Engineering Fundamentals

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CHAPTER 2

ENGINEERING FUNDAMENTALS

You are about to become acquainted with the fascinating world of physics. You will learn about the various natural and physical laws and phenomena. Physics is concerned with those aspects of nature that can be understood in a fundamental way in terms of elementary principles and laws. The forces of physics and the laws of nature are at work in every piece of machinery and equipment. It is by these forces and laws that the machinery and equipment produce work.

In the following paragraphs, you will learn about matter, magnetism, electricity, motion, properties of mass, temperature, pressure, various laws and principles of physics dealing with motion, gases, hydraulics and pneumatics, and basic information on metals.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

    1. Describe the basic principles of physics.

MATTER

If Western science has roots, they probably lie in the rubble that was once ancient Greece. Except for the Greeks, ancient people had little interest in the structure of materials. They accepted a solid as being just that—a continuous, uninterrupted substance. One Greek school of thought believed that if a piece of matter, such as copper, were subdivided, it could be subdivided indefinitely and still only that material would be found. Others reasoned that a limit exists to the number of subdivisions that could be made and have the material still retain its original characteristics. They held fast to the idea that all substances are built upon a basic particle. Experiments have revealed that, indeed, several basic particles, or building blocks, are within all substances.

Matter cannot be created or destroyed. This law holds within the experimental error of the most precise chemical reactions. This theory of the conservation of energy will be discussed later in this chapter. Matter is defined as anything that occupies space and has weight; that is, the weight and dimensions of matter can be measured. Examples of matter are air, water, clothing, and even our own bodies. So, we can say matter is found in any one of three states: gaseous, liquid, and solid.

In the following paragraphs, we will describe how substances are classified as elements and compounds and how they are made up of molecules and atoms. We will then learn about protons, electrons, and the physics of electricity.

ELEMENTS AND COMPOUNDS

An element is a substance that cannot be reduced to a simpler substance by chemical means. Examples of elements with which you are in everyday contact are iron, gold, silver, copper, and oxygen. Over 100 known elements are in existence. All the different substances we know about are composed of one or more of these elements.

When two or more elements are chemically combined, the resulting substance is called a compound. A compound is a chemical combination of elements that can be separated by chemical means. Examples of common compounds are water, which consists of hydrogen and oxygen, and table salt, which consists of sodium and chlorine. A mixture, on the other hand, is a combination of elements and compounds, not chemically combined, that can be separated by physical means. Examples of

mixtures are air, which is made up of nitrogen, oxygen, carbon dioxide, and small amounts of rare gases, and sea water, which consists chiefly of salt and water.

MOLECULES

A molecule is a chemical combination of two or more atoms (atoms are described in the next paragraph). In a compound, the molecule is the smallest part that has all the characteristics of the compound. Consider water, for example. Depending on the temperature, it may exist as a liquid (water), a solid (ice), or a gas (steam). Regardless of the temperature, it will still have the same composition. If we start with a quantity of water, divide it and pour out one-half of the amount. If we continue this process enough times, the result will be a quantity of water that cannot be further divided without ceasing to be water. This quantity is called a molecule of water. If this molecule of water is divided, instead of two parts of water, we will have one part of oxygen and two parts of hydrogen (H_2O).

ATOMS

Molecules are made up of smaller particles called atoms. An atom is the smallest particle of an element that retains the characteristics of that element. The atom of one element, however, differs from the atoms of all other elements. Because over 100 elements are known, there must be over 100 different atoms, or a different atom for each element. Just as thousands of words are made by a combination of the proper letters of the alphabet, so are thousands of different materials made by the chemical combination of the proper atoms. Any particle that is a chemical combination of two or more atoms is called a molecule. The oxygen molecule has two atoms of oxygen, and the hydrogen molecule has two molecules of hydrogen. Sugar, on the other hand, is a compound composed of atoms of carbon, hydrogen, and oxygen. These atoms are combined into sugar molecules. Because the sugar molecules can be broken down by chemical means into smaller and simpler units, we cannot have sugar atoms.

You will see in *Figure 2-1* that the atoms of each element are made up of electrons, protons, and, in most cases, neutrons, which are collectively called subatomic particles. Furthermore, the electrons, protons, and neutrons of one element are identical to those of any other element. The reason there are different elements is that the number and arrangement of electrons and protons within the atom are different for the different elements.

The electron is considered to be a small negative charge of electricity. The proton has a positive charge of electricity equal and opposite to the charge of the electron. Scientists have measured the mass and size of the electron and proton. They know how much charge each has. The electron and proton each have the same quantity of charge, although the mass of the proton is about 1,837 times that of the electron. In some atoms, a neutral particle exists, called a neutron. The neutron is a mass about equal to that of a proton, but it has no electrical charge. According to a popular theory, the electrons, protons, and neutrons of the atoms are thought to be arranged in a manner similar to a miniature solar system. The protons and neutrons form a heavy nucleus with a positive charge, around which the very light electrons revolve.

One hydrogen and one helium atom are shown in *Figure 2-1*. Each has a relatively simple structure. The hydrogen atom has only one proton in the nucleus, with one electron rotating about it. The helium atom is a little more complex. It has a nucleus made up of two protons and two neutrons, with two electrons rotating about the nucleus. Elements are classified numerically according to the complexity of their atoms. The atomic number of an atom is determined by the number of protons in its nucleus.

In a neutral state, an atom contains an equal number of protons and electrons. Therefore, an atom of hydrogen, which contains one proton and one electron, has an atomic number of 1; and helium, with two protons and two electrons, has an atomic number of 2. The complexity of atomic structure increases with the number of protons and electrons.
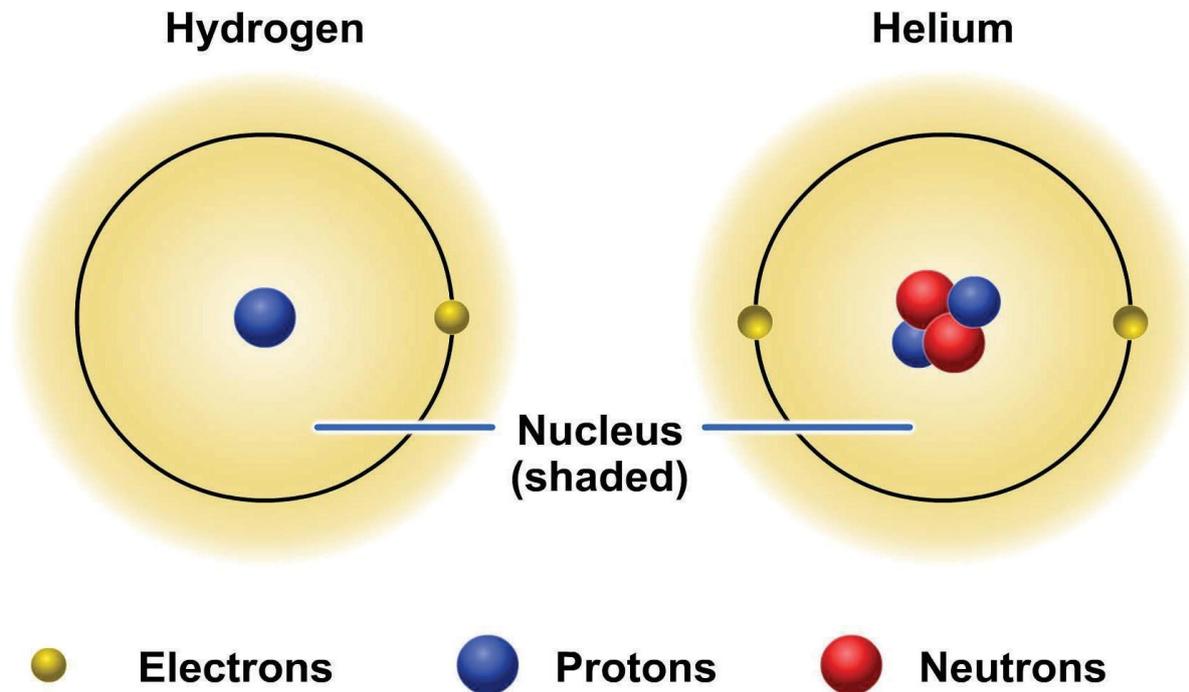
Hydrogen   Helium

Nucleus
(shaded)

● Electrons   ● Protons   ● Neutrons

Figure 2-1 — Structure of simple atoms.

MAGNETISM

To understand properly the principles of how electrical equipment produces work, you must understand magnetism, the effects of magnetism on electrical equipment, and the relationship of the different properties of electricity. Magnetism and electricity are so closely related that the study of either subject would be incomplete without at least a basic knowledge of the other.

Much of today's electrical and electronic equipment could not function without magnetism. Computers, recorders, and video reproduction equipment use magnetic tape. High-fidelity speakers use magnets to convert amplifier outputs into audible sound. Electric motors use magnets to convert mechanical motion into electrical energy. Magnetism is generally defined as that property of a material that enables it to attract pieces of iron. Material with this property is known as magnetic. The word magnetic originated from the ancient Greeks, who found stones possessing this characteristic. Materials that are attracted by a magnet, such as iron, steel, nickel, and cobalt, have the ability to become magnetized. Thus, they are magnetic materials. Materials such as paper, wood, glass, or tin, which are not attracted by magnets, are considered nonmagnetic. Nonmagnetic materials are not able to become magnetized. You will find additional information on the basic principles of magnetism in the Navy Electricity and Electronics Training Series (NEETS), Module 1, NAVEDTRA 14173.

