Audel™

Pumps and Hydraulics

All New 6th Edition

Rex Miller
Mark Richard Miller
Harry Stewart

Wiley Publishing, Inc.

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About the Authors

Rex Miller was a Professor of Industrial Technology at The State University of New York, College at Buffalo for more than 35 years. He has taught at the technical school, high school, and college level for more than 40 years. He is the author or co-author of more than 100 textbooks ranging from electronics through carpentry and sheet metal work. He has contributed more than 50 magazine articles over the years to technical publications. He is also the author of seven civil war regimental histories.

Mark Richard Miller finished his BS in New York and moved on to Ball State University, where he earned a master's degree, then went to work in San Antonio. He taught high school and finished his doctorate in College Station, Texas. He took a position at Texas A&M University in Kingsville, Texas, where he now teaches in the Industrial Technology Department as a Professor and Department Chairman. He has co-authored 11 books and contributed many articles to technical magazines. His hobbies include refinishing a 1970 Plymouth Super Bird and a 1971 Road-runner.

Harry L. Stewart was a professional engineer and is the author of numerous books for the trades covering pumps, hydraulics, pneumatics, and fluid power.

Introduction

The purpose of this book is to provide a better understanding of the fundamentals and operating principles of pumps, pump controls, and hydraulics. A thorough knowledge of pumps has become more important, due to the large number of applications of pump equipment in industry.

The applied principles and practical features of pumps and hydraulics are discussed in detail. Various installations, operations, and maintenance procedures are also covered. The information contained will be of help to engineering students, junior engineers and designers, installation and maintenance technicians, shop mechanics, and others who are interested in technical education and selfadvancement.

The correct servicing methods are of the utmost importance to the service technician, since time and money can be lost when repeated repairs are required. With the aid of this book, you should be able to install and service pumps for nearly any application.

The authors would like to thank those manufacturers that provided illustrations, technical information, and constructive criticism. Special thanks to TAT Engineering and Sherwood Pumps.

Part I

Introduction to Basic Principles of Pumps and Hydraulics

Chapter I

Basic Fluid Principles

Pumps are devices that expend energy to raise, transport, or compress fluids. The earliest pumps were made for raising water. These are known today as *Persian* and *Roman waterwheels* and the more sophisticated *Archimedes screw*.

Mining operations of the Middle Ages led to development of the *suction* or *piston pump*. There are many types of suction pumps. They were described by Georgius Agricola in his *De re Metallica* written in 1556 A.D. A suction pump works by atmospheric pressure. That means when the piston is raised, it creates a partial vacuum. The outside atmospheric pressure then forces water into the cylinder. From there, it is permitted to escape by way of an outlet valve. Atmospheric pressure alone can force water to a maximum height of about 34 feet (10 meters). So, the force pump was developed to drain deeper mines. The downward stroke of the force pump forces water out through a side valve. The height raised depends on the force applied to the piston.

Fluid is employed in a closed system as a medium to cause motion, either linear or rotary. Because of improvements in seals, materials, and machining techniques, the use of fluids to control motions has greatly increased in the recent past.

Fluid can be either in a liquid or gaseous state. Air, oil, water, oxygen, and nitrogen are examples of fluids. They can all be pumped by today’s highly improved devices.

Physics

A branch of science that deals with matter and energy and their interactions in the field of mechanics, electricity, nuclear phenomena, and others is called *physics*. Some of the basic principles of fluids must be studied before subsequent chapters in this book can be understood properly.

