^{TM} or Super Thaw^{TM}

A fun demonstration relating to heat capacity also can be used to expose a money-making ploy used by television marketers a few years ago. The claim was that by using their Miracle Thaw^{TM}or Super Thaw^{TM} device of space-age alloys, it was possible to thaw foods much faster than by letting them sit on the kitchen counter. The device was a slab of one-half inch vaned metal approximately 12 by 18 inches either aluminum-colored or painted black. When an ice cube is placed on the table or counter and one is placed on the device, the ice cube melts noticeably faster on the metal. The sellers claimed the alloy conducted heat from the room at a much higher rate to the frozen object and they supplied a table showing the savings in thaw times of various frozen meats placed on the Superthaw^{TM}. Their argument seemed to make sense because the Second Law or Thermodynamics does show that heat does indeed flow from the warmer to colder object. For 20 dollars apiece the Superthaws^{TM} flew out the door. The boom went bust when consumers found that an aluminum frying pan of equal thickness as the Super or Miracle Thaw^{TM} device melted ice and thawed food just as fast. The melting capacity of the devices were only related to the heat capacities of the metals from which they were made not to some mysterious heat conduction property as the sellers claimed. I am not sure as to the availability of the Super Thaw^{TM} or Miracle Thaw^{TM} today. A few years ago I was able to by one at Ames on a clearance sale for $7.

Heat and Expansion

As it is a form of energy it follows that heat can be converted to other types of energy, e.g. mechanical, electrical, radiant, and chemical. Most things, when heated, expand (a thermal to mechanical energy transformation). Increased motion of molecules and thus expansion is readily explained under the kinetic molecular theory of matter. Engineers recognize and compensate for this fact when designing roads and bridges but it is still not unusual to see sections of buckled road during summer heat waves due to expanding concrete. Bridges commonly have expansion strips strategically located to allow for expansion during hot days and contraction on cold days. James Buchanan Eads was mindful of heat and expansion when he constructed the first steel bridge in the late 1860’s. Steel at that time was an unknown in bridge building and Eads confidently proposed constructing a 540 foot steel center arch anchored in bedrock and two 502 foot side arches across the Mississippi River in St. Louis. The construction was not without its problems. “In one crisis .... temperatures of 100 degrees had caused the steel to expand, making it too long by fractions of an inch. Eads was in London negotiating a new loan .... when his assistants wired that even applying hundreds of tons of ice had failed to cool and contract the metal. Eads had anticipated the problem and wired back the solution (telescoping the metal and screwing it into place, in the same way one might adjust a shower rod)..... supremely confident of success, Eads left for Paris without waiting to hear the result.”[1]

Demonstration: Differential Expansion Rates of Liquids

In this demonstration it is possible to show the differential expansion rates of liquids when heated. Needed are five 300 ml round bottomed flasks, five #5 one-holed rubber stoppers, five one meter lengths of 5 mm hollow glass tubing, 200 ml each of water, baby oil, alcohol, and acetone. Also needed is a large pan capable of holding the four flasks, and enough hot water to cover the bottoms of the flasks. Add the liquids to the four flasks and carefully insert the glass tubes into the rubber stoppers. Use lubricant and cover the tubes with cloth in case one breaks when inserting. The tube should almost touch the bottom of the flask. Place each flask into the pan. Try to make all liquid levels in the tubes equal at the start. Pour the hot water into the pan. The liquids should immediately expand into the glass tubes. Students can see if the results coincide with their guesses as to the order of expansion. The proper order is water (least expansion), baby oil, alcohol, and acetone(most expansion). Students may note that the more volatile the liquid the greater the expansion rate.

Lab Investigation: Calibration of a Thermometer

The preceding demonstration leads to an equally interesting lab investigation. Students can be directed to calibrate their own thermometers. It is possible to obtain uncalibrated alcohol thermometers from a supply source such as Science Kit or Frey Scientific. Students can prepare a beaker of boiling water for the boiling point and an ice bath for the freezing point. Each point can be marked with an indelible marker and the intervals between can be marked assuming that water expands equally from the freezing point to the boiling point of water. Once made the thermometers can be used for future heat experiments.

Discussion

The instructor might lead a discussion on the arbitrary nature of the choice of a temperature scale. Why, for instance, was 212 degrees for the boiling point and 32 degrees for the freezing point of water chosen for the Fahrenheit scale? Daniel Gabriel Fahrenheit (1686 - 1736) was a German physicist who invented the alcohol thermometer in 1709 and the mercury thermometer in 1724 when he developed a way to prevent mercury sticking to glass. Prior to Fahrenheit's invention, thermometers were called thermoscopes and had no numerical scales or standard liquid fillers. Fahrenheit decided to create a numerical scale with zero as the coldest winter temperature in Amsterdam where he was living. He chose his own body temperature as 100. Apparently Fahrenheit had a slight fever as further measurements showed that normal body temperature is 98.6

The choice of one hundred and zero for the Celsius scale is more obvious. It was established by the Swedish physicist, Ander Celsius (1701 - 1744). He chose the boiling point of water as 0 degrees and the melting point of ice as 100 degrees. After his death the scale was reversed to the more familiar thermometer used today. The word centigrade is often use in place of Celsius but technically is not correct. The Tenth Conference on Weights and Measures in 1954 made centigrade obsolete. The correct designation is "degrees Celsius".

