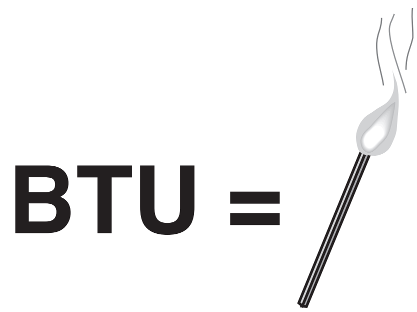
SATURN
RESOURCE MANAGEMENT

Measurement of Heat Energy



A kitchen match contains about one BTU of heat energy. One hundred thousand BTUs equals one therm of heat energy.

What is Energy?

Energy is a measurable quantity of heat, work, or light. *Potential energy* is stored energy, like a cord of wood. *Kinetic energy* is transitional energy, like a flame.

More than 99% of the energy we use comes from the sun. The only other significant source is nuclear material in the earth. Plants build their tissues with sunlight, and the composition of all fossil fuels is ancient plant and animal tissue. We burn fossil fuels to produce heat and work energy.

We measure energy many ways: therms of natural gas, kilowatt-hours of electricity, barrels of oil, gallons of propane, and pounds of steam are all common measurements of energy. Although energy measurement takes many forms, all types of energy are equivalent.

The energy from last summer's sunshine is chemically locked in the produce we buy at the grocery store. That chemical energy in food is burned in our bodies to provide the kinetic energy and heat required to keep the human machine functioning. Solar energy from the age of the dinosaurs, stored for eons as chemical energy in deposits of coal and oil, provides energy for our modern world.

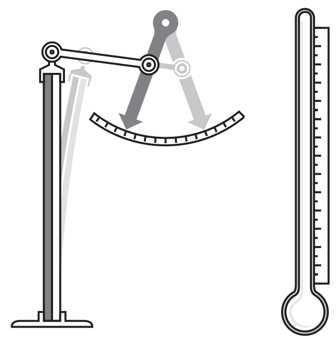
Laws of Thermodynamics

Two laws of the science of thermodynamics govern the behavior of heat in our universe. These laws were first described in the nineteenth century and helped to spawn the industrial revolution. Remember that no device, system, or idea can violate these laws. Attempts have been made but no exceptions have ever been demonstrated.

The first law of thermodynamics says that energy is neither created nor destroyed. Energy merely moves from place to place and changes form. The potential energy of gasoline becomes the automobile's movement, the engine's heat, and tires' friction on the road.

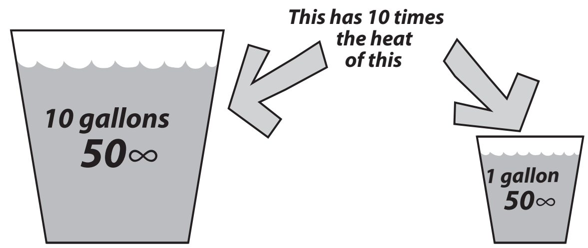
The second law of thermodynamics says that heat moves from high temperature regions to low temperature regions — never the reverse (without additional energy from an external source).

Measuring Temperature



Temperature is measured by the movement of a bimetal element or by the expansion of the liquid metal mercury.

Quantities: Heat and Material



If two different amounts of the same material have the same temperature, the heat content in each is directly related to the mass of the material.

Temperature and Heat

Temperature is a measure of how fast the molecules in a substance are moving or vibrating. Temperature is the average kinetic energy or motion of molecules. Molecules in a solid are stationary, but they vibrate faster and faster as heat is added, raising the temperature.

Heat flows because of a difference in temperature between two places. Heat is measured in *British thermal units (BTU)*, which is the amount of heat required to raise a pound of water's temperature 1°F. A BTU is approximately the amount of heat released by burning one wooden kitchen match. The number of BTUs of heat that a pound of any material absorbs or releases for each degree of temperature change is called its *specific heat*. It is measured in BTUs per pound per degree Fahrenheit (BTU/lb./°F). Water has a specific heat of 1 BTU/lb./°F. It takes only 0.2 BTU to raise a pound of aluminum 1°F, so aluminum has a specific heat of 0.2 BTU/lb./°F. If we add one BTU to a pound of aluminum, it will get 5°F warmer.

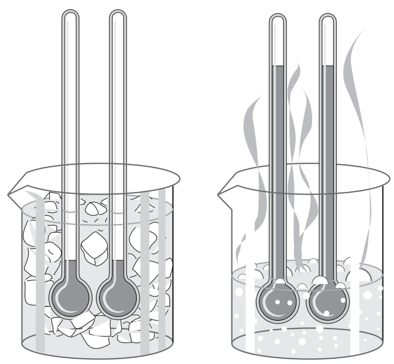
The temperature of a given weight of material tells us how much energy that material contains, which is called *enthalpy*.