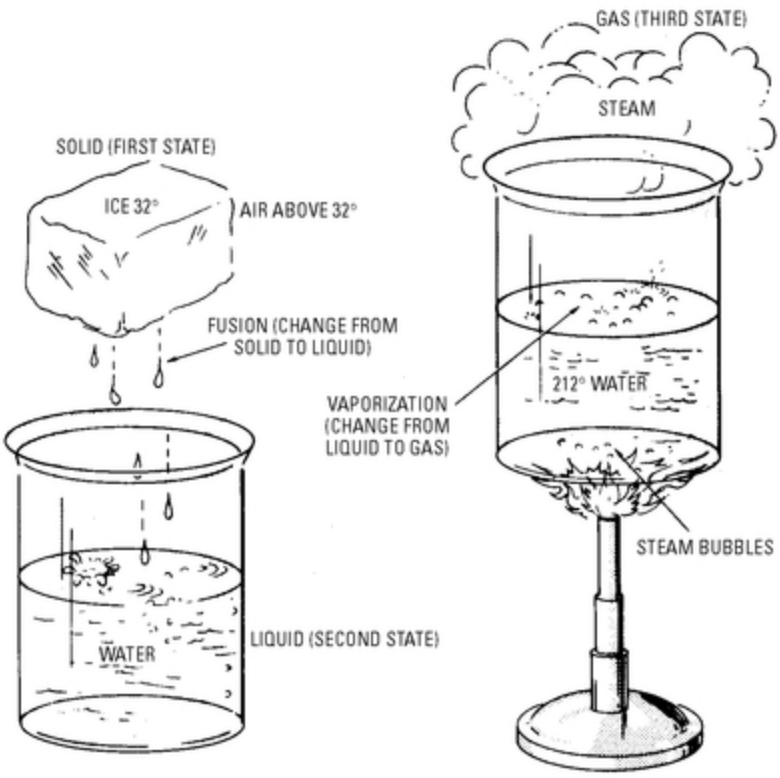
Matter

Matter can be defined as anything that occupies space, and all matter has inertia. Inertia is that property of matter by which it will remain at rest or in uniform motion in the same straight line or direction unless acted upon by some external force. *Matter* is any substance that can be weighed or measured. Matter may exist in one of three states:

- Solid (coal, iron, ice)
- Liquid (oil, alcohol, water)
- Gas (air, hydrogen, helium)

Water is the familiar example of a substance that exists in each of the three states of matter (see Figure 1-1) as ice (solid), water (liquid), and steam (gas).

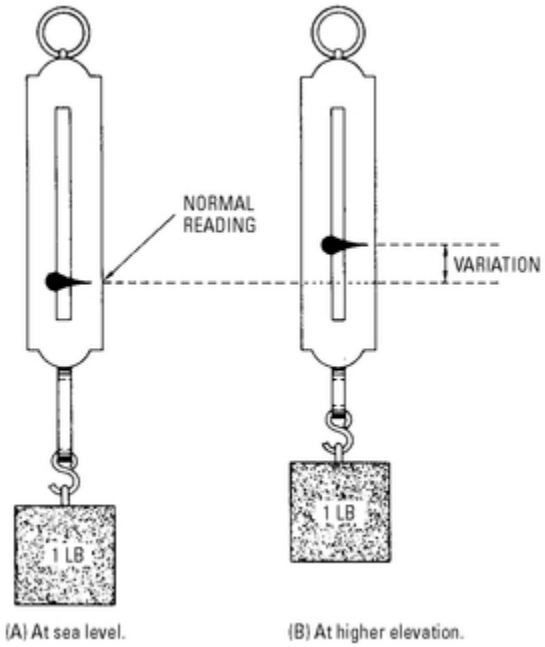
Figure 1-1 The three states of matter: solid, liquid, and gas. Note that the change of state from a solid to a liquid is called fusion, and the change of state from liquid to a gas is called vaporization.



Body

A body is a mass of matter that has a definite quantity. For example, a mass of iron 3 inches × 3 inches × 3 inches has a definite quantity of 27 cubic inches. It also has a definite weight. This weight can be determined by placing the body on a scale (either a lever or platform scale or a spring scale). If an accurate weight is required, a lever or platform scale should be employed. Since weight depends on gravity, and since gravity decreases with elevation, the reading on a spring scale varies, as shown in Figure 1-2.

Figure 1-2 Variation in readings of a spring scale for different elevations.



