Heat and Thermal Energy

When scientists originally studied thermodynamics, they were really studying heat and thermal energy. Heat can do anything: move from one area to another, get atoms excited, and even increase energy. Did we say energy? That's what heat is. When you increase the heat in a system, you are really increasing the amount of energy in the system. Now that you understand that fact, you can see that the study of thermodynamics is the study of the amount of energy moving in and out of systems.

Heat of Atoms

Now all of this energy is moving around the world. You need to remember that it all happens on a really small scale. Energy that is transferred is at an atomic level. Atoms and molecules are transmitting these tiny amounts of energy. When heat moves from one area to another, it's because millions of atoms and molecules are working together. Those millions of pieces become the energy flow throughout the entire planet.

Heat Movement

Heat moves from one system to another because of differences in the temperatures of the systems. If you have two identical systems with equal temperatures, there will be no flow of energy. When you have two systems with different temperatures, the energy will start to flow. Air mass of high pressure forces large numbers of molecules into areas of low pressure. Areas of high temperature give off energy to areas with lower temperature. There is a constant flow of energy throughout the universe. Heat is only one type of that energy.

Increasing Energy and Entropy

Another big idea in thermodynamics is the concept of energy that changes the freedom of molecules. For example, when you change the state of a system (solid, liquid, gas), the atoms and/or molecules have different arrangements and degrees of freedom to move. That increase in freedom is called entropy. Atoms are able to move around more and there is more activity. That increase in freedom (also called randomness) is an increase in entropy.

Energy Likes to Move

If there is a temperature difference in a system, heat will naturally move from high to low temperatures. The place you find the higher temperature is the heat source. The area where the temperature is lower is the heat sink. When examining systems, scientists measure a number called the temperature gradient. The gradient is the change in temperature divided by the distance. The units are degrees per centimeter. If the temperature drops over a specific distance, the gradient is a negative value. If the temperature goes up, the gradient has a positive value. The greater the gradient, the more energy will be exchanged.

Ever Hear of Convection Ovens?

Convection is the way heat is transferred from one area to another when there is a "bulk movement of matter." It is the movement of huge amounts of material, taking the heat from one area and placing it in another. Warm air rises and cold air replaces it. The heat has moved. It is the transfer of heat by motion of objects. Convection occurs when an area of hot water rises to the top of a pot and gives off energy. Another example is warm air in the atmosphere rising and giving off energy. They are all examples of convection. The thing to remember is that objects change position.

Radiating Energy

When the transfer of energy happens by radiation, there is no conductive medium (such as in space). That lack of medium means there is no matter there for the heat to pass through. Radiation is the energy carried by electromagnetic waves (light). Those waves could be radio waves, infrared, visible light, UV, or Gamma rays. Heat radiation is usually found in the infrared sections of the EM spectrum. If the temperature of an object doubles (in Kelvin), the thermal radiation increases 16 times. Therefore, if it goes up four times, it increases to 32 times the original level.

Scientists have also discovered that objects that are good at giving off thermal radiation are also good at absorbing the same energy. Usually the amount of radiation given off by an object depends on the temperature. The rate at which you absorb the energy depends on the energy of the objects and molecules surrounding you.

Conducting Energy and Heat

Conduction is a situation where the heat source and heat sink are connected by matter. As we discussed before, the heat flows from the source down the temperature gradient to the sink. It is different from convection because there is no movement of large amounts of matter, and the transfers are through collisions. The source and the sink are connected.

If you touch an ice cream cone, the ice cream heats up because you are a warmer body. If you lie on a hot sidewalk, the energy moves directly to your body by conduction. When scientists studied good thermal radiators, they discovered that good thermal conductors are also good at conducting electricity. So when you think of a good thermal conductor, think about copper, silver, gold, and platinum.

Getting Hotter = Getting Bigger

Now you need to think about states of matter a little bit. We'll start with gases. The idea behind thermal expansion is that gases expand as the temperature increases. If you have a balloon and you heat up the contents, the balloon will get larger. Scientists use the term ideal gas law to describe this activity.

Liquids expand and contract, too, but there is a lot less change than in gases. Scientists say they have a smaller thermal expansion coefficient. As you can probably figure out, solids expand and contract the least of all the states of matter. The expansion coefficient is different for each piece of matter. It is a unique value, just like specific heat capacity. Two examples of coefficients are air at .00367 and alcohol at .000112.