ELECTRICITY

Electricity is a combination of a force called voltage and the movement of invisible particles known as current. The force of voltage can be compared to the force generated by a water pump, which moves water through a distribution system, generally an arrangement of pipes. Voltage is the force that causes current to flow through a system of wires. Current is the movement of invisible particles that causes electrical devices to operate. We cannot see current, but we can determine its presence by the effects it produces. For example, *Figure 2-2* shows the effect of current. It shows how the voltage force from a battery causes electrical current to flow through wires and an electrical motor. The current is invisible, but it produces the effect of making the motor run. Current flows through the wires much the same way as water flows through pipes.
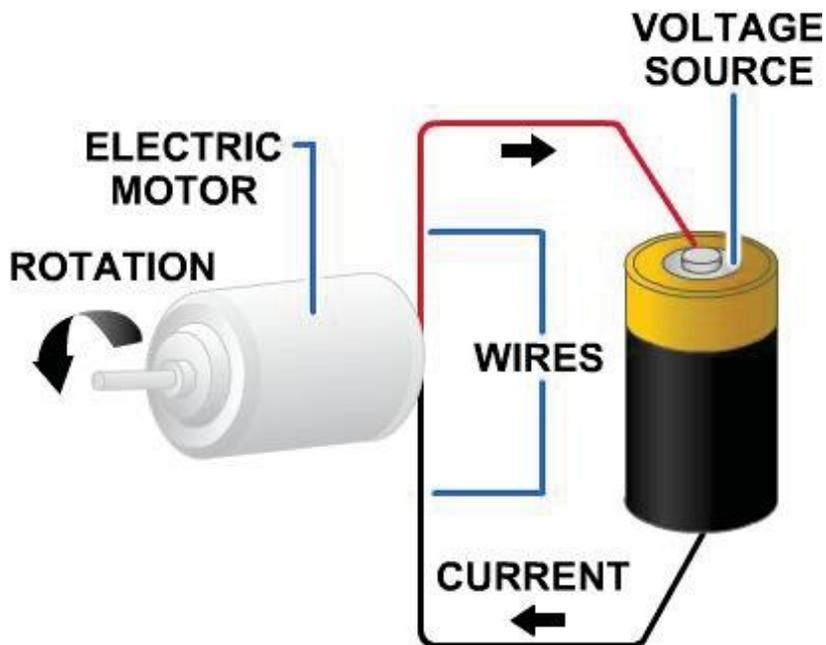

Figure 2-2 — The effect of current.

Current consists of electrons, which are invisible atomic particles. Voltage is the force that causes current, in the form of electrons, to move through wires and electrical devices. However, one important difference between current in wires and water in pipes is that water can flow out of a broken pipe, but current cannot flow out of a broken wire. When a wire is broken, the force of the voltage is removed from the motor, as shown in *Figure 2-3*. The circulating pump in the working system creates a force that moves hot water through the pipes and radiator. The battery creates a force that moves current through the wires and causes the motor to run. The wire and pipe are broken open in the broken system. In these instances, the circulating pump forces water to flow out of the pipe, but even though the battery still creates a voltage force, current does not flow out of the wire. You will find additional information on the basic principles of electricity in the NEETS, module 1, NAVEDTRA 172-01-00-88, chapter 1.

OHM'S LAW

In the early part of the 19th century, George Simon Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship is called Ohm's law and is stated as follows:

$I = E/R$, where: I = current in amperes, E = voltage in volts, and R = resistance in ohms.

As stated in Ohm's law, current is inversely proportional to resistance. This means, as the resistance in a circuit increases, the current decreases proportionately. In the equation $I = E/R$, if any two quantities are known, the third one can be determined.

NEWTON'S LAWS

Sir Isaac Newton was an English philosopher and mathematician who lived from 1642 to 1727 A.D. He was the formulator of the basic laws of modern philosophy concerning gravity and motion. Before we discuss motion and other related factors, you should be familiar with Newton's laws. These laws are the bases for the theories of physics that we describe in the following sections.

Newton's First Law

Newton's first law (*Figure 2-4, view A*) states, "A body (mass) at rest tends to remain at rest, and a body in motion tends to move at a constant speed, in a straight line unless acted upon by some external force."

Newton's Second Law

Figure 2-3 — Different characteristics of current and water.

Newton's second law (*Figure 2-4, view B*) states, "An unbalance of force on a body tends to produce an acceleration in the direction of force, and that acceleration, if any, is directly proportional to the force and inversely proportional to the mass of the body."

Newton's Third Law

His third law (*Figure 2-4, view C*) states that "for every acting force (action) there is an equal and opposite reacting force (reaction)." The action and reaction are simultaneous, and it does not matter which is the action and which is the reaction—both forces are a part of a single interaction, and neither force exists without the other.

In an airplane, the greater the mass of air handled by the engine, the more it is accelerated by the engine. The force built up to thrust the plane forward is also greater. In a gas turbine, the thrust velocity can be absorbed by the turbine rotor and converted to mechanical energy. This conversion is done by the addition of more and progressively larger power turbine wheels.
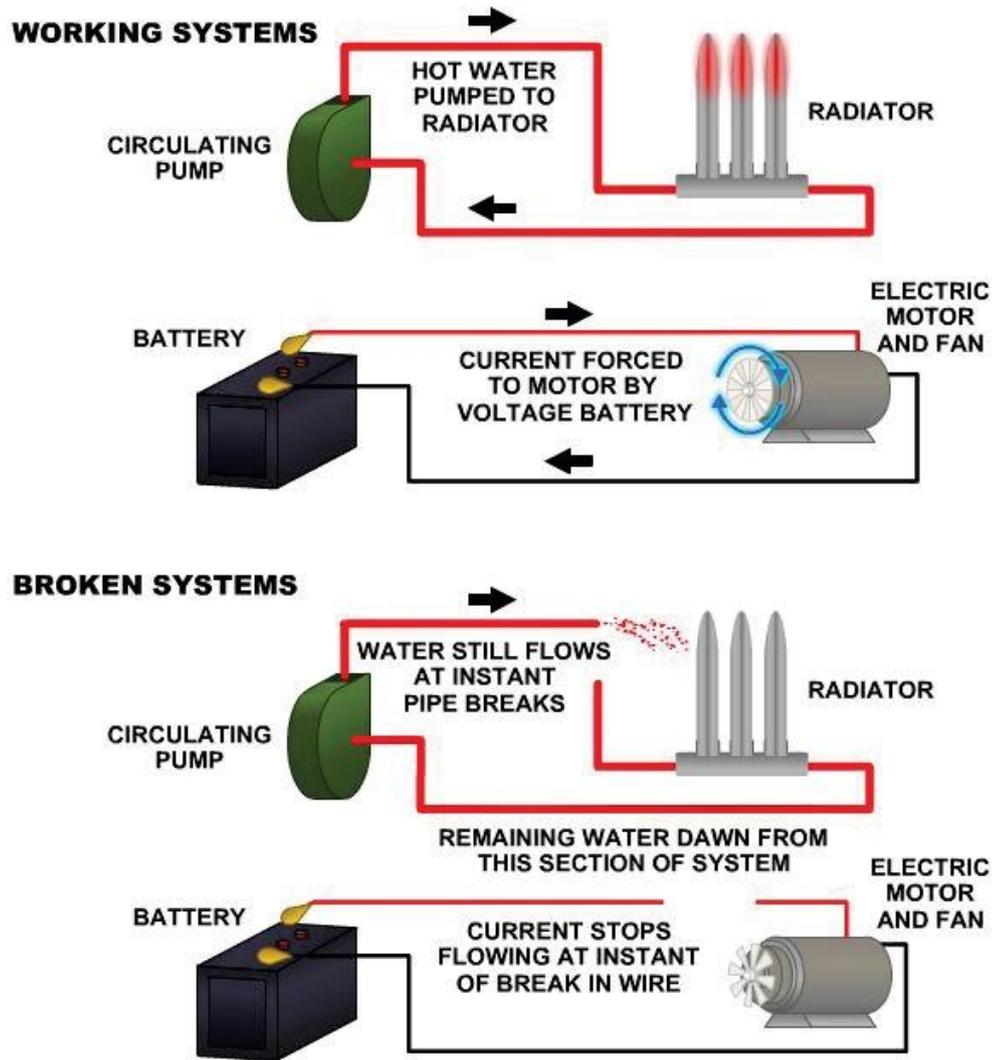
SPEED, VELOCITY, AND ACCELERATION

Speed is defined as the distance covered per unit of time, such as a car traveling at 60 miles per hour (mph). Velocity is speed in a certain direction, such as a car traveling due north at 60 mph. acceleration is the rate at which velocity increases. If, for example, the propeller shaft rate of rotation increases from stop to 100 revolutions per minute (rpm) in 20 minutes, the acceleration is 5 rpm. In other words, the velocity has increased 5 rpm during each minute, for a total period of 20 minutes. A body moving at a constant speed has no acceleration. When the velocity of an object increases by the same amount each second or minute, you have uniform acceleration. Uniform deceleration occurs when the decrease in velocity is the same each second or minute.

MASS, WEIGHT, FORCE, AND INERTIA

Very few terms are used in physics with greater frequency and assurance than mass, and fewer are more difficult to define. Mass is often confused with weight. This mistake is made common because the unit of measurement for both mass and weight is the gram. The mass of an object is the quantity of matter that the object contains. The weight of the object is equal to the gravitational force with which the object is attracted to the Earth. Force is what makes an object start to move, speed up, slow down, or keep moving against resistance. Force may be either a push or a pull. You exert a force when you push against a truck, whether you move the truck or only try to move it. You also exert a force when you pull on a heavy piano, whether you move the piano or only try to move it. Forces can produce or prevent motion.

Figure 2-4 — Newton's three laws.

A tendency to prevent motion is the frictional resistance offered by an object. This frictional resistance is called frictional force. While it can never cause an object to move, it can check or stop motion. Frictional force wastes power, creates heat, and causes wear. Although frictional force cannot be entirely eliminated, it can be reduced with lubricants.