Energy

Energy is the capacity for doing work and overcoming resistance. Two types of energy are *potential* and *kinetic* (see Figure 1-3).

Potential energy is the energy that a body has because of its relative position. For example, if a ball of steel is suspended by a chain, the position of the ball is such that if the chain is cut, work can be done by the ball.

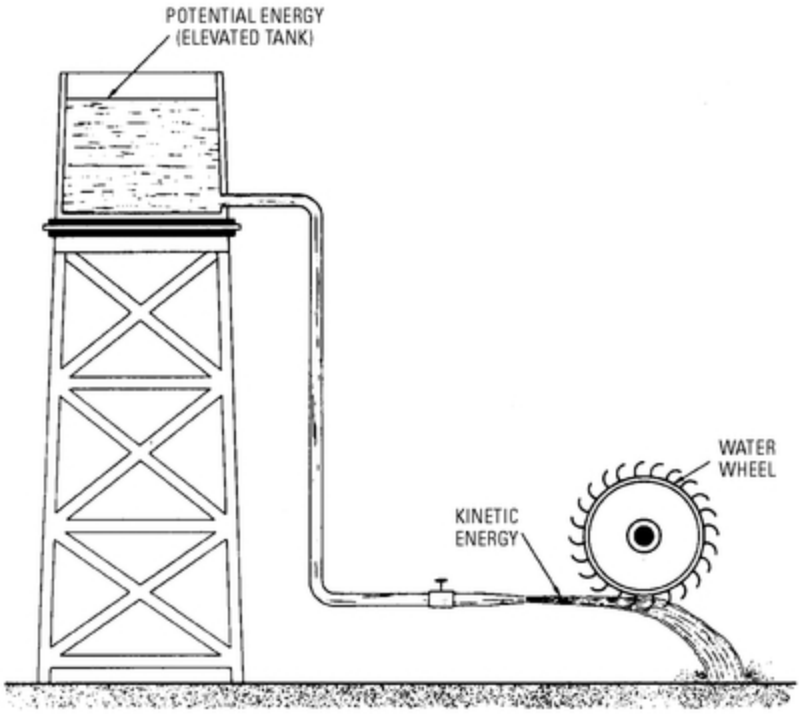
Kinetic energy is energy that a body has when it is moving with some velocity. An example would be a steel ball rolling down an incline. Energy is expressed in the same units as work (foot-pounds).

As shown in Figure 1-3, water stored in an elevated reservoir or tank represents potential energy, because it may be used to do work as it is liberated to a lower elevation.

Conservation of Energy

It is a principle of physics that energy can be transmitted from one body to another (or transformed) in its manifestations, but energy may be neither created nor destroyed. Energy may be dissipated. That is, it may be converted into a form from which it cannot be recovered (the heat that escapes with the exhaust from a locomotive, for example, or the condensed water from a steamship). However, the total amount of energy in the universe remains constant, but variable in form.

Figure 1-3 Potential energy and kinetic energy.

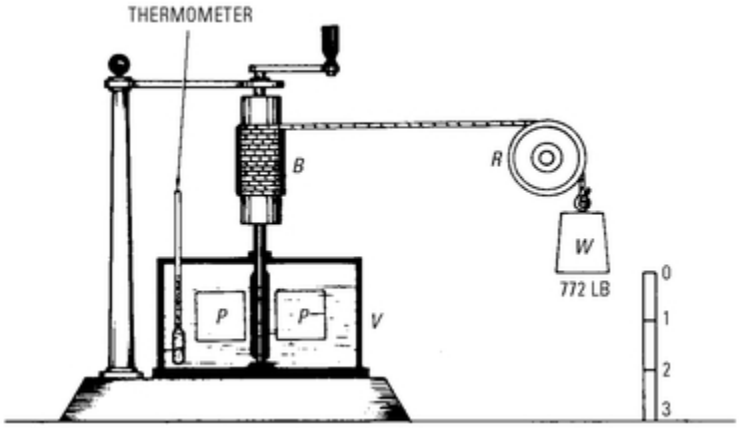


Joule's Experiment

This experiment is a classic illustration (see Figure 1-4) of the conservation of energy principle. In 1843, Dr. Joule of Manchester, England, performed his classic experiment that