Sensible and Latent Heat

The relationship between water's temperature and its heat content is predictable—add a BTU to a pound of water, and by definition, it gets one Fahrenheit degree warmer. Add 150 BTUs to a pound of 50°F water, and its temperature increases 150°F to the temperature of 200°F. This *sensible* relationship ends at 212°F — water's boiling point. With continued heating, the pound of water remains at 212°F, while it absorbs 970 BTUs during its complete evaporation into steam — six times the heat it absorbed going from 50°F to 212°F.

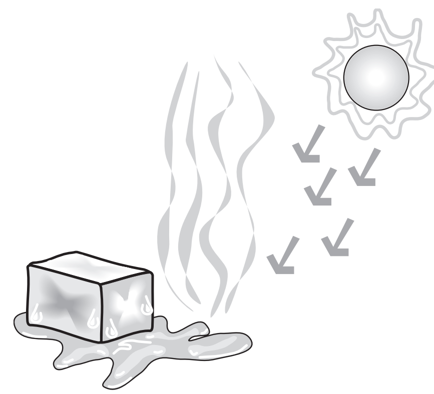
This unexpected or hidden heat, which is released or absorbed as a substance changes form, is called *latent heat*. Our pound of liquid water vaporized when we added 970 BTUs, which is called the *latent heat of evaporation* for water. If we could catch all the steam and recondense it, the 970 BTUs would be released again. This is the principle of steam heating.

Boiling and Freezing Points

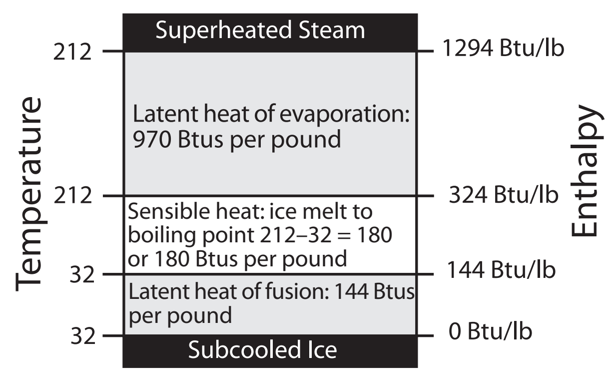


The boiling point and freezing point of water are important to calibrating thermometers because these two states are easy to recognize and duplicate. Freezing point: 32°F or 0°C; boiling point: 212°F or 100°C.

Latent Heat



Latent heat is the heat absorbed or released when a material changes phase between a solid and a liquid or between a liquid and a gas.



At the phase changes, temperature remains constant while enthalpy changes dramatically. Although often considered zero BTUs/lb. enthalpy, ice still has some energy content.

Our pound of water would go through a similar metamorphosis if we were to cool it: the water would lose 1°F for every BTU removed until reaching its freezing point, 32°F. We would then have to remove 144 BTUs — water's *latent heat of fusion* — to turn the pound of water into a block of ice. Conversely, it would take 144 BTUs of heat to melt the pound of ice again.

Steam-heating systems, air conditioners, and refrigerators use latent heat to carry energy from one place to another. In steam heating systems, water is vaporized at a boiler and condensed back to a liquid in radiators. In an air conditioner, a special fluid called a refrigerant vaporizes at the evaporator, absorbing heat from inside the home in the process. The hot gas is then piped outdoors to a condenser, where it *condenses* back to a liquid, releasing its latent heat into the outdoor air.

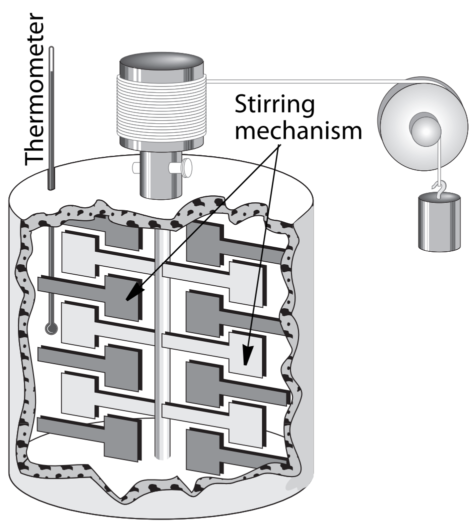
Heat and Work

The American system of measurement has many ways of describing energy — the BTU for heat and the foot-pound for work being two of the most common. If you lift a one-pound weight one foot off the floor, you have done one *foot-pound* of work.