At the same conference the magnitude of the Kelvin degree was adopted to be the same as that of the Celsius degree. The Kelvin scale established absolute zero as zero degrees Kelvin and the freezing point of water to three significant figures as 273 degrees Kelvin. The conversion of Kelvin degrees to Celsius is ^{0} C + 273^0.

Water and Energy

Water is vital to all life on this planet. It is the medium in which myriad chemical reactions take place and the oceans regulate global temperature by absorbing and losing heat because of its high heat capacity. Ocean currents moderate temperatures in many northern and southern latitudes that otherwise would be much colder. The cell, the fundamental unit of life, is largely water. Humans and all life forms owe much of their existence to unique properties of water such as ice floating instead of sinking, and its ability to dissolve an inordinate array of chemical compounds. Water is also an ubiquitous substance. Three fourths of the globe is covered with it. Drinkable amounts are found underground and rivers of it allow human settlements in what otherwise would be uninhabitable desert. Because of water's ready availability, it makes an ideal and interesting subject for studying heat energy and because of its environmental effects serves as a barometer of the effects of human activity.

Activity: Convection currents

A simple convection current can be established using a 1000 ml beaker, food coloring, water, an eye dropper or pipette, and a heat source such as a candle or an alcohol burner. About 800 ml of cold water is added to the beaker. A drop of food coloring in introduced to the bottom edge of the beaker using the eye-dropper or pipette. Care should be taken to keep the drop of coloring from diffusing through the water. Heat from the burner or candle is applied to the beaker just below the dye. Within a minute or so a generally circular migration of dye should occur. The heated water rises because it is less dense than the surrounding water. When it reaches the top, the continued rising of heated water pushes it across the surface. As it travels the water cools and falls to the bottom of the other side of the heated water. The circulation will continue until the dye diffuses throughout the water.

Demonstration: The Hot Water Heater

Students can be asked where hot water tanks are usually found in the house. Most will answer either in the basement or on the ground floor, never in the attic. Students might offer various opinions as to why this is so but it is convection that explains much of water tank operation.. Convection current in a water tank is easily demonstrated using four 500 or four 1000 ml Erlenmeyer flasks. Fill two of the flasks with hot water. Food coloring is added to each. The other flasks are filled with cold water. In setup one the cold water flask is inverted and placed on the flask containing hot water. A playing card serves as an interface between the two flasks. In setup two the flask containing hot water is placed on top of the cold water with a playing card once again separating them. Care should be taken to prevent spills as hot water can burn the skin and cause quite a mess in the classroom. Each card is removed from between the flasks and observations are made as to what happens. The setup with the hot water on the bottom will show a vigorous and immediate mixing with the cold water. The one with the hot water on the top does very little to no noticeable mixing. It is easily understood that cold water, being denser than hot water, displaces it when on top. Much the same thing happens in a hot water heater. The cold water supply tube feeds into the bottom of the tank. As it heats the hot water rises in the tank and is pushed out through the pipes by the denser cold water when the faucet is turned on. To place the hot water tank in the attic would not be as efficient as placing it in the basement. Besides, a forty or fifty gallon collection of water in the top floor can cause quite a bit of destruction of property if it fails.

Discussion

Convection currents also occur in air. Land and sea breezes at coastal areas occur because during the day land heats up faster that water because of water’s higher heat capacity. Hotter air rises over land, gets pushed over the water where it cools and falls. The air then gets pushed into land and a sea breeze from the cooler ocean results. At night the land cools faster than the ocean and the convection current is reversed and a land breeze results. Winds are caused by the unequal heating of large air masses.

Ocean currents such as the gulf stream extend from the warm waters of the Gulf of Mexico to the shores of northern Europe. This warmer water moderates temperatures along coastal areas. Ocean currents also support large fish populations that fishermen follow for predictable catches. The El Nino ocean effect which shows up periodically off the west coast of Peru disrupts ocean currents. Its higher temperatures alter weather patterns and cause the migration of cold water fish out of normally rich fishing grounds. Economic losses were significant during the 1996 El Nino event bringing heavy rains to some land areas and drought to others. To what extent global warming plays in such events is a matter of speculation and argument in scientific quarters. Students could explore global warming and the El Nino phenomenon.

Geologists present the pangeal or continental drift theory which proposes that the continents of the earth were once one giant land mass that has slowly separated over the ages. It is thought that convection currents originating in the magma, the liquid rock below the earth's mantle, exert pressure on the continents causing them to drift ever further apart. This same principle serves a vital function in lakes. Lake water heats throughout the summer. In the fall the top layer of the lake cools faster than the lower levels. A temperature gradient of several degrees, with the denser colder on top, starts a convection current in which the cooler water sinks and falls to the bottom of the lake. Sediments and nutrient materials on the bottom are dredged up in what is known as an upwelling. This is a good thing for lake health.

The Expansion of Water and Freezing

An interesting and vital feature of water is that it expands when it freezes. The vast majority of substances contract as they lose heat. The fact that water expands makes ice slightly less dense than its liquid state. Ice therefore floats instead of sinking. If ice did sink, large bodies of water where sunlight could not reach would have a build-up of ice from year to year. Eventually lakes and rivers would be choked with ice and life as we know it would be threatened.