demonstrated to the world the mechanical equivalent of heat. It was discovered that the work performed by the descending weight (*W* in Figure 1-4) was not lost, but appeared as heat in the water—the agitation of the paddles having increased the water temperature by an amount that can be measured by a thermometer. According to Joule's experiment, when 772 foot-pounds of work energy had been expended on the 1 pound of water, the temperature of the water had increased 1°F. This is known as *Joule's equivalent*: That is, 1 unit of heat equals 772 foot-pounds (ft-lb) of work. (It is generally accepted today that ft-lb. be changed to lb.ft. in the meantime or transistion period you will find it as ft-lb. or lb.ft.)

Figure 1-4 Joule's experiment revealed the mechanical equivalent of heat.



Experiments by Prof. Rowland (1880) and others provide higher values. A value of 778 ft-lb is generally accepted, but 777.5 ft-lb is probably more nearly correct, the value 777.52 ft-lb being used by Marks and Davis in their steam tables. The value 778 ft-lb is sufficiently accurate for most calculations.

Heat

Heat is a form of energy that is known by its effects. The effect of heat is produced by the accelerated vibration of molecules. Theoretically, all molecular vibration stops at -273°C (known as absolute zero), and there is no heat formed. The two types of heat are *sensible* heat and *latent* heat.

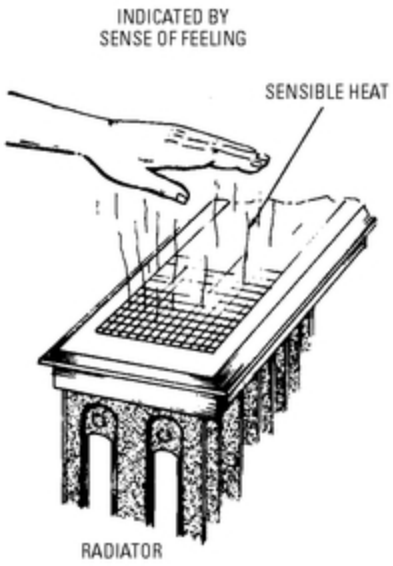
Sensible Heat

The effect of this form of heat is indicated by the sense of touch or feeling (see Figure 1-5).

Sensible heat is measured by a thermometer. A thermometer is an instrument used to measure the temperature of gases, solids, and liquids. The three most common types of thermometers are *liquid-in-glass* , *electrical*, and *deformation*.

The liquid-in-glass generally employs mercury as the liquid unless the temperature should drop below the freezing point of mercury, in which case alcohol is used. The liquid-in-glass is relatively inexpensive, easy to read, reliable, and requires no maintenance. The thermometer consists of a glass tube with a small uniform bore that has a bulb at the bottom and a sealed end at the top. The bulb and part of the tube are filled with liquid. As the temperature rises, the liquid in the bulb and tube expand and the liquid rises in the tube. When the liquid in the thermometer reaches the same temperature as the temperature outside of the thermometer, the liquid ceases to rise.

Figure 1-5 The radiator is an example of sensible heat.



In 1714, Gabriel Daniel Fahrenheit built a mercury thermometer of the type now commonly in use.