Inertia is the property that causes objects at rest to remain at rest and objects in motion to remain in motion until acted upon by an outside force. An example of inertia is one body that has twice as much mass as another body of the same material, offering twice as much force in opposition to the same acceleration rate.
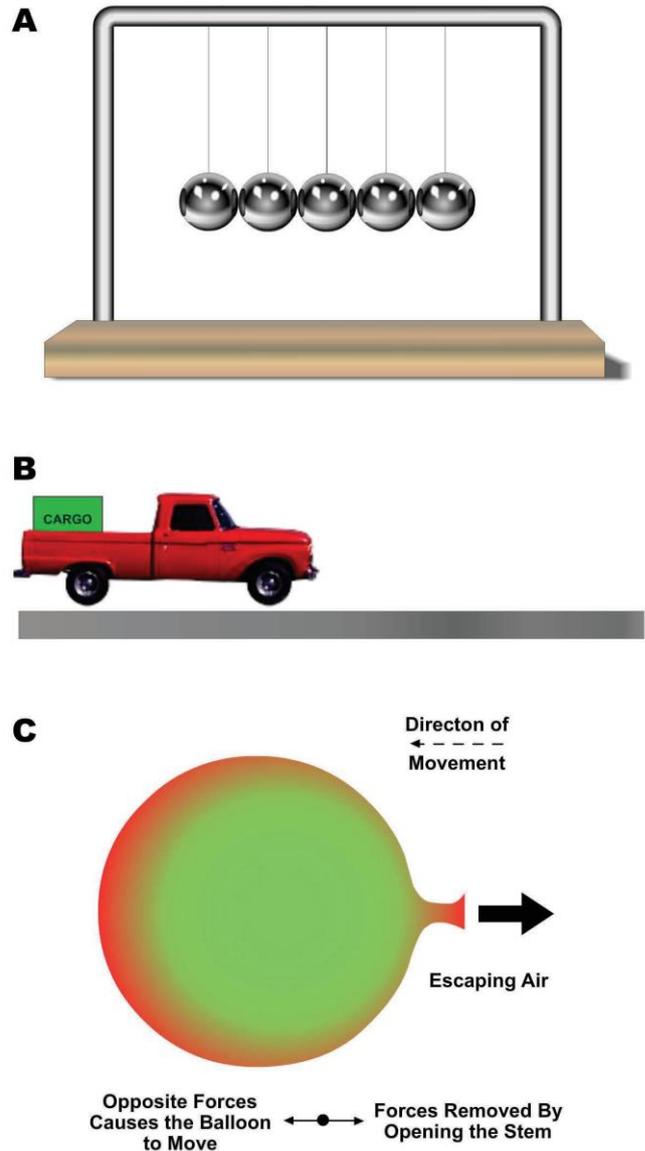
Inertia in a body depends on its motion. The physical principles of mass and inertia are involved in the design and operation of the heavy machinery that is to be placed into motion, such as an engine's flywheel and various gears that are at work in the ship's engineering plant. The great mass of the flywheel tends to keep it rotating once it has been set in motion. The high inertia of the flywheel keeps it from responding to small fluctuations in speed and thus helps keep the engine running smoothly.

ENERGY

Can you define energy? Although everyone has a general idea of the meaning of energy, a good definition is hard to find. Energy is perhaps most commonly defined as the capacity for doing work. However, this definition is not very complete. Energy can produce other effects that cannot possibly be considered work. For example, heat can flow from one object to another without doing work; yet heat is a form of energy, and the process of heat transfer is a process that produces an effect. A better definition of energy, therefore, states that energy is the capacity for producing an effect.

Energy exists in many forms. For convenience, we usually classify energy according to the size and nature of the bodies or particles with which it is associated. Thus, we say that mechanical energy is the energy associated with large bodies or objects—usually, things that are big enough to see. Thermal energy is energy associated with molecules. Chemical energy is energy that arises from the forces that bind the atoms together in a molecule. Chemical energy is demonstrated whenever combustion or any other chemical reaction takes place. Electrical energy (light, x rays, and radio waves) is associated with particles that are even smaller than atoms.

Mechanical energy, thermal energy, and chemical energy must also be classified as being either stored energy or energy in transition.

Stored energy can be thought of as energy that is actually contained in or stored in a substance or system. There are two kinds of stored energy: (1) potential energy and (2) kinetic energy. When energy is stored in a substance or system because of the relative positions of two or more objects or particles, we call it potential energy. When energy is stored in a substance or system because of the relative velocities of two or more objects or particles, we call it kinetic energy.

Mechanical energy in transition is called work. Thermal energy in transition is called heat. In the next section, we will discuss mechanical and thermal energy and energy transformations.

If you do not completely understand this classification, come back to it from time to time as you read the following sections on mechanical energy and thermal energy. The examples and discussion given in the following sections will probably help you understand this classification.

Mechanical Energy

Consider the two stored forms of mechanical energy. Mechanical potential energy exists because of the relative positions of two or more objects. For example, a rock resting on the edge of a cliff in such a position that it will fall freely if pushed has mechanical potential energy. Water at the top of a dam has mechanical potential energy. A sled that is being held at the top of an icy hill has mechanical potential energy.

Mechanical kinetic energy exists because of the relative velocities of two or more objects. If you push that rock, open the gate of the dam, or let go of the sled, something will move. The rock will fall; the water will flow; the sled will slide down the hill. In each case, the mechanical potential energy will be changed to mechanical kinetic energy. Another way of saying this is that the energy of position will be changed to the energy of motion.

In these examples, you will notice that an external source of energy is used to get things started. Energy from some outside source is required to push the rock, open the gate of the dam, or let go of

the sled. All real machines and processes require this kind of boost from an energy source outside the system. For example, a tremendous amount of chemical energy is stored in fuel oil; but this energy will not turn the power turbine until you have expended some energy to start the oil burning. Similarly, the energy in any one system affects other energy systems. However, it is easier to learn the basic principles of energy if we forget about all the energy systems that might be involved in or affected by each energy process. In the examples given in this chapter, therefore, we will consider only one energy process or energy system at a time, disregarding both the energy boosts that may be received from outside systems and the energy transfers that may take place between the system we are considering and other systems.

Notice that both mechanical potential energy and mechanical kinetic energy are stored forms of energy. It is easy to see why we regard mechanical potential energy as being stored, but it is not so easy to see the same thing about mechanical kinetic energy. Part of the trouble comes about because mechanical kinetic energy is often referred to as the energy of motion, thus leading to the false conclusion that energy in transition is somehow involved. This is not the case, however. Work is the only form of mechanical energy that can be properly considered as energy in transition.

If you have trouble with the idea that mechanical kinetic energy is stored, rather than in transition, think of it like this: A bullet that has been fired from a gun has mechanical kinetic energy because it is in motion. The faster the bullet is moving, the more kinetic energy it has. There is no doubt in anybody's mind that the bullet has the capacity to produce an effect, so we may safely say that it has energy. Although the bullet is not in transition, the energy of the bullet is not transferred to any other object or system until the bullet strikes some object that resists its passage. When the bullet strikes against a resisting object, then, and only then, can we say that energy in transition exists, in the form of heat and work.

In this example, we are ignoring the fact that some work is done against the resistance of the air and that some heat results from the passage of the bullet through the air. But this does not change the basic idea that kinetic energy is stored energy rather than energy in transition. The air must be regarded as a resisting object, which causes some of the stored kinetic energy of the bullet to be converted into energy in transition (heat and work) while the bullet is passing through the air. However, the major part of the stored kinetic energy does not become energy in transition until the bullet strikes an object firmer than the air that resists its passage.

Mechanical potential energy is measured in foot-pounds (ft. lb). Consider, for example, the rock at the top of the cliff. If the rock weighs 5 pounds and if the distance from the rock to the earth at the base of the cliff is 100 feet, 500 ft. lb of mechanical potential energy exists because of the relative positions of the rock and the earth. Another way of expressing this idea is by the following formula:

$PE = WxD$, where: $PE =$ total potential energy of the object (in $ft - lb$),
$W =$ total weight of the object (in pounds), $D =$ distance between the earth and the object (in feet).

Mechanical kinetic energy is also measured in foot-pounds. The amount of kinetic energy present at any one time is directly related to the velocity of the moving object and to the weight of the moving object.

Mechanical potential energy can be changed into mechanical kinetic energy. If you push that 5-pound rock over the edge of the 100-foot cliff, it begins to fall, and as it falls, it loses potential energy and gains kinetic energy. At any given moment, the total mechanical energy (potential plus kinetic) stored in the system is the same—500 ft. lb. But the proportions of potential energy and kinetic energy are changing all the time as the rock is falling. Just before the rock hits the earth, all the stored mechanical energy is kinetic energy. As the rock hits the earth, the kinetic energy is changed into energy in transition—that is, work and heat.

Mechanical kinetic energy can likewise be changed into mechanical potential energy. For example, suppose you throw a baseball straight up in the air. The ball has kinetic energy while it is in motion, but the kinetic energy decreases and the potential energy increases as the ball travels upward. When the ball has reached its uppermost position, just before it starts its fall back to earth, it has only potential energy. Then, as it falls back toward the earth, the potential energy is changed into kinetic energy again.

Mechanical energy in transition is called work. When an object is moved through a distance against a resisting force, we say that work has been done. The formula for calculating work is

$W = FxD$, where: $W = work$, $F = force$, and $D = distance$.

As you can see from this formula, you need to know how much force is exerted and the distance through which the force acts before you can find how much work is done. The unit of force is the pound. When work is done against gravity, the force required to move an object is equal to the weight of the object. Why? Because weight is a measure of the force of gravity or, in other words, a measure of the force of attraction between an object and the earth. How much work will you do if you lift that 5-pound rock from the bottom of the 100-foot cliff to the top? You will do 500 ft. lb of work—the weight of the object (5 pounds) times the distance (100 feet) that you move it against gravity.

We also do work against forces other than the force of gravity. When you push an object across the deck, you are doing work against friction. In this case, the force you work against is not only the weight of the object but also the force required to overcome friction and slide the object over the surface of the deck.

Notice that mechanical potential energy, mechanical kinetic energy, and work are all measured in the same unit, ft. lb. One ft. lb of work is done when a force of 1 pound acts through a distance of 1 foot. One ft. lb of mechanical potential energy or mechanical kinetic energy is the amount of energy that is required to accomplish 1 ft. lb of work.

The amount of work done has nothing at all to do with how long it takes to do it. When you lift a weight of 1 pound through a distance of 1 foot, you have done 1 ft. lb of work, regardless of whether you do it in half a second or half an hour. The rate at which work is done is called power. The common unit of measurement for power is the horsepower (hp). By definition, 1 hp is equal to 33,000 ft. lb of work per minute or 550 ft. lb of work per second. Thus, a machine that is capable of doing 550 ft. lb of work per second is said to be a 1 hp machine. (As you can see, your horsepower rating would not be very impressive if you did 1 ft. lb of work in half an hour. Figure it out—it works out to be just a little more than one-millionth of a horsepower.)