To prove that heat and work are equivalent, a British physicist, James Joule, used mechanical energy (or work) to stir water. He found that for every 778 foot-pounds of work he performed stirring one pound of water, the pound of water absorbed 1 BTU. Joule determined this by measuring temperature change of stirred water in an insulated tank. Now we know that 778 foot-pounds is equivalent to 1 BTU. This was an essential piece of knowledge for the industrial revolution.

The *joule,* an international energy unit, describes both work and heat. A million BTUs (MMBTU) approximately equals a gigajoule (billion joules).

Work Equals Heat



Joule's experiment demonstrated the equivalence of heat and work by stirring water in an insulated tank. For each 778 foot-pounds of work expended to stir the water, he found the water had increased its enthalpy or heat content by 1 BTU.

Energy Versus Power

The differences between energy and power are fundamental, although the two are often confused. At the beginning of this chapter, we defined *energy* as a measurable quantity of heat, work, or light. *Power* is energy divided by time. Power is the rate work is done or heat is released.

Measurements of energy include foot-pounds of work, BTUs of heat, and kilowatt-hours of electricity.

The 100,000-BTUs/hour figure on the nameplate of your furnace is its power rating — its ability to deliver heat to the house when needed. Its power rating is the same in the summer, when it is idle, as in winter, when it's running. The winter operating hours determine how much fuel is converted to heat and how much the occupants pay the utility company.

Power and Energy Units

Power Unit	Energy Unit
BTU/hour (BTUH)	BTU
watt (joule/second)	watt-hour (3600* joules)
kilowatt (1kilojoule/second)	kilowatt-hour (3.6 megajoules)
foot-pound/minute	foot-pounds

* A factor of 3600 is obtained by converting seconds into hours. 60 min. X 60 sec.

One horsepower is 33,000 foot-pounds per minute, and it's a rather antiquated American unit for measuring mechanical power. Electrical power is measured in watts and kilowatts. A watt is actually a joule per second, so, like all power measurements, it is energy divided by time.

To get the quantity of energy produced or consumed, multiply power by the time the energy system is operating. If a 100,000-BTU/hour furnace runs for 10 hours, it converts 1 million BTUs of the fuel's potential energy to heat. If a 1500 watt heater runs for 10 hours, 15,000 watt-hours or 15 kilowatt-hours of electricity is consumed.

If a wood cutter cuts a cord of wood per day (power rating), and works for seven days, then he cuts seven cords of wood (energy). Converting the woodcutter's week of work into BTUs, we would multiply seven cords by 20 million BTUs (the heat content of one cord of hardwood) to get a total of 140 million BTUs of energy collected.

If a wood stove burned a cord in 200 hours of operation, its power would be approximately 100,000 BTUs per hour (20 million BTUs ÷ 200 hours = 100,000 BTUs/hour).

Pressure Versus Flow

Fluids flow because pressure pushes them along an open path allowing their flow. Both the pressure and a path are necessary for flow. Water, air, heat, and electricity follow similar laws as they flow from place to place — each in a unique way.

Pressure builds because of a difference in some measurable condition between two areas, which are sometimes labeled positive and negative to denote a pressure difference. Heat moves from place to place because of a difference in temperature (°F). Electricity moves because of a difference in electrical energy (volts). The wind blows because of differences in air pressure (pascals, inches of mercury). Water flows downhill because of a difference in altitude (feet). Water vapor flows because of a difference in concentration in water vapor molecules between two areas (pounds of water vapor per pound of dry air).

If a pressure and a path exist, fluids flow from the high-pressure region to the low-pressure region. If the pressure continues, the flow continues. If the pressure equalizes, the flow stops. For example, wind moves air from a high pressure region to a low pressure region, until the pressure difference between the two regions has equalized.

Where there is a pressure difference but no path, there's no flow. A large pressure difference exists between the air inside and outside your car tires, but, hopefully, there is no flow because there are no paths — holes in the tires. If a light switch is turned off, the switch creates a break in the path, interrupting electricity's flow, even though there is voltage — electrical pressure — in the circuit.

The substance connecting two regions may be: a *conductor,* where the medium can flow rapidly; a *resistor*, where the medium flows slowly; or a *barrier*, which stops flow or slows it down to a negligible rate. Glass, for instance, is a heat and light conductor, an electrical resistor, and an air and vapor barrier.

See "Air Pressure and Flow" on page 79 and "Ohm's Law" on page 43 for practical examples.