Things Shrink When They get Cold

The opposite of expansion is contraction. If things expand with the addition of heat, it makes sense that they contract when heat is removed. If you remove enough heat from a gas it will become a liquid. Liquids can turn into solids with further cooling. What happens when you remove almost all of the energy from a system? Scientists use the terms absolute zero to describe a system that has no kinetic energy. When there is no kinetic energy in a system, all molecular motion stops. It seems that even the atoms begin to merge at these low temperatures. Physicists have recently created the Bose-Einstein state of matter that has a small group of atoms with nearly all of the kinetic energy taken out of the system.

Making Heat

How do you make heat? You could burn things (chemical reactions), or you could rub things together (friction). When you burn things, thermal energy is released. Thermal energy is measured in calories. For example, when you burn wood, you release 3000 calories for each gram of wood. When you burn an apple, it creates only 600 calories. The amount of energy released is directly related to the chemical bonds that are broken and formed. If you use that idea, there is more energy available when you break and rebond the atoms in wood, than when you do the same to an apple.

Losing Energy

We just talked about friction. Heat is also created because of inefficiency. When a car engine runs, a lot of heat is given off. Much of that heat is the result of the friction and inefficiency in the running motor. When you lift something and your muscle contracts, you are only 25% efficient. Seventy-five percent of the energy is lost to heat.

More Transfer of Energy

Heat is the thermal energy transported from one system to another because of a temperature difference. The transfer of that energy stops when the temperature balances out in the entire environment. Scientists use the unit of a calorie to measure heat. You might be saying, "I've heard of calories. Are those like the ones in food?" The answer is "Yes." One calorie is measured as the amount of energy needed to raise the temperature of one gram of water, one degree Celsius. When you “burn” food (this happens VERY slowly in your body), you release energy.

Specific Heat Capacity

There is also something totally important called specific heat capacity. It is the amount of energy required to raise the temperature of one gram of a substance by one degree Celsius. The specific heat capacity for water is one. As we said, heat is a form of thermal energy. Because it's energy, scientists also use the units of Joules to measure the energy. One calorie equals 4.186 Joules which also equals 4.186 Watts seconds (Ws). Does that mean you can measure the amount of energy you make in your body in one second and express that in terms of an electric value (Watts)? Yes, the rate at which energy is created or used in your body can be expressed as electrical power.

Three Big Temperature Scales

Since we're going to be talking about heat, temperatures, and energy, we wanted to introduce you to how temperature is measured. The big three are Fahrenheit, Celsius and Kelvin. Even though scientists may use only a few scales to measure temperature, there are dozens of types of devices that measure temperatures. All of these devices are called thermometers because they measure temperature. There are thermometers to measure your body temperature, the temperature in your oven, and even the temperature of liquid oxygen.

Fahrenheit is the Classic

Fahrenheit is the classic English system of measuring temperatures. Water freezes at 32 degrees Fahrenheit and boils at 212 degrees. The scale was created by Gabriel Daniel Fahrenheit in 1724 and divides the difference between the boiling point and freezing point of water into 180 equal degrees. You will probably be asked to convert temperatures back and forth from Fahrenheit to Celsius. Here's the formula: (Fahrenheit-32)\*5/9=Celsius.

Celsius Based on Water

Celsius is the modern system of measuring temperature. It fits in with much of the metric system and has nice round numbers. In Celsius, we call the freezing point of water 0 degrees Celsius, and the boiling point 100 degrees Celsius. Then the scale is divided into 100 equal degrees between those two points. The scale used to be known as centigrade but the name was changed several years ago. Both Celsius and Fahrenheit are used when discussing our day-to-day weather temperatures. Celsius degrees are larger than Fahrenheit degrees.

Kelvin to Absolute Zero

Kelvin is an important scale used in most of science. The big difference is that it is based on a single point (absolute zero) which is given a value of 0 degrees. From there, the scale increases by degrees that are the same size as Celsius degrees. It is a scale that is based on energy content, rather than on arbitrary temperature values like the other two scale (based on water). Water freezes at the value 273.15 and boils at 373.15 Kelvin. The word "Kelvin" comes from Lord Kelvin, who did a lot of work with temperatures.