Thermal Energy

Earlier in this chapter we discussed molecules. You should remember that all substances are composed of very small particles called molecules. The energy associated with molecules is called thermal energy. Thermal energy, like mechanical energy, exists in two stored forms and in one transitional form. The two stored forms of thermal energy are (1) internal potential energy and (2) internal kinetic energy. Thermal energy in transition is called heat.

Although molecules are too small to be seen, they behave in some ways pretty much like the larger objects we considered in the discussion of mechanical energy. Molecules have energy of position (internal potential energy) because of the forces that attract molecules to each other. In this way, they are somewhat like the rock and the earth we considered before. Molecules have energy of motion (internal kinetic energy) because they are constantly in motion. Thus, the two stored forms of thermal energy—internal potential energy and internal kinetic energy—are in some ways similar to mechanical potential energy and mechanical kinetic energy, except everything is on a smaller scale.

For most purposes, we will not need to distinguish between the two stored forms of thermal energy. Therefore, instead of referring to internal potential energy and internal kinetic energy, from now on we will simply use the term internal energy. By internal energy, then, we will mean the total of all internal energy stored in the substance or system because of the motion of the molecules and because of the forces of attraction between molecules. Although the term may be unfamiliar to you, you probably know more about internal energy than you realize. Because molecules are constantly in motion, they exert a pressure on the walls of the pipe, cylinder, or other object in which they are contained. Also, the temperature of any substance arises from, and is directly proportional to, the activity of the molecules. Therefore, every time you read thermometers and pressure gauges, you are finding out something about the amount of internal energy contained in the substance. High pressures and temperatures indicate that the molecules are moving rapidly and that the substance, therefore, has a lot of internal energy.

Heat is a more familiar term than internal energy, but may actually be more difficult to define correctly. The important thing to remember is that heat is thermal energy in transition—that is, it is thermal energy that is moving from one substance or system to another.

An example will help to show the difference between heat and internal energy. Suppose there are two equal lengths of pipe made of identical materials and containing steam at the same pressure and temperature. One pipe is well insulated; the other is not insulated at all. From everyday experience you know that more heat will flow from the uninsulated pipe than from the insulated pipe. When the two pipes are first filled with steam, the steam in one pipe contains exactly as much internal energy as the steam in the other pipe. We know this is true because the two pipes contain equal volumes of steam at the same pressure and at the same temperature. After a few minutes, the steam in the uninsulated pipe will contain much less internal energy than the steam in the insulated pipe, as we can tell by measuring the pressure and the temperature of the steam in each pipe. What has happened? Stored thermal energy—internal energy—has moved from one system to another, first from the steam to the pipe, then from the uninsulated pipe to the air. This movement or flow of thermal energy from one system to another is called heat.

A good deal of confusion exists concerning the use of the word heat. For example, you will hear people say that a hot object contains a lot of heat when they really mean that it contains a lot of internal energy. Or you will hear that heat is added to or removed from a substance. Because heat is the flow of thermal energy, it can no more be added to a substance than the flow of water could be added to a river. (You might add water, and this addition might increase the flow, but you could hardly say that you added flow.) The only thermal energy that can in any sense be added to or removed from a substance is internal energy.

Energy Transformations

The machinery and equipment in the engineering plant aboard ship are designed either to carry energy from one place to another or to change a substance from one form to another. The principles of energy transformations and some of the important energy changes that occur in the shipboard propulsion cycle are discussed in the following paragraphs.

Conservation of Energy

The basic principle dealing with the transformation of energy is the principle of the conservation of energy. This principle can be stated in several ways. Most commonly, perhaps, it is stated that energy can be neither destroyed nor created, but only transformed. Another way to state this principle is that the total quantity of energy in the universe is always the same. Another way of expressing this principle is through an equation: energy in = energy out.

The energy out may be quite different in form from the energy in, but the total amount of energy input must always equal the total amount of energy output.

Another principle, the principle of the conservation of matter, states that matter can be neither created nor destroyed, but only transformed. As you probably know, the development of the atom bomb demonstrated that matter can be converted into energy; other developments have demonstrated that energy can be converted into matter. Therefore, the principle of the conservation of energy and the principle of the conservation of matter are no longer considered as two parts of a single law or principle but are combined into one principle. That principle states that matter and energy are interchangeable, and the total amount of energy and matter in the universe is constant.

The interchangeability of matter and energy is mentioned here only to point out that the statement "energy in must equal energy out" is not strictly true for certain situations. However, any noticeable conversion of matter into energy or energy into matter can occur only under very special conditions, which we need not consider now. All the energy transformations that we will deal with can be understood quite simply if we consider only the principle of the conservation of energy—that is, energy in equals energy out.

Transformation of Heat to Work (Laws of Gases)

The energy transformation from heat to work is the major interest in the shipboard engineering plant. To see how this transformation occurs, we need to consider the pressure, temperature, and volume relationships that hold true for gases.

Robert Boyle, an English scientist, was among the first to study the compressibility of gases. In the middle of the 17th century, he called it the "springiness" of air. He discovered that when the temperature of an enclosed sample of gas was kept constant and the pressure doubled, the volume was reduced to half the former value. As the applied pressure was decreased, the resulting volume increased. From these observations he concluded that for a constant temperature, the product of the volume and pressure of an enclosed gas remains constant. This conclusion became Boyle's law.

You can demonstrate Boyle's law by confining a quantity of gas in a cylinder that has a tightly fitted piston. Apply force to the piston to compress the gas in the cylinder to some specific volume. If you double the force applied to the piston, the gas will compress to one-half its original volume (*Figure 2-5*).

Changes in the pressure of a gas also affect the density. As the pressure increases, its volume decreases; however, no change occurs in the weight of the gas. Therefore, the weight per unit volume (density) increases. So, the density of a gas varies directly as the pressure if the temperature is constant.
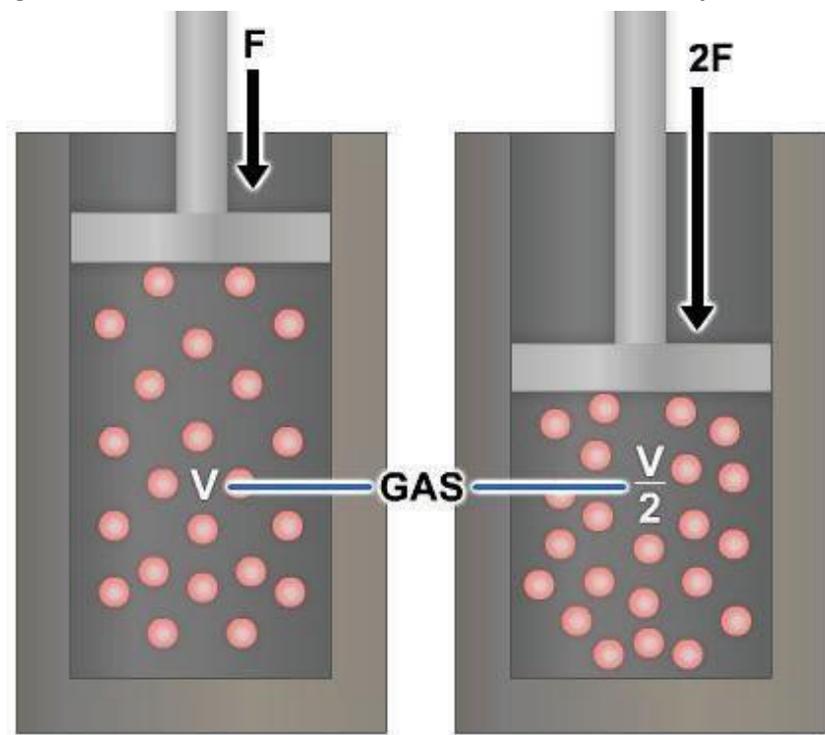

Figure 2-5 — Compressibility of gas.

In 1787, Jacques Charles, a Frenchman, proved that all gases expand the same amount when heated 1 degree if the pressure is kept constant. The relationships that these two men discovered are summarized as follows:

- Boyle's law—when the temperature is held constant, an increase in the pressure on a gas causes a proportional decrease in volume. A decrease in the pressure causes a proportional increase in volume, as shown in *Figure 2-6*. At sea level, the balloon has a given volume with respect to temperature and atmospheric pressure. As the balloon descends 1 mile below sea level, the volume of the balloon decreases due to increased atmospheric pressure. Conversely, as the balloon ascends to 1 mile above sea level, the balloon expands as the atmospheric pressure decreases.