Demonstrations of Freezing

Students can examine the expansion of water when it freezes by filling an ice cube tray and marking the level of water. After a day in the freezer, the tray can be examined and expansion beyond the mark by the ice cubes will be visible. A plastic 2-liter bottle filled with water will expand out the top when frozen. Some equipment supply houses sell an ice expansion device which shows the awesome power of expanding ice. The apparatus consists of a hollow, orange-sized, thick-walled cast iron sphere with a screw cap. Water is added to the fill mark, the cap is screwed into place, and the object is placed in a freezer for 24 hours. When it is removed, the apparatus will have been split open by the expansion of ice. This demonstration should serve as a reminder for students to check the antifreeze level in the family car. Many an engine block has been ruined when water has frozen because of inadequate levels of antifreeze. In fact most car engines have a protective device built into them. There are pressure bolts in the engine block which pop out to relieve pressure when ice forms in the engine.

The Latent Heats of Vaporization and Fusion of Water

Water's ability to absorb large amounts of heat with little temperature change is shown at two thresholds. One is at the freezing point and the other is at the boiling point. These points are referred to as the latent heats of fusion and vaporization respectively. In the lab these points can be readily explored using relatively simple materials. For a heat source a Bunsen or alcohol burner or a hotplate is adequate. Also needed are a 1000 or 500 ml beaker, a thermometer, a stirring rod, ice, and a timing device. The ice should be taken from a freezer using the coldest setting. Ice can be any temperature from 0 degrees down, the colder the better. The ice can be crushed or in cubes. Cold water is added to cover the ice and stirred with the stirring rod **not** the thermometer. Students should stir until the coldest possible temperature is reached. A table should be made of time and temperature. The beaker should be placed over the heat source and the temperature should be taken every minute until the water boils. Readings should be then taken for five minutes past the boiling point. Remind students to mark on the data table the point at which the ice disappeared and the point at which the water boiled. Students also should keep stirring throughout the experiment to keep the heat distributed as evenly as possible. When all data is collected, a graph can be constructed with time on the X axis and temperature on the Y axis. If the data has been accurately gathered, an interesting curve should emerge. Students will note that the ice gained temperature up to about 0 degrees Celsius. For several minutes no temperature change was evident until all of the ice was melted. This period of no temperature change is termed the **latent heat of fusion**. Apparently the heat energy is being absorbed to break the molecular bonds in the crystalline lattice ice form for conversion to the less orderly liquid state. Once the ice has melted, the temperature should rise steadily and regularly to 100 degrees Celsius. Once again the temperature does not rise past 100 degrees. This stage is termed the **latent heat of vaporization**. The heat energy is being used to convert water molecules from the comparatively orderly liquid lattice to the chaotic, random vapor state. Students can be directed to compare the amount of heat energy required to convert one gram of ice to water (79.71 calories) and one gram of water to steam (538.7 calories). It takes much more heat energy to change water to steam than to turn ice to water.

Discussion

This might be a good point to discuss with students some practical applications of latent heats. If a person has ever been perspiring on a hot day, the welcome cool breeze can be credited with accelerating the evaporation of water from the skin. Each gram of perspiration turned to vapor takes 538.7 calories of heat from the person, thus making him feel much cooler. A home shopping show on television recently has been offering a simple device guaranteed to cool a person off on the hottest days. It consists of a plastic bottle, a pump, and a small hose attached to the bottle. The user pumps air into the bottle after adding water. When triggered, a fine mist is sprayed around one's face and head. Rapid evaporation of the mist absorbs heat from the immediate surroundings and noticeable (according to the sellers) cooling of the user. The claims make sense in light of the latent heat of vaporization of water. The price is about $20 for two bottles. I recently ordered them and am anxious to try them out. Some golf courses in the southwest use a similar device on golf carts to cool golfers.

The Boiling Point of Water

A number of misconceptions surround the concept of boiling. A 500 ml. round-bottomed flask with 300 ml. of boiling water sitting on a hot plate or on an iron-ring and ringstand apparatus heated by a Bunsen burner can be set before the class. The instructor can begin by asking students what is happening. Typically someone will venture the observation that the water is boiling. Others may note that vapor or steam is issuing from the top of the flask. The instructor might ask what causes the large number of bubbles to rise to the surface of the water. Students I have asked guessed that they were oxygen or hydrogen. Others guess that they are water vapor. A glowing splint held to the mouth of the flask can indicate which gas it is. If it pops, it is hydrogen. If the splint glows brighter or bursts into flames, it is oxygen. When the test is made, the splint extinguishes quickly. This shows that water vapor is being produced. A discussion of faster-moving molecules because of added heat is not a difficult concept for students to accept. Large numbers of molecules leave the liquid surface as vapor because of the energy gained from the heat source. At this point the flask can be removed from the heat and a number 5 stopper can be inserted into the top of the flask. Care should be taken because the flask is very hot. The water should not be boiling at this point. If the flask is held under cold water or if cold water is allowed to run over the flask from a faucet, the water surprisingly begins boiling again. Students might be hard-pressed to explain what is happening inside the flask. The instructor can then introduce the idea of air pressure and boiling. The pressure exerted by the ocean of air that surrounds us is approximately 15 pounds per square inch of earth surface at sea level. Air has mass and gravity attracts it thus accounting for air pressure. If a water molecule is to escape as water vapor from the flask, it must overcome air pressure as well as attractive forces of other water molecules and gravity. Heat increases the speed or energy of water molecules and makes escape easier. If air pressure is decreased, it is as if a lid had been lifted and the molecules escape much more easily. The water in this example is near the boiling point when the stopper is inserted. When cold water is applied to the flask, water vapor condenses lessening surrounding air pressure. The water molecules in the flask then boil off much more easily. After a short time, the water ceases boiling as equilibrium is reached in the flask. Students can be asked what would happen on the moon where because of little atmosphere the air pressure is practically zero. The answer is that water would boil at room temperature or even below. People who bake or cook at high altitudes have to take the lower boiling point of water and adjust their cooking or baking time accordingly.