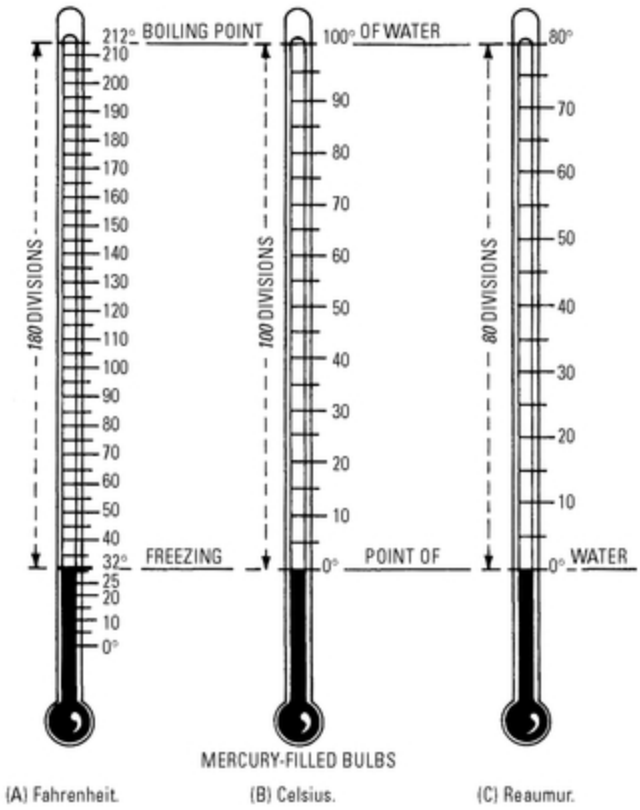
Electrical thermometers are of the more sophisticated type. A *thermocouple* is a good example. This thermometer measures temperatures by measuring the small voltage that exists at the junction of two dissimilar metals. Electrical thermometers are made that can measure temperatures up to 1500°C.

Deformation thermometers use the principle that liquids increase in volume and solids increase in length as temperatures rise. The *Bourdon tube thermometer* is a deformation thermometer.

Extremely high temperatures are measured by a *pyrometer*. One type of pyrometer matches the color (such as that of the inside of a furnace) against known temperatures of red-hot wires.

Figure 1-6 shows the Fahrenheit, Celsius, and Reaumur thermometer scales. Figure 1-7 illustrates the basic principle of a thermocouple pyrometer.

Figure 1-6 Three types of thermometer scales.



Latent Heat

This form of heat is the quantity of heat that becomes concealed or hidden inside a body while producing some change in the body other than an increase in temperature.

When water at atmospheric pressure is heated to 212°F, a further increase in temperature does not occur, even though the supply of heat is continued. Instead of an increase in temperature, vaporization occurs, and a considerable quantity of heat must be added to the liquid to transform it into steam. The total heat consists of *internal* and *external* latent heats. Thus, in water at 212°F and at atmospheric pressure, considerable heat is required to cause the water to begin boiling (internal latent heat). The additional heat that is required to boil the water is called *external latent*

heat. Figure 1-8 shows a familiar example of both internal and external latent heat.

Figure 1-7 Basic principle of a thermocouple pyrometer. A thermocouple is used to measure high temperatures. In principle, when heat is applied to the junction of two dissimilar metals, a current of electricity begins to flow in proportion to the amount of heat applied. This current is brought to a meter and translated in terms of heat.

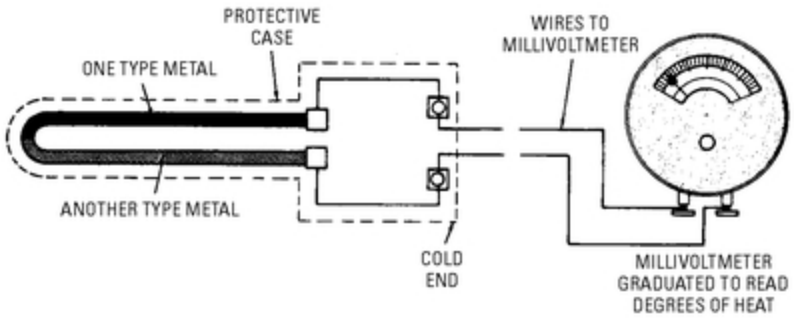


Figure 1-8 Domestic setting for illustrating internal (left) and external (right) latent heat.