- Charles's law
    o When the pressure is held constant, an increase in the temperature of a gas causes a proportional increase in volume. A decrease in the temperature causes a proportional decrease in volume, as shown in *Figure 2-7*. Balloons A and B have an outside
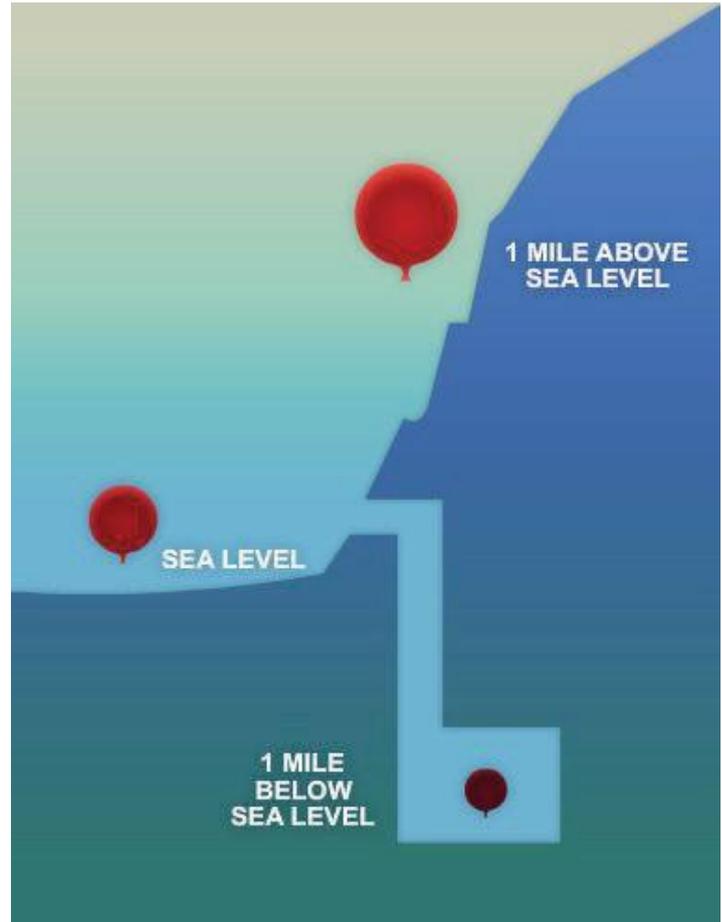

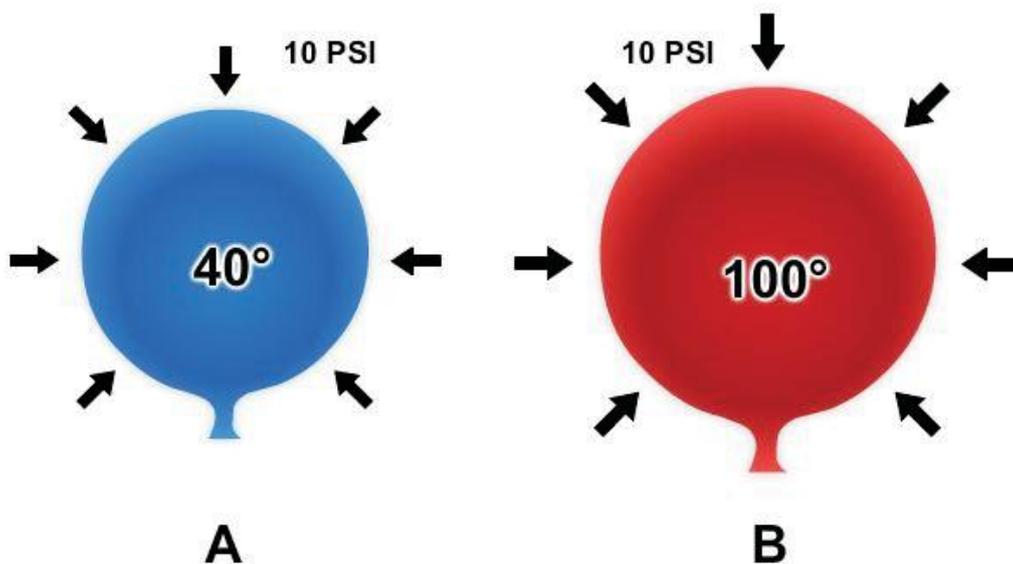**Figure 2-6 — Pressure differential in respect to sea level.**

Figure 2-7 — Pressure differential in respect to temperature.

pressure of 10 pounds per square inch (psi). Both have the same volume of air. Balloon A is at 40 degrees Fahrenheit (°F) and balloon B is at 100 °F. This example shows that increased temperature causes the balloon size to increase

o   When the volume is held constant, an increase in the temperature of a gas causes a proportional increase in pressure. A decrease in the temperature causes a proportional decrease in pressure, as shown in *Figure 2-8*. Tanks A and B are of the same size and have an equal volume of gas. Tank A has a pressure of 10 psi when heated to 40 °F. Tank B has a pressure of 12 psi when heated to 100 °F. Unlike the balloons, the steel tanks do not expand to accommodate the changes in temperature and pressure. This example shows that changes in temperature are inversely proportional to changes in gas pressure when the volume is held constant.

Suppose we have a boiler in which steam has been formed. With the steam stop valves still closed, the volume of the steam remains constant while the pressure and the temperature are both increasing. When operating pressure is reached and the steam stop valves are opened, the high pressure of the steam causes the steam to flow to the turbines. The pressure of the steam thus provides the potential for doing work. The actual conversion of thermal energy to work is done in the turbine section.
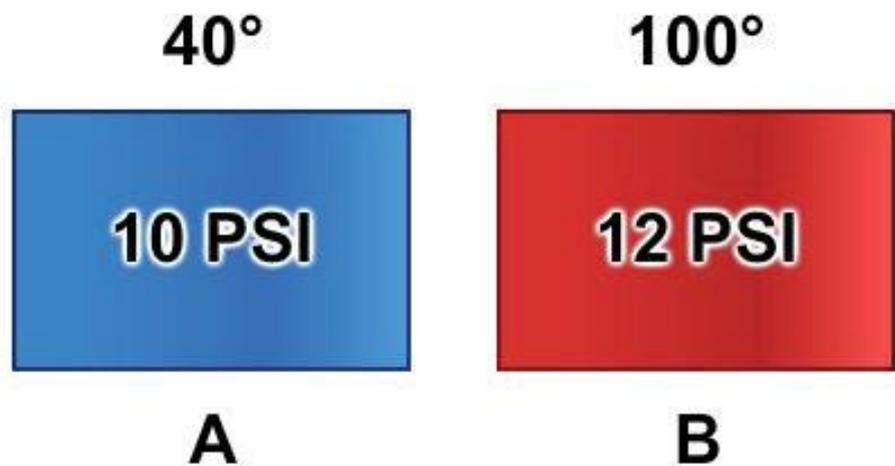

Figure 2-8 — Interaction of gases in respect to temperature and pressure.

Steam

Steam is water to which enough heat has been added to convert it from the liquid to the gaseous state. When heat is added to water in an open container, steam forms. However, it quickly mixes with air and cools back to water that is dispersed in the air, making the air more humid. If you add the heat to water in a closed container, the steam builds up pressure. If you add exactly enough heat to convert all the water to steam at the temperature of boiling water, you get saturated steam. Saturated steam is steam saturated with all the heat it can hold at the boiling temperature of water.

The boiling temperature of water becomes higher as the pressure over the water becomes higher. Steam hotter than the boiling temperature of water is called superheated steam. When steam has 250 °F of superheat, the actual temperature is the boiling temperature plus 250 °F. At 600 psi, the boiling temperature of water is 489 °F. So, if steam at 600 psi has 250 °F of superheat, its actual temperature is 739 °F. Wet steam is steam at the boiling temperature that still contains some water particles. Desuperheated steam is steam that has been cooled by being passed through a pipe extending through the steam drum. In the process, the steam loses all but 20 to 30 °F of its superheat. The advantage of desuperheated steam is that it is certain to be dry, yet not so hot as to require special alloy steels for the construction of the piping that carries the desuperheated steam about the ship.

Combustion

Combustion refers to the rapid chemical union of oxygen with fuel. Perfect combustion of fuel would result in carbon dioxide, nitrogen, water vapor, and sulphur dioxide. The oxygen required to burn the fuel is obtained from the air. Air is a mechanical mixture containing by weight 21 percent oxygen, 78 percent nitrogen, and 1 percent other gases. Only oxygen is used in combustion. Nitrogen is an inert gas that has no chemical effect upon combustion.

The chemical combination obtained during combustion results in the liberation of heat energy. A portion of this energy is used to propel the ship. What actually happens is a rearrangement of the atoms of the chemical elements into new combinations of molecules. In other words, when the fuel oil temperature (in the presence of oxygen) is increased to the ignition point, a chemical reaction occurs. The fuel begins to separate and unite with specific amounts of oxygen to form an entirely new substance. Heat energy is given off in the process. A good fuel burns quickly and produces a large amount of heat.

Although perfect combustion is the objective, it has been impossible to achieve as yet in either a boiler or the cylinders of an internal-combustion engine. Theoretically, it is simple. It consists of bringing each particle of the fuel (heated to its ignition temperature) into contact with the correct amount of oxygen. The following factors are involved:

- Sufficient oxygen must be supplied

- The oxygen and fuel particles must be thoroughly mixed

- Temperatures must be high enough to maintain combustion

- Enough time must be allowed to permit completion of the process

Complete combustion can be achieved and is accomplished by more oxygen being supplied to the process than would be required if perfect combustion were possible. The result is that some of the excess oxygen appears in the combustion gases.

Units of Heat Measurement

Both internal energy and heat are measured using the British thermal unit (Btu). For most practical engineering purposes, 1 Btu is the thermal energy required to raise the temperature of 1 pound of pure water to 1°F. Burning a wooden kitchen match completely will produce about 1 Btu.

When large amounts of thermal energy are involved, it is usually more convenient to use multiples of the Btu. For example, 1Kilo British Thermal Unit (kBtu) is equal to 1,000 Btu, and 1 Million British Thermal Units (MBtu) is equal to 1 Btu.

Another unit in which thermal energy may be measured is the calorie. The calorie is the amount of heat required to raise the temperature of 1 gram of pure water 1 degree Celsius (°C). One Btu equals 252 calories.

Sensible Heat and Latent Heat

Sensible heat and latent heat are terms often used to indicate the effect that the flow of heat has on a substance. The flow of heat from one substance to another is normally reflected in a temperature change in each substance—the hotter substance becomes cooler, the cooler substance becomes hotter. However, the flow of heat is not reflected in a temperature change in a substance that is in the process of changing from one physical state (solid, liquid, or gas) to another. When the flow of heat is reflected in a temperature change, we say that sensible heat has been added to or removed from the substance (heat that can be sensed or felt). When the flow of heat is not reflected in a temperature

change but is reflected in the changing physical state of a substance, we say that latent heat has been added or removed.

Does anything bother you in this last paragraph? It should. Here we are talking about sensible heat and latent heat as though we had two different types of heat to consider. This is common (if inaccurate) engineering language. So keep the following points clearly in mind: (1) heat is the movement (flow) of thermal energy; (2) when we talk about adding and removing heat, we really mean that we are providing temperature differentials so thermal energy can flow from one substance to another; and (3) when we talk about sensible heat and latent heat, we are talking about two different kinds of effects that can be produced by heat, but not about two different types of heat.