If the instructor has access to a vacuum pump and a bell jar, the effects of pressure on boiling of water can be easily shown. Water is brought to boil in a 500ml flask as above. This time, however, the stopper is not used. The open-topped flask is placed on the platform of the vacuum pump. This instructor places the flask on an inverted beaker. This elevates the flask and allows air to be removed from the bell jar from under the lip of the beaker. Grease is applied to the bottom lip of the bell jar which is then placed on the platform of the vacuum pump. Care should be taken to make sure the grease seal prevents air leaks. The pump is then turned on and students observe what happens as air pressure inside the bell jar is reduced. They may note that water vapor rises from the flask and condenses on the top of the bell jar. After a few seconds, the water in the flask suddenly bursts into a rolling boil. Large amounts of water continues to condense on the upper end of the bell jar and it becomes quite hot to the touch. The explanation for the boiling is that removal of the air reduces air pressure dramatically. This allows the water molecules to escape as vapor (boil) very easily. When the flask is removed from the bell jar, it is not appreciably warmer than room temperature. The water vapor condensed on the cooler bell jar surface accounting for the large amounts of water produced. The heat on the bell jar is due to the steam releasing its energy as it condensed.

Lab Activity: Calculating Absolute Zero

An interesting topic for discussion and exploration is the concept of absolute zero. Scientists have come painfully close to this mark but always fail. Limitations of insulating containers is one factor. Even more fundamental is the idea of the kinetic molecular theory of matter. Matter, even in the frozen state, has some motion of molecules. While it is true that motion slows precipitously as absolute zero is approached, some motion is always there. This motion accounts for some heat. If all motion ceased, the definition of matter in motion would be contradicted. So theoretically and in practice absolute zero is not attainable. Absolute zero, then, is the temperature at which the kinetic energy or motion of molecules is at a minimum. The figure adopted at the Tenth Conference on Weights and Measures was minus 273.16 degrees Celsius, zero degrees Kelvin, or minus 459 degrees Fahrenheit.

It is possible to determine absolute zero to a reasonable accuracy using a pressure device and a graphing technique known as extrapolation. The materials needed are boiling water, a room temperature water bath, and an ice bath. Also needed are a thermometer (one for each water bath is more convenient), graph paper, a straight edge, and a pencil. A calculator is optional. The theory behind this calculation is that as temperature drops molecular motion slows. This translates into less pressure. The assumption is that pressure in a vessel will drop in a predictable, linear fashion to zero at absolute zero. By determining three points it is possible to extrapolate or extend the straight graph line to absolute zero. With this in mind, it is necessary to obtain a pressure device. Frey Scientific offers one for $82.95 (FO1839). Their manual suggests boiling water, cold water, and a dry ice and alcohol bath. If it is inconvenient to obtain dry ice, a salt and ice bath can be used instead. The pressure device typically has an air attachment. Using a hand pump the pressure before beginning should be increase to about 22 pounds per square inch. This increased pressure gives a wider range of change when the device is submerged in the different water baths. The first pressure reading is taken by plunging the device into the ice bath. Salt should have been mixed with the ice to lower the temperature as low as possible. Students should record the temperature and pressure after about 3 or 4 minutes of submersion. The device can then be submerged in the room temperature water bath. Once again temperature and pressure should be recorded after 3 or 4 minutes. Finally, the device is submerged in the boiling water. Students should note a dramatic rise in pressure. Record the temperature and pressure after 3 or 4 minutes. Students are then directed to construct a graph of temperature on the X-axis and pressure on the Y-axis. *Hint: The temperature line can be numbered backwards by tens starting at 100 degrees Celsius at the far right of the graph paper. A vertical line can be drawn at zero degrees for the Y-axis. Numbering should continue to about minus 300. If care has been taken in gathering data, the three points should approximate a straight line. If not, split the difference and draw a best-fit line. By extending the line far enough (extrapolating) it is possible to finally hit the X-axis with the line. This point would indicate zero volume or absolute zero. The accepted value is minus 273.16 degrees Celsius. Experimental error can be determined by subtracting the experimental value by the accepted value for absolute zero. This number is then divided by the accepted value for absolute zero. Multiplying the calculate value by 100 yields the experimental error. This method generally lands within an experimental error of 10 percent or less. A discussion of sources of experimental error in the performance of this exercise is a good idea at the conclusion of this exercise.

Many strange phenomena are observed as temperatures approach absolute zero. Students can research topics such as superconductivity and magnetic levitation. Dry ice and liquid nitrogen are available for some teachers and serve as fascinating sources of demonstrations and explorations of supercold liquids.

The Transfer and Transformations of Heat

The First Law of Thermodynamics states that energy is not created or destroyed but it can be transferred or transformed. In the series of examples that follow heat will be converted to mechanical, electrical, radiant, and chemical energy. Thermal transfer will also be discussed.