Energy Transformation and Heat Flow

Energy is neither created nor destroyed. Energy merely flows from place to place and changes form. While it is more accurate to say that energy is transformed or converted to another form, it's more common to say that energy is used or consumed.

Energy Transformation

Potential energy is energy locked in a stable state that can be used for work or heat. Our woodcutter's seven cords of wood remains potential energy until they are burned in a wood stove. Your body converts chemical energy from food to heat and motion. A large snowbank melts to become a million pounds of water flowing through a dam's turbine.

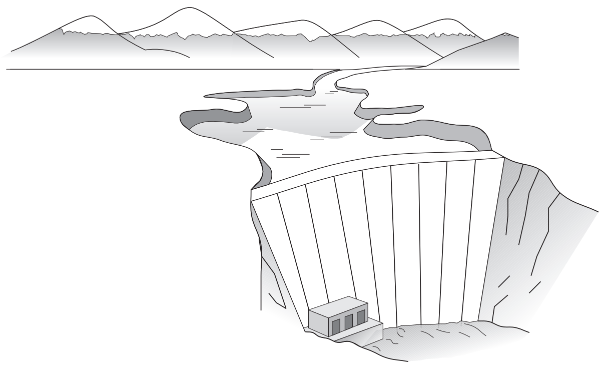
Burning wood or water flowing through the turbine represent kinetic energy. When gasoline explodes in an engine's cylinder, its potential energy becomes the kinetic energy of the rotating crankshaft.

Energy Transport

It is usually more convenient to convert potential energy to kinetic energy at a central location like a power station or boiler room. This confines the heavy machinery, mess, and danger of energy conversion to appropriately designed facilities.

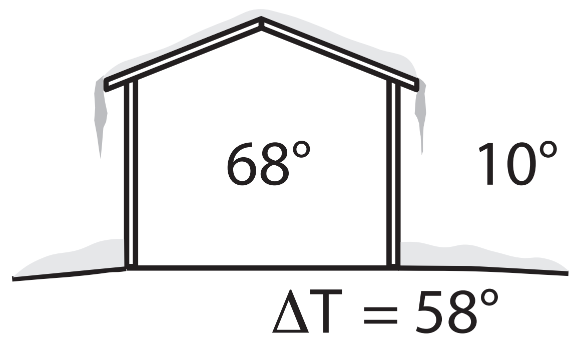
Energy transport is the intentional movement of energy from one place to another. The fuel pump delivers gas to the carburetor, so the engine can burn the fuel. The furnace fan delivers hot air through ducts to the heat registers in the home. Steam pressure moves latent heat from a steam boiler through pipes to radiators. Generators at the power plant push electricity down the wires to your home.

Potential and Kinetic Energy



The dam and snow-capped mountains store water as potential energy. As the water moves through the dam, its potential energy is converted to kinetic energy in rotating electrical generators.

Temperature Difference



The difference in temperature between indoors and outdoors (represented by ΔT) is the driving force for heat flow and presents the need for a heating device to replace the lost energy.

Electricity is the easiest form of energy to move. It flows easily through copper or aluminum wires over long distances.

Mechanical energy is the most difficult type of energy to move. Rotating shafts and belts can move the mechanical energy only a short distance, while a significant part of the energy is dissipated through friction.

Some of the heating energy flowing through pipes and ducts is lost by conduction, convection, and radiation from heated pipes and ducts to their surroundings and also by air, steam, or water escaping from their conduits.

See "Forced-Air Systems" on page 161, "Hot-Water and Steam-Heating Systems" on page 165, and "Electric Circuits and Devices" on page 43.

Types of Heat Flow

Heat travels from areas of high temperature to areas of lower temperature in three ways: *conduction, convection,* and *radiation*.

Conduction is the way heat flows in solids. Heat flows through a solid by the vibrations of its stationary molecules spreading through the material.

Convection is the way heat flows in fluids where the molecules can move around, as in water and air. Winds and ocean currents transmit heat from warm areas to cooler areas around the globe by convection.

Radiation is the way heat flows in a line of sight between bodies of different temperatures. Heat radiation occurs between all objects that can "see" each other through space or through a gas, like air.

Conduction — Conduction is the most familiar and predictable type of heat flow. Heat conducts through solid objects and between objects touching one another. When you grab a hot frying pan, you get burned because the pan's heat conducts into your hand. As an object becomes warmer, the molecules vibrate, bump, and rub against each other more vigorously, passing heat through the material. This flow of heat is always from higher temperature to lower temperature.

The *K-value* or conductance measures the rate of heat conduction through a one-square-foot slab of any material one-inch thick. Metals like aluminum have high K-values, while K-values for insu-