As previously discussed, the three basic physical states of all matter are solid, liquid, and gas (or vapor). The physical state of a substance is closely related to the distance between molecules. As a general rule, the molecules are closest together in solids, farther apart in liquids, and farthest apart in gases. When heat flow to a substance is not reflected in a temperature increase in that substance, the energy is being used to increase the distance between the molecules of the substance and to change it from a solid to a liquid or from a liquid to a gas. You might say that latent heat is the energy price that must be paid for a change of state from solid to liquid or from liquid to gas. The energy is not lost. It is stored in the substance as internal energy. The energy price is repaid, so to speak, when the substance changes back from gas to liquid or from liquid to solid because heat flows from the substance during these changes of state.

The relationship between sensible heat and latent heat for water at atmospheric pressure is shown in *Figure 2-9*. The same kind of chart could be drawn for other substances; however, different amounts of thermal energy would be involved in the changes of state for each substance.

If we start with 1 pound of ice at 0 °F, we must add 16 Btu to raise the temperature of the ice to 32 °F. We call this method, adding sensible heat. To change the pound of ice at 32 °F to a pound of water at 32 °F, we must add 144 Btu (the
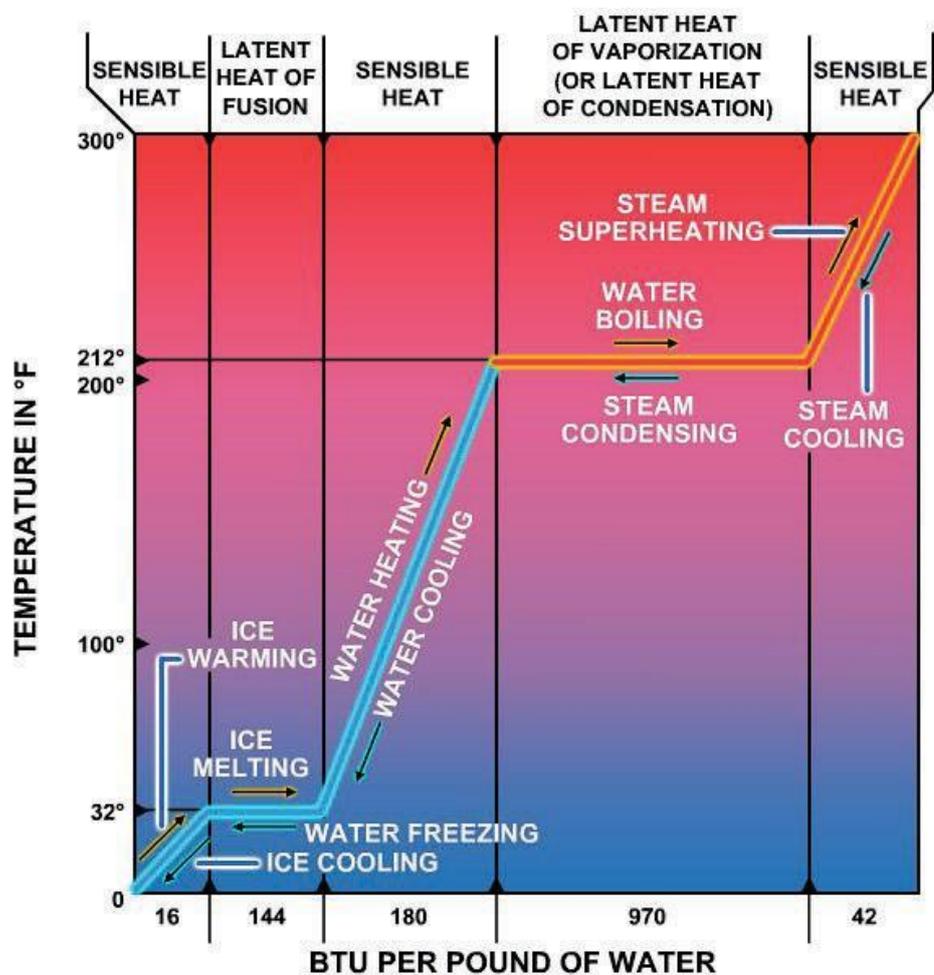

Figure 2-9 — Relationship between sensible heat and latent heat.

2-15

latent heat of fusion). No change in temperature will occur while the ice is melting. After all the ice has melted, however, the temperature of the water will be raised as additional heat is supplied. If we add 180 Btu—that is, 1 Btu for each degree of temperature between 32 and 212 °F—the temperature of the water will be raised to the boiling point. To change the pound of water at 212 °F to a pound of steam at 212 °F, we must add 970 Btu (the latent heat of vaporization). After all the water has been converted to steam, the addition of more heat will cause an increase in the temperature of the steam. If we add about 44 Btu to the pound of steam that is at 212 °F, we can superheat it to 300 °F.

The same relationships apply when heat is being removed. The removal of 44 Btu from the pound of steam that is at 300 °F will cause the temperature to drop to 212 °F. As the pound of steam at 212 °F changes to a pound of water at 212 °F, 970 Btu are given off. When a substance is changing from a gas or vapor to a liquid, the heat that is given off is latent heat of condensation. Notice, however, that the latent heat of condensation is exactly the same as the latent heat of vaporization. The removal of another 180 Btu of sensible heat will lower the temperature of the pound of pure water from 212 to 32 °F. As the pound of water at 32 °F changes to a pound of ice at 32 °F, 144 Btu are given off without any accompanying change in temperature. Further removal of heat causes the temperature of the ice to decrease.

TEMPERATURE

The temperature of an object is a measure of the heat level of that object. This level can be measured with a thermometer.

The temperature scales employed to measure temperature are the Fahrenheit scale and the Celsius scale. In engineering and for practically all purposes in the Navy, the Fahrenheit scale is used. You may, however, have to convert Celsius readings to the Fahrenheit scale, so both scales are explained here.

The Fahrenheit scale has two main reference points—the boiling point of pure water at 212 °F and the freezing point of pure water at 32 °F. The measure of a degree of Fahrenheit is 1/180 of the total temperature change from 32 to 212 °F. The scale can be extended in either direction—to higher temperatures without any limits and to lower temperatures (by minus degrees) down to the lowest temperature theoretically possible, absolute zero. This temperature is – 460 °F, or 492 °F below the freezing point of water.

In the Celsius scale, the freezing point of pure water is 0 °C and the boiling point of pure water is 100 °C. Therefore, 0 and 100 °C are equivalent to 32 and 212 °F, respectively. Each degree of Celsius is larger than a degree of Fahrenheit. Only 100 Celsius degrees are between the freezing and boiling points of water, while this same temperature change requires 180 degrees on the Fahrenheit scale. Therefore, the degree of Celsius is 180/100 or 1.8 °F. In the Celsius scale, absolute zero is – 273 °C. To convert from one temperature scale to another, use the following algebraic equations:

From Fahrenheit to Celsius

$$°C = 5/9 \times (°F - 32)$$

From Celsius to Fahrenheit

$$°F = (9/5 \times °C) + 32$$

Figure 2-10 shows the two temperature scales in comparison. It also introduces the simplest of the temperature measuring instruments, the liquid-in-glass thermometer. The two thermometers shown are exactly alike in size and shape. The only difference is the outside markings or scales on them. Each thermometer is a hollow glass tube that is sealed at the top and has a mercury-filled bulb at the bottom. Mercury, like any liquid, expands when heated and will rise in the hollow tube. *View A of*

Figure 2-10 shows the Fahrenheit thermometer with its bulb standing in melting ice (32 °F), and *view B* shows the Celsius thermometer with its bulb standing in boiling water (100 °C).

The main point to remember is that the level of the mercury in a thermometer depends only on the temperature to which the bulb is exposed. If you were to exchange the thermometers, the mercury in the Celsius thermometer would drop to the level that the mercury now stands in the Fahrenheit thermometer. Likewise, the mercury in the Fahrenheit thermometer would rise to the level that the mercury now stands in the Celsius thermometer. The temperatures would be 0 °C for the ice water and 212 °F for the boiling water.

If you place both thermometers in water containing ice, the Fahrenheit thermometer will read 32 °F and the Celsius thermometer will read 0 °C. Heat the water slowly. The temperature will not change until the ice in the water has completely melted (a great deal of heat is required just to melt the ice). Then both mercury columns will begin to rise. When the mercury level is at the +10°C mark on the Celsius thermometer, it will be at the +50°F mark on the Fahrenheit thermometer. The two columns will rise together at the same speed and, when the water finally boils, they will stand at 100 °C and 212 °F, respectively. The same temperature change—that is, the same amount of heat transferred to the water—has raised the temperature 100 °C and 180 °F, but the actual change in heat energy is exactly the same.

Figure 2-10 — Relationship between sensible heat and latent heat.

PRESSURE DEFINITIONS

Pressure, like temperature, is one of the basic engineering measurements and one that must be frequently monitored aboard ship. As with temperature readings, pressure readings provide you with an indication of the operating condition of equipment. Pressure is defined as the force per unit area.