Thermal to Mechanical Energy Transformation

Every power plant performs a thermal to mechanical energy transformation. Heat energy from the combustion of fossil fuels or nuclear reactions is used to produce large amounts of steam under tremendous pressure. The steam then typically drives a turbine (mechanical energy) which then produces electricity for transport to customers over long distances. Students can make their own steam turbines. The source of steam will come from a 500ml round-bottomed flask. A 20mm length of 5mm hollow glass tubing is cut. One end should be heated and then stretched to form an eyedropper like tapered end. The end can be cut with a triangular file. Care should be taken to not burn yourself and the glass should not be cut until it is cool. After the rod cools, it should then be heated again in the center and bent to a 90 degree angle. After it cools once again, the tube should be carefully fitted into a #6 one-holed rubber stopper. Glycerin will help the tube slide in the stopper and a cloth should be wrapped around the glass tube to prevent puncturing the skin in case of breaking. The flask is filled approximately one-half way with water and the stopper with the glass tubing is inserted. When the water is brought to boiling, a nice stream of steam issues from the tapered glass tube. A turbine wheel can then be made from a piece of oak-tag or one half of a manila folder. A 6 to 8 inch circle is drawn on the paper with a compass. The circle is then cut out. Using a cork borer, a hole of slightly less diameter than a test tube is cut from the center. Then a series of parallel cuts of approximately 3/4 to 1 inch is made on the outer border of the circle. The cuts should be about 1 inch apart. Each cut edge is bent down until all edges are used. The circle is then placed over the test tube. If the hole is of the proper diameter, friction should hold it on the end of the test tube. A sharpened pencil is placed in the test tube so that the point rests against the bottom of the tube. The eraser end can be squeezed into a one-holed stopper. The stopper can be held with a test tube clamp which is then attached to a ring stand. The apparatus should be leveled so that it spins with very little friction on the pencil point. If the ring stand and circle is positioned so that the steam from the flask hits the vanes of the circle, the apparatus should spin at a high rate of speed. You have created a steam turbine! You have also performed a thermal to mechanical energy transformation.

Various thermal engines using a metal known as nitinol are available from Flinn Scientific. First developed in 1961, nitinol is a metal alloy of equal parts titanium and nickel. Its crystalline structure allows it to be “trained” to return to its original shape once stretched and then subjected to heat in a certain temperature range. The simplest and least expensive (AP1937, $1.15) expression of the heat engines is called the Nitinol “Live” Wire. At room temperature it can be twisted or bent to any shape desired. When place into hot water, it springs back to its original shape (thermal to mechanical energy). For $27.90, (AP1936) the Space Wings Electronic Kit features a flying toy using nitinol wire for the flapping wings and no motor. For $47.50 it is possible to buy a Thermomobile (AP1960) which consist of a nitinol wire loop around two pulleys, one brass and one plastic. When the brass pulley is placed in hot water, it heats the nitinol wire causing it make both pulleys spin. It is a fascinating heat engine.

Thermal Transfer

An interesting lab activity involving thermal transfer is a study of Newton’s Law of Cooling. Students may be surprised to learn that Isaac Newton explored things other than gravity. He formulated the Universal Law of Gravitation to be sure but he also did extensive investigations involving light and heat. In his law of cooling Newton stated essentially that the hotter an object was in relation to its surroundings the faster the rate at which it cooled. This can be verified with a relatively simple experiment. Students should obtain two beakers of about 400 ml up to 1000 ml. Boiling water and water of approximately 60 to 70 degrees Celsius are also needed. A timing device and two thermometers are also needed as is graph paper, a straight edge and a pencil. Students can construct a data table consisting of a column for temperature and a column for time in minutes. The experiment can be run for ten or 15 minutes depending on the time in the class period. One beaker is filled approximately one-half with the 60- to 70-degree water and the other with the boiling water. Care should be taken to avoid spilling the water as it can cause burns. Temperatures are taken as soon as possible and the timing device should be activated. Every minute for the length of the experiment, the two temperatures are recorded. At the end of the experiment a graph can be constructed of temperature on the Y-axis and time in minutes on the X-axis. Different colors can represent the two beakers which can be placed on the same graph for easy visual comparison. Students will note that the boiling water lost heat at first at a much greater rate than the cooler water. As a matter of fact the time it takes to just pour the boiling water into the beaker until the first temperature reading is taken results in about a 15-degree temperature loss. After a few minutes both beakers of water should be at the same temperature as they are at the end. This shows that the higher temperature difference at first resulted in a proportionally greater heat loss. A discussion of the Second Law of Thermodynamics in which heat flow results from the hotter to cooler object also can be brought into the discussion.