Unit of Heat

The *heat unit* is the amount of heat required to raise the temperature of 1 pound of water 1°F at the maximum

density of the water. The *British thermal unit* (abbreviated Btu) is the standard for heat measure. A unit of heat (Btu) is equal to 252 calories, which is the quantity of heat required to raise the temperature of 1 pound of water from 62°F to 63°F.

Assuming no loss of heat, 180 Btu are required to raise the temperature of 1 pound of water from 32°F to 212°F. If the transfer of heat occurs at a uniform rate and if six minutes are required to increase the temperature of the water from 32°F to 212°F, 1 Btu is transferred to the water in (6 × 60) ÷ 180, or 2 seconds.

Specific Heat

This is the ratio of the number of Btu required to raise the temperature of a substance 1°F to the number of Btu required to raise the temperature of an equal amount of water 1°F. Some substances can be heated more quickly than other substances. Metal, for example, can be heated more quickly than glass, wood, or air. If a given substance requires one-tenth the amount of heat to bring it to a given temperature than is required for an equal weight of water, the number of Btu required is $^{1}/_{10}$ (0.1), and its specific heat is $^{1}/_{10}$ (0.1).

Example

The quantity of heat required to raise the temperature of 1 pound of water 1°F is equal to the quantity of heat required to raise the temperature of 8.4 pounds of cast iron 1°F. Since the specific heat of water is 1.0, the specific heat of cast iron is 0.1189 (1.0 ÷ 8.4).

Thus, the specific heat is the ratio between the two quantities of heat. Table 1-1 shows the specific heat of some common substances.

Transfer of Heat

Heat may be transferred from one body to another that is at a lower temperature (see Figure 1-9) by the following:

- Radiation
- Conduction
- Convection

When heat is transmitted by radiation, the hot material (such as burning fuel) sets up waves in the air. In a boiler-type furnace, the heat is given off by *radiation* (the heat rays radiating in straight lines in all directions). The heat is transferred to the crown sheet and the sides of the furnace by means of radiation.

Contrary to popular belief that heat is transferred through solids by radiation; heat is transferred through solids (such as a boilerplate) by conduction (see Figure 1-10). The temperature of the furnace boilerplate is only slightly higher than the temperature of the water that is in contact with the boilerplate. This is because of the extremely high conductivity of the plate.

Conduction of heat is the process of transferring heat from molecule to molecule. If one end of a metal rod is held in a flame and the other end in the hand, the end in the hand will become warm or hot. The reason for this is that the molecules in the rod near the flame become hot and move rapidly, striking the molecules next to them. This action is repeated all along the rod until the opposite end is reached. Heat is transferred from one end of the rod to the other by

conduction. Conduction depends upon unequal temperatures in the various portions of a given body.

Table 1-1 Specific Heat of Common Substances

Solids		*Liquids*	
Copper	0.0951	Water	1.0000
Wrought Iron	0.1138	Sulfuric acid	0.3350
Glass	0.1937	Mercury	0.0333
Cast Iron	0.1298	Alcohol	0.7000
Lead	0.0314	Benzene	0.9500
Tin	0.0562	Ether	0.5034
Steel, Hard	0.1175		
Steel, Soft	0.1165		
Brass	0.0939		
Ice	0.5040		

Gases		
Type	*At Constant Pressure*	*At Constant Volume*
Air	0.23751	0.16847
Oxygen	0.21751	0.15507
Hydrogen	3.40900	2.41226
Nitrogen	0.24380	0.17273
Ammonia	0.50800	0.29900
Alcohol	0.45340	0.39900

Convection of heat is the process of transmitting heat by means of the movement of heated matter from one location to another. Convection is accomplished in gases and liquids.

In a place heated by a radiator, the air next to the radiator becomes warm and expands. The heated air becomes less dense than the surrounding cold air. It is forced up from the radiator by the denser, colder air. Most home heating systems operate on the principle of transmission of heat by convection.