The simplest pressure units are the ones that indicate how much force is applied to an area of a certain size. These units include pounds per square inch, pounds per square foot, ounces per square inch, newtons per square millimeter, and dynes per square centimeter, depending upon the system you use.
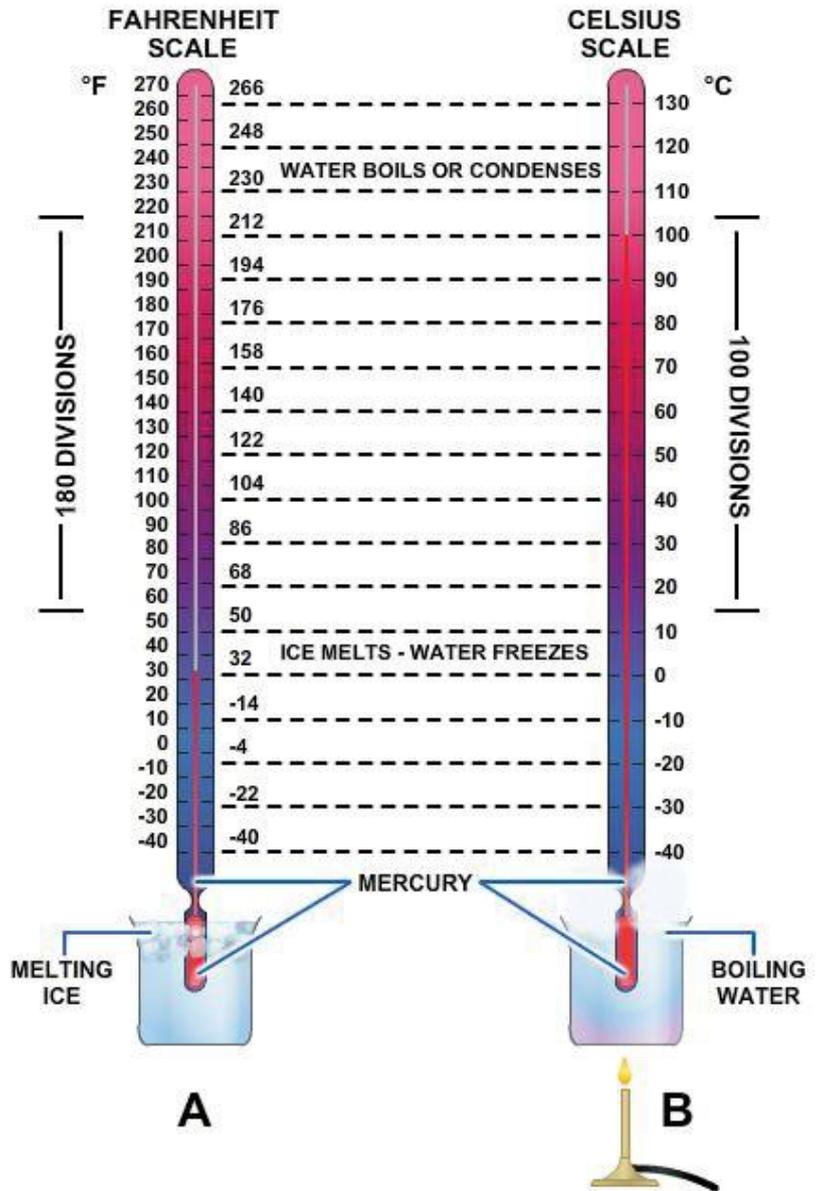
You also use another kind of pressure unit that involves length. These units include inches of water (inH_2O), inches of mercury (inHg), and inches of some other liquid of a known density. Actually, these units do not involve length as a fundamental dimension. Rather, length is taken as a measure of force or weight. For example, a reading of 1 inH_2O means that the exerted pressure is able to support a column of water 1 inch high, or that a column of water in a U-tube would be displaced 1 inch by the pressure being measured. Similarly, a reading of 12 inHg means that the measured pressure is sufficient to support a column of mercury 12 inches high. What is really being expressed (even though it is not mentioned in the pressure unit) is that a certain quantity of material (water, mercury, and so on) of known density exerts a certain definite force upon a specified area. Pressure is still force per unit area, even if the pressure unit refers to inches of some liquid.

In interpreting pressure measurements, a great deal of confusion arises because the zero point on most pressure gauges represents atmospheric pressure rather than zero absolute pressure. Thus, it is often necessary to specify the kind of pressure being measured under any given conditions. To clarify the numerous meanings of the word *pressure,* the relationships among gauge, atmospheric, vacuum, and absolute pressures are shown in *Figure 2-11*.

Gauge pressure is the pressure actually shown on the dial of a gauge that registers pressure relative to atmospheric pressure. An ordinary pressure gauge reading of zero does not mean there is no pressure in the absolute sense; rather, it means there is no pressure in excess of atmospheric pressure.

Figure 2-11 — Relationships among gauge pressure, atmospheric pressure, vacuum, and absolute pressure.

Atmospheric pressure is the pressure exerted by the weight of the atmosphere. At sea level, the average pressure of the atmosphere is sufficient to hold a column of mercury at the height of 76 centimeters or 29.92 inches. Because a column of mercury 1 inch high exerts a pressure of 0.49 psi at its base, a column of mercury 29.92 inches high exerts a pressure that is equal to 29.92 × 0.49, or about 14.7 psi. Because we are dealing now in absolute pressure, we say that the average atmospheric pressure at sea level is 14.7 pounds per square inch absolute (psia). It is zero on the ordinary pressure gauge.

Notice, however, that the figure of 14.7 psia represents the average atmospheric pressure at sea level; it does not always represent the actual pressure being exerted by the atmosphere at the moment a gauge is being read. Because fluctuations from this standard are shown on a barometer (an instrument used to measure atmospheric pressure), the term barometric pressure is used to describe the atmospheric pressure that exists at any given moment. The operating principle of a typical barometer is shown in *Figure 2-12*.
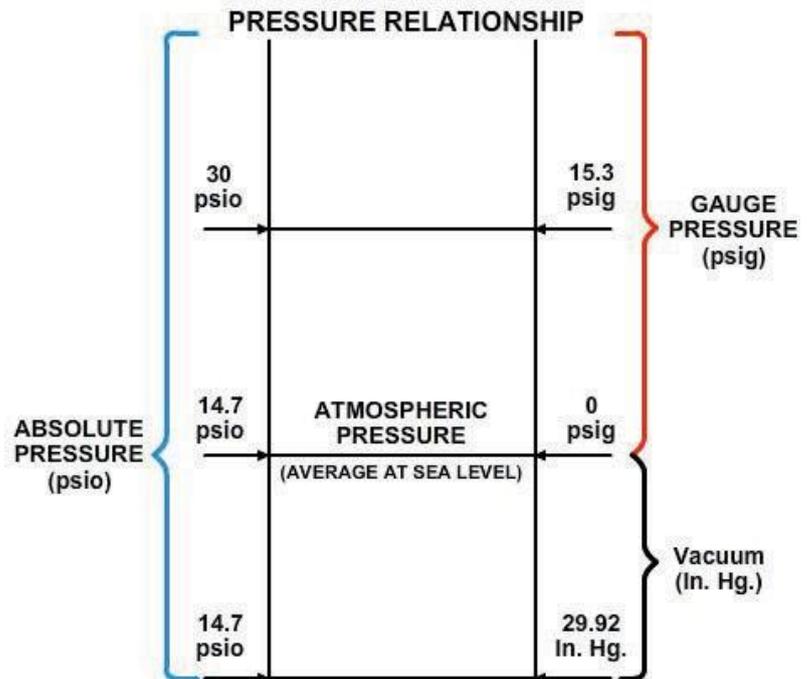
Barometric pressure is the term used to describe the actual atmospheric pressure that exists at any given moment. Barometric pressure may be measured by a simple mercury column or by a specially designed instrument called an aneroid barometer.

A space in which the pressure is less than atmospheric pressure is said to be under partial vacuum. The vacuum is expressed in terms of the difference between the absolute pressure in the space and the pressure of the atmosphere. Most commonly, vacuum is expressed in inches of mercury, with the vacuum gauge scale marked from 0 to 30 inHg. When a vacuum gauge reads zero, the pressure in the space is the same as atmospheric pressure; in other words, there is no vacuum. A vacuum gauge reading of 29.92 inHg would indicate a perfect (or nearly perfect) vacuum. In actual practice, a perfect vacuum is impossible to obtain even under laboratory conditions. A reading between 0 and 29.92 inHg is a partial vacuum.
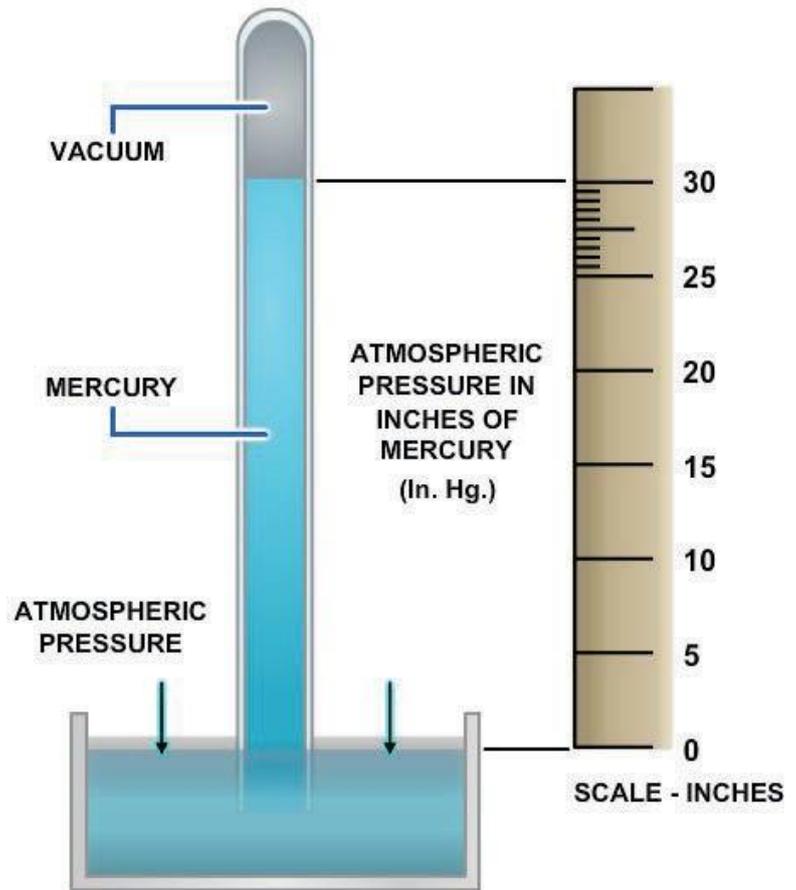

Figure 2-12 — Typical barometer.

Absolute pressure is atmospheric pressure plus gauge pressure, or absolute pressure minus vacuum. For example, a gauge pressure of 300 pounds per square inch gauge (psig) equals an absolute pressure of 314.7 psia (300 + 14.7). Or, for example, consider a space in which the measured vacuum is 10 inHg; the absolute pressure in this space is figured by subtracting the measured vacuum (10 inHg) from the nearly perfect vacuum (29.92 inHg). The absolute pressure then will be 19.92 or about 20 inHg absolute. Note that the amount of pressure in a space under vacuum can only be expressed in terms of absolute pressure.