The Thermocouple

A thermocouple is a device which shows a nice thermal to electrical energy transformation. Essentially it is a device in which the voltage difference caused by the junction of two different metals is used to measure a temperature difference. The reverse in which two different metals such as copper and iron are heated can cause a voltage change on a voltmeter is also possible. In 1821 a German scientist named T. J. Seebeck discovered that two conductors joined and heated to different temperatures caused a voltage change. The voltage is reversible in that if one conductor is of greater temperature, the current flows one way and if the other conductor is of greater temperature, the current is reversed. It is relatively easy for a student to make his own thermocouple. Materials needed are a beaker, ice water, two 14 or 16 gauge wires, e. g. iron and copper, a Bunsen burner, and a sensitive galvanometer. One end of a one-foot piece of copper wire is stripped of insulation and attached to one terminal of the galvanometer. The other end is also stripped and joined to the bare end of a one-foot piece of iron wire. This junction is placed in a beaker of ice water because for best results a “cold junction” is required. The other end of the iron wire is stripped and joined to the bare end of another one-foot section of copper wire. Finally the bare end of the second piece of copper wire is attached to the remaining terminal of the galvanometer. When the junction (not the one in ice water) is heated, a deflection of the galvanometer needle should occur indicating a current flow. Depending on the metals used, thermocouples can be used to determine temperatures if the galvanometer is calibrated carefully. Iron-copper junctions can give temperature ranges up to 275 degrees Celsius. Platinum and rhodium junctions can measure temperatures up to 1600^{o}C.

Thermal to Radiant Energy Transformation

An easy thermal to radiant energy transformation is to simply heat a copper wire in a Bunsen burner flame until it glows. A more involved transformation requires two parabolic mirrors of about 18 inches diameter, two ring stands and ring stand clamps, an iron ball of at least 2 inches diameter, and a radiometer. If one of the parabolic mirrors is placed in the sun, the focal point can be located with an index card held at the place where the sun’s reflected rays focus from off of the mirror. The mirror should then be stood up against one of the ring stands. The reflector I have has a hole in the center into which I place a number 5 rubber stopper. I then use the ring stand clamp to hold the other end of the stopper which supports the mirror in an upright position. The radiometer should then be placed at the focal point of the mirror. Placing the radiometer on a box helps to elevate it to better reach the focal point. The other parabolic mirror is set up in a similar fashion about four of five feet away from the first mirror. The iron ball is then heated in a Bunsen or fisher burner for five to 10 minutes. The ball, which should be supported by a rod, is stood about 12 or 18 inches from the second mirror. The heated ball emits infrared radiation which is reflected off of mirror two. It travels to mirror one where it is reflected again and focused onto the radiometer. The radiometer should then spin. To prove that the reflected rays are causing the radiometer to spin and not the heat from the ball directly it is possible to move mirror two and have the radiometer stop spinning. I have had only modest success with this demonstration. Instead of an iron ball I used a cast iron plate of about five-inch diameter. The radiometer spun slowly.

Another interesting example of thermal to radiant energy transformation occurs when irradiated table salt is sprinkled onto a hotplate set on high. In a dark room the salt briefly glows red as it turns from an amber color to the more familiar white. I was fortunate to have irradiated salt given to me by a technician at the Penn State main campus nuclear reactor. When salt is irradiated with gamma rays, it turns an amber color. The technician explained that it was thought that electrons were elevated to a higher energy level because of the irradiation. When heated they returned to the original energy state with a simultaneous release of light energy. The label on the salt container assures that in spite of the slightly different color the salt is still quite safe to handle.

Thermal to Chemical Energy Transformation

An unusual and fun demonstration of thermal to chemical energy transformation is one in which steam is used to burn paper. Required for the demonstration are a 500ml round-bottomed flask, water, ring stand, a Bunsen burner, an iron ring on which to place the flask and 12 to 14 inches of 1/4 inch hollow copper tubing. Copper tubing is readily available from your neighborhood hardware store. The copper tubing can be formed into about 3 loops by carefully wrapping it around a plastic film canister. Care should be taken not to kink the tubing. About four inches of straight tubing should be left at each end. One end of the tubing is then inserted into a one-holed stopper. The tubing-stopper apparatus is then placed into the round bottomed flask. When the water in the flask boils, steam exits through the copper tube. The steam readily condenses and is visible to all students. A mirror held up to the steam also condenses the steam. Students can then be informed that a hole is going to be burned in a piece of paper. The flash point of paper is 451^{o} Fahrenheit. It becomes immediately apparent that the steam issuing from the flask is not hot enough to burn a hole in a piece of paper! The instructor then takes a second Bunsen burner or even better, a fisher burner and applies the heat to the copper tube. The steam from the coil quickly disappears because it is too hot to condense in the surrounding air. Holding a mirror to the coil orifice causes the steam to condense, proving that steam is still being produced. Heat is applied until the copper coil glows red. A piece of paper now held about 1/2 inch from the coil opening becomes scorched. Steam is now burning paper!

Another thermal to chemical transformation can be seen in certain liquid crystals set in plastic. Color changes occur at various temperatures depending on the chemical chosen. These chemical "color changers" are available in tee shirts, aquarium thermometers, fever detectors, and children's toys. Flinn Scientific sells heat sensitive paper in a rainbow of colors that changes color when subjected to heat from a person's hand. It sells for $12.50 for 50-8.5 x 11-inch sheets. (#AP9074-79) in their 1999 catalogue.

Energy Transformations that Result in Heat Energy

It was stated earlier that the Second Law of Thermodynamics states implicitly that all energy forms result eventually in heat energy. The fact that no engine is 100 % efficient not only negates the possibility of a perpetual motion machine, but also is a testimonial to the pesky nature of heat energy. It just can't be avoided. Following will be some examples of devices or experiments that result in heat energy.

Electrical to Thermal Energy Transformation

Examples of electrical to thermal energy transformations abound and students without much difficulty probably name several. An incandescent light bulb produces a large amount of heat with the light as holding one's hand next to a glowing bulb will confirm. An electric range and a space heater both produce heat energy in abundance.