Nearly all substances expand with an increase in temperature, and they contract or shrink with a decrease in temperature. There is one exception to this statement for all temperature changes, the exception being water. It is a

remarkable characteristic of water that at its maximum density (39.1°F) water expands as heat is added and that it also expands slightly as the temperature decreases from that point.

Figure 1-9 Transfer of heat by radiation, conduction, and convection. It should be noted that the air, not the water, is the cooling agent. The water is only the medium for transferring the heat to the point where it is extracted and dissipated by the air.

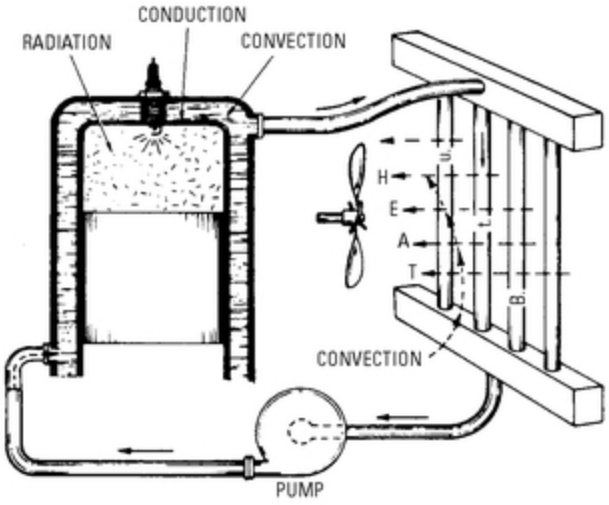
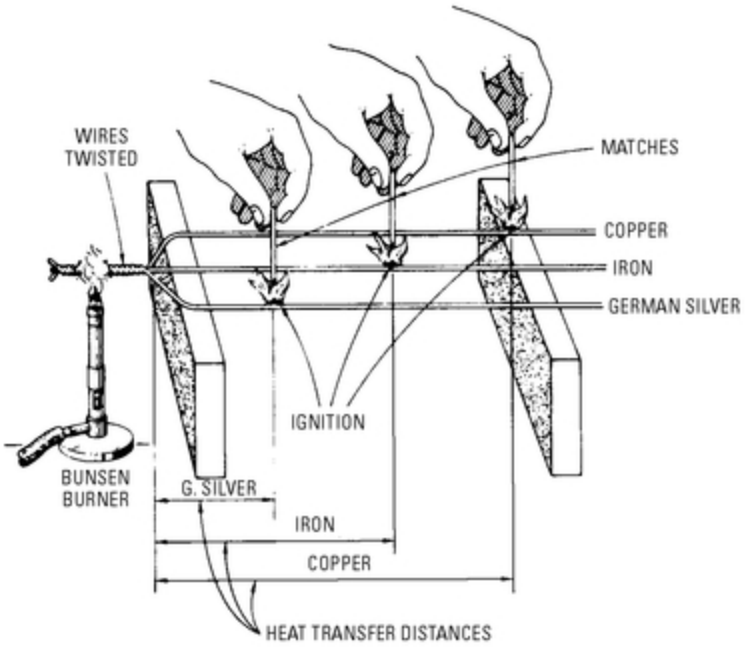


Figure 1-10 Differences in heat conductivity of various metals.



Increase in heat causes a substance to expand, because of an increase in the velocity of molecular action. Since the molecules become more separated in distance by their more frequent violent collisions, the body expands.

Linear expansion is the expansion in a longitudinal direction of solid bodies, while *volumetric expansion* is the expansion in volume of a substance.

The *coefficient of linear expansion* of a solid substance is the ratio of increase in length of body to its original length, produced by an increase in temperature of 1°F.

Expansion and contraction caused by a change in temperature have some advantages, but also pose some disadvantages. For example, on the plus side, rivets are heated red-hot for applying to bridge girders, structural steel, and large boilerplates. As the rivets cool, they contract, and provide a solid method of fastening. Iron rims are first heated and then placed on the wheel. As the iron cools, the rim contracts and binds the wheel so that it will not come off. Common practice is to leave a small space