Radiant to Thermal Energy Transformation

A radiant to thermal energy transformation that is probably familiar to many students is a greenhouse. If a commercial greenhouse is in your area, it might be worth the effort to visit it so that students can experience first hand the heating effects present inside. An experimental greenhouse can be constructed easily for classroom use. A Styrofoam or cardboard container can be obtained. Insulation can be placed in the cardboard box but none is needed in the Styrofoam container. A thermometer can be taped inside the box so that it can be read when plastic wrap is placed over the front. A second thermometer can be placed on top of the box for comparison of outside and inside temperatures. A heat lamp can be directed at the box so that both the inside and outside are equally exposed to the infrared rays. After about 10 minutes, a large temperature difference can be observed with the inside being much hotter. All students know not to leave a pet in the car on a summer day with the windows up and this demonstration will remind them of this. A discussion of the greenhouse effect and global warming can follow from this demonstration.

Chemical to Thermal Energy Transformations

Chemical reactions that result in heat being given off (exothermic) or in heat being absorbed (endothermic) are legion. What follows will be a selection of demonstrations that show both reaction types with an eye for the dramatic and even spectacular. An interesting demonstration of the heat given off in the ignition of methane gas is possible using a 2 liter plastic pop container or a one gallon plastic container. The container should be cut in half and the top half saved. Select a one-holed rubber stopper that fits into the opening the container. A 15cm section of glass tubing is then inserted into the rubber stopper. Care must be taken to not snap the glass when inserting. A lubricant such as glycerin or a drop of dish-washing liquid on the end of the glass tubing helps its insertion. It is probably a good idea to wrap cloth around the glass when inserting it into the stopper. The tubing should be inserted so that approximately 10 cm. is inside the plastic container. The plastic container should then be inverted on an iron ring so that the stopper end is facing down. I use a ring stand clamp to hold the stopper. This eliminates the need for an iron ring. A few feet of rubber tubing is then attached to the glass tubing. The other end is attached to the demonstration table gas outlet. The plastic container is then filled with water so that the water level is about 5 to 10 centimeters above the end of glass tubing in the container. A few squirts of dishwashing liquid is then added to the water and stirred thoroughly. Make sure that the rubber tubing is raised so that its top point is above the water level. This prevents back-siphoning of the soapy liquid. The gas jet should then be turned on full blast. Many bubbles should then form and begin to fill the container. After a minute or so**,** a large mass of gas-filled bubbles should begin to rise from the container. Methane gas is less dense than air so the bubbles rise. Students could be introduced to buoyancy and why things float at this point. The bubble mass will rise higher and higher. The instructor then can take a meter stick with a lit candle taped to one end**.** When the candle is touched to the bubble mass, a fireball immediately rises to the ceiling. Simultaneously, an enormous amount of heat is released. Students seem to love this demonstration. Safety considerations include wearing eye protection and not standing too close to the reaction. The fireball, while large and very exothermic, dissipates quite rapidly and poses a very small fire hazard. I should acknowledge Bob Becker and his book, Twenty Demonstrations Guaranteed to Knock your Socks Off, Vol. I, for this demonstration.

Students readily recognize the energy contained in natural gas. It is a ready and abundant source of heat energy used in industry and in the home. Because the major waste products are simply carbon dioxide and water, it is a relatively nonpolluting energy source but students might point out that carbon dioxide is a green-house gas that contributes to global warming. It is true that gases such as methane, carbon dioxide, sulfur and nitrogen oxides are called green-house gases because their presence in the atmosphere helps to trap infrared radiation from the sun. Once introduced into the atmosphere these gases are long-lived, lasting forty to one hundred years plus. Many evidences exist that the earth has experienced a warming trend in the last century. In the case of the cloud of pollution issuing from the Indian subcontinent mentioned in the introduction the big question is whether man-introduced gases are responsible for warming and whether the effects are temporary or of a longer duration. There is evidence that the smog cloud blocks sunlight causing lower temperatures. It is also true that the sun goes through cycles in which more or less heat is produced due to nuclear reactions being more or less intense at different times. Also the destruction of rain forests in the Amazon basin and carbon dioxide absorbing ocean phytoplankton plays a part in carbon dioxide buildup on this planet. In short the question of global warming is complex with many variables. It is arguable that man is introducing many more problematic pollutants into the atmosphere than at any time in recorded history. Just how much of the problem is due to natural gas combustion and release alone is a topic for research and study.

Chemical to Thermal Energy: Chemical Heat Packs

Several years ago while attending a science teacher conference, I was introduced to a novel product called The Heat Solution. This consisted of a plastic bag containing about eight ounces of a gelatinous, clear substance. The package contents identified it as food grade sodium acetate. Also contained in the sealed plastic container was a metal disc about the size of a penny. When the disc was bent slightly, a rapid crystallization of the sodium acetate occurred. The crystallization was extremely exothermic. The instructions suggest crushing the crystals to maximize heat production. The package achieves temperatures of about 135 degrees Fahrenheit and can be used as a hand or pocket warmer. The heat lasts for about 45 minutes and can be recharged by placing the pack in boiling water for about 10 to 15 minutes, removing it, and allowing it to cool. The explanation for the exothermic reaction is that the sodium acetate in the pack is in an unstable, supersaturated state. Bending the metal disc provides a surface on which a single crystal forms. Crystallization then occurs at a rapid rate with a simultaneous release of heat energy. Students can be reminded of the latent heat of fusion or the heat it takes to melt a crystal such as ice. The regular crystal lattice is at a lower energy state than the more random liquid state. It takes heat to melt an object and this heat is released when the object solidifies. It is possible to perform an experiment to measure the caloric output of the heat pack. 400 ml of water is added to a 600ml beaker. The temperature of the water is recorded and the activated heat pack is submerged in the water. After several minutes the temperature is taken again. The calories produced by the heat pack can be calculated by multiplying the volume of water (400ml) by the temperature change. **A calorie is defined as the heat energy required to raise the temperature of one ml of water one degree Celsius**. If the 400 ml of water in our experiment experienced a temperature change of 10 degrees, 4000 calories of heat was produced by the heat pack. Students can be reminded that a food calorie equals 1000 regular calories. So in our example, the heat pack produced just 4 food calories!

Mechanical to Thermal Energy Transformation

Of all possible energy transformations involving heat students are probably most familiar with this one. Students readily acknowledge that friction produces heat. Rubbing two sticks together or one’s hands are familiar examples. A car’s brakes produce large amounts of heat in their operation. When Benjamin Thompson described heat produced during the boring of cannons during the Revolutionary War, he was describing mechanical to thermal conversions. Machine shops still employ oil to reduce heat when producing metal products.

An interesting class activity begins with collecting an array of materials such as wooden dowel rods, metal rods, baby food jars with caps, thermometers, ropes, newspapers, blocks of wood, and beakers. Students are challenged to use the items to produce as much heat as they can and to transfer it to the water in the beakers. The beakers can be in the 1000ml range and contain 500 ml of water at a known temperature. Students might rub the dowel rods together, wrap the rope around the metal and wooden rods and use it to turn them rapidly against the wooden blocks. The heated rods can then be plunged in the water. Water might be added to the baby food jars from the beakers, capped, and shaken or rolled vigorously. Students should wrap the jars in layers of newspaper to prevent heat loss and gain from their hands. The heated water then can be poured back into the beakers. These are just a few suggestions. Your students probably can think of more. After about ten minutes the temperature of the water can be taken and the calories of heat energy produced can be calculated. A calorie is the amount of heat energy required to raise the temperature of one ml. of water one degree Celsius. Students will appreciate the strenuous effort required to produce rather modest heat gains.

Chemical to Thermal Energy Transformation: An Endothermic Reaction.

While endothermic reactions are not as numerous as exothermic ones, they do exist and the instructor should do his best to demonstrate them to students. Barium hydroxide and ammonium thiocyanate are both white solids in powder form. Equal amounts are introduced into a flask and mixed together by shaking. The flask should be stoppered to prevent the release of ammonia gas. A slurry forms as the two solids mix and the temperature drops dramatically. In fact it is possible to place a few drops of water on a block of wood and hold the edge of the flask to the water. The water will freeze and the block of wood will stick to the bottom of the flask! Another simple endothermic reaction occurs when water is added to potassium nitrate. A 10 to 15 degree Celsius temperature drop occurs as the mixture is stirred. Cold packs used to treat sprains at sporting events contain ammonium nitrate and a small container of water. When the pack is activated by breaking the water-containing cylinder, a dramatic endothermic reaction occurs. Once used, the pack is discarded.

Conclusion

The demonstrations, discussions, and lab activities presented above represent this writer’s attempt to present some ideas about heat energy, its effects on our planet, and its transformations to other energy types. I hope that some of the activities will be appropriate to the needs of any science teachers that happen to read them. In my experience, students like demonstrations that not only are informative but interesting in themselves. The activities that have been presented have for the most part been tried in the classroom with real success. The discussion of heat energy’s effects on our environment is by no means complete and are intended to stimulate further student research and investigation. The fact that all energy eventually results in heat serves as a sober reminder that all of human activity has consequences for the environment. That we are contributors to global warming by our extravagant squandering of energy resources worldwide is virtually certain. What we as humans intend to do about is another question. If we continue on our present course, eventually a day of reckoning will be thrust upon us and changes of lifestyle will occur that may not be pleasant. If, on the other hand, we decide to take appropriate measures to circumvent the squandering and injudicious use of energy resources, will it be enough? Already huge quantities of greenhouse gases and chlorofluorocarbons are present in the atmosphere and they will linger there for years to come no matter what we do from now on. Add to this the several hundred million cars worldwide with air conditioning refrigerant that in all likelihood will eventually find its way into the atmosphere and a very bleak future for the ozone layer emerges. Tropical rainforests and ocean phytoplankton which have traditionally served as a sink for carbon dioxide are being destroyed at an ever accelerating rate. The latent heat of fusion of water assures that the polar ice caps can absorb tremendous amounts of heat energy before their ice melts. The polar ice heat buffer zones are not infinite, however. Evidence exists that the polar ice caps are melting as well as being polluted by human activity far removed from them physically. Are we going to see rising seas that submerge low-lying islands and seacoast cities worldwide because of ice melts due to global warming? The recent El Nino event and its following La Nina are not well understood. Could their origins be in human activity? Encroaching desert in farming regions, the migration of warm weather plant and animals northward, and changes in growing seasons are alarm bells that signal possible global warming. I have no answers for the questions posed. I do suggest that students be reminded of the consequences as well as the applications of heat energy.

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