You may have noticed that sometimes we use the letters psig to indicate gauge pressure and other times we merely use psi. By common convention, gauge pressure is always assumed when pressure is given in pounds per square inch, pounds per square foot, or similar units. The g (for gauge) is added only when there is some possibility of confusion. Absolute pressure, on the other hand, is always expressed as pounds per square inch absolute (psia), pounds per square foot absolute (psfa), and so forth. It is always necessary to establish clearly just what kind of pressure we are talking about, unless this information is very clear from the nature of the discussion.

To this point, we have considered only the most basic and most common units of measurement. Remember that hundreds of other units can be derived from these units; remember also that specialized fields require specialized units of measurement. Additional units of measurement are introduced in appropriate places throughout the remainder of this training manual. When you have more complicated units of measurement, you may find it helpful to review the basic information given here first.

PRINCIPLES OF HYDRAULICS

The word hydraulics is derived from the Greek word for water (hydor) plus the Greek word for a reed instrument similar to oboe (aulos). The term hydraulics originally covered the study of the physical behavior of water at rest and in motion. However, the meaning of hydraulics has been broadened to cover the physical behavior of all liquids, including the oils that are used in modern hydraulic systems. The foundation of modern hydraulics began with the discovery of the following law and principle:

- Pascal's law—this law was discovered by Blaise Pascal, a French philosopher and mathematician who lived from 1623 to 1662 A.D. His law, simply stated, is interpreted as pressure exerted at any point upon an enclosed liquid is transmitted undiminished in all directions. Pascal's law governs the behavior of the static factors concerning noncompressible fluids when taken by themselves.

- Bernoulli's principle—this principle was discovered by Jacques (or Jakob) Bernoulli, a Swiss philosopher and mathematician who lived from 1654 to 1705 A.D. He worked extensively with hydraulics and the pressure-temperature relationship. Bernoulli's principle governs the relationship of the static and dynamic factors concerning noncompressible fluids. *Figure 2-13* shows the effect of Bernoulli's principle. Chamber A is under pressure and is connected by a tube to chamber B, also under pressure. Chamber A is under static pressure of 100 psi. The pressure at some point, X, along the connecting tube consists of a velocity pressure of 10 psi. This pressure is exerted in a direction parallel to the line of flow. Added is the unused static pressure of 90 psi, which obeys Pascal's law and operates equally in all directions. As the fluid enters chamber B from the constricted space, it slows down. In so doing, its velocity head is changed back to pressure head. The force required to absorb the fluid's inertia equals the force required to start the fluid moving originally. Therefore, the static pressure in chamber B is again equal to that in chamber A. It was lower at intermediate point X.
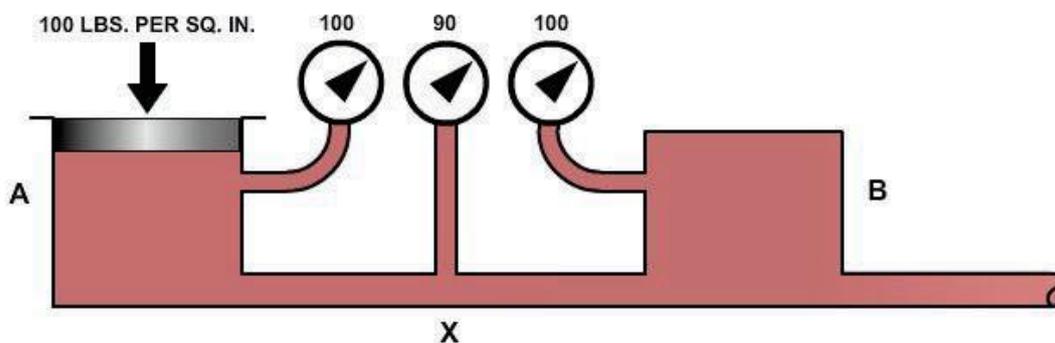

Figure 2-13 — Relationship of static and dynamic factors (Bernoulli's principle).

Figure 2-13 disregards friction, and it is not encountered in actual practice. Force or head is also required to overcome friction. But, unlike the inertia effect, this force cannot be recovered again although the energy represented still exists somewhere as heat. Therefore, in an actual system the pressure in chamber B would be less than in chamber A. This force is a result of the pressure used in overcoming friction along the way. At all points in a system, the static pressure is always the original static pressure less any velocity head at the point in question. It is also less the friction head consumed in reaching that point. Both velocity head and friction represent energy that came from the original static head. Energy cannot be destroyed. So, the sum of the static head, velocity head, and

friction at any point in the system must add up to the original static head. This, then, is Bernoulli's principle; more simply stated, if a noncompressible fluid flowing through a tube reaches a constriction, or narrowing of the tube, the velocity of fluid flowing through the constriction increases, and the pressure decreases.

When we apply a force to the end of a column of confined liquid, the force is transmitted not only straight through to the other end but also equally in every direction throughout the column. This equal distribution is why a flat fire hose takes on a circular cross section when it is filled with water under pressure. The outward push of the water is equal in every direction. Water will leak from the hose at the same velocity, regardless of where the leaks are in the hose.

Let us now consider the effect of Pascal's law in the systems shown in *Figure 2-14, views A and B*. If the total force at the input piston is 100 pounds and the area of the piston is 10 square inches, then each square inch of the piston surface is exerting 10 pounds of force. This liquid pressure of 10 psi is transmitted to the output piston, which will be pushed upward with a force of 10 psi. In this example, we are merely considering a liquid column of equal cross section so the areas of these pistons are equal. All we have done is carry a 100-pound force around a bend. However, the principle shown is the basis for almost all mechanical hydraulics.

EQUAL INPUT AND OUTPUT AREA

The same principle may be applied where the area of the input piston is much smaller than the area of the output piston, or vice versa. In *view B of Figure 2-14*, the area of the input piston is 2 square inches and the area of the output piston is 20 square inches. If you apply a pressure of 20 pounds to the 2-square-inch piston, the pressure created in the liquid will again be 10 psi. The upward force on the larger piston will be 200 pounds—10 pounds for each of its 20 square inches. Thus, you can see that if two pistons are used in a hydraulic system, the force acting on each piston will be directly proportional to its area.
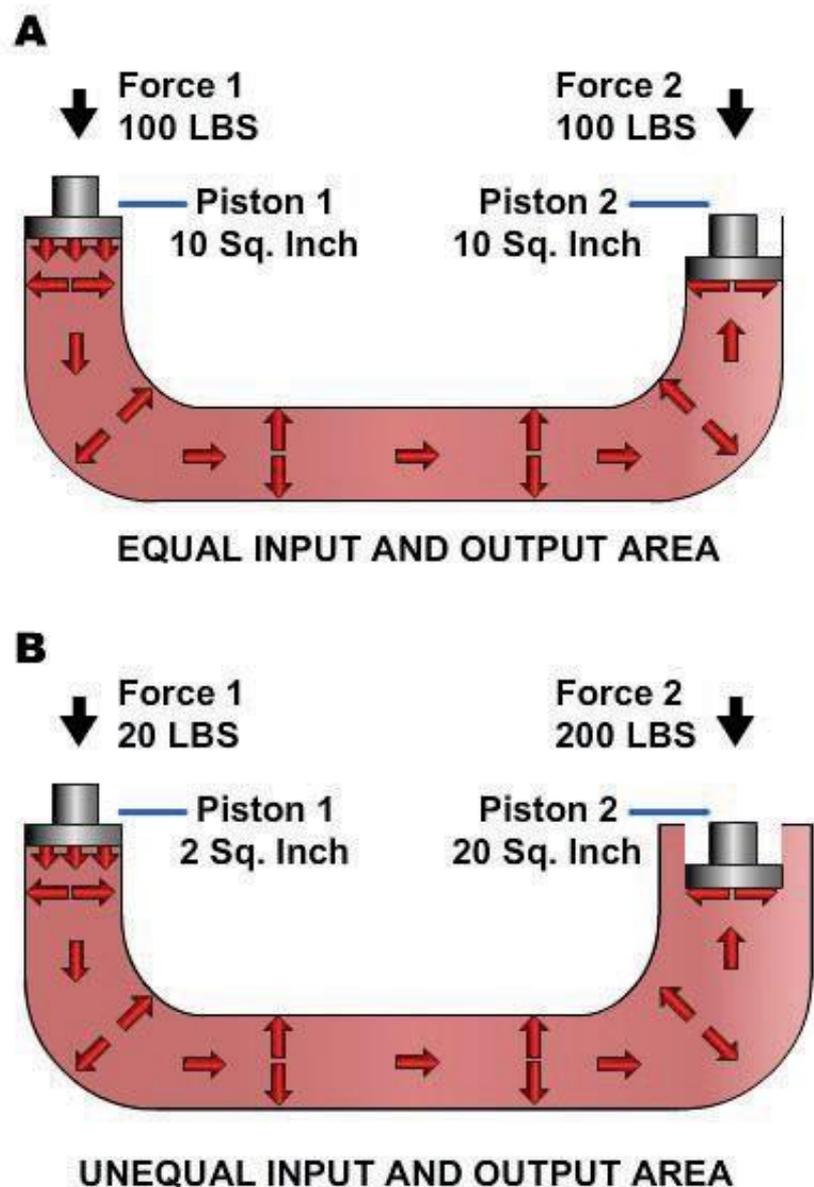

UNEQUAL INPUT AND OUTPUT AREA

Figure 2-14 — Principle of mechanical hydraulics.

PRINCIPLES OF PNEUMATICS

Pneumatics is that branch of mechanics that deals with the mechanical properties of gases. Perhaps the most common application of these properties in the Navy today is the use of compressed air. Compressed air is used to transmit pressure in a variety of applications. For example, in tires and air-cushioned springs, compressed air acts as a cushion to absorb shock. Air brakes on locomotives and large trucks contribute greatly to the safety of railroad and truck transportation. In the Navy, compressed air is used in many ways, for example, tools such as riveting hammers and pneumatic drills are air operated. Automatic combustion control systems use compressed air for the operation of the instruments. Compressed air is also used in diving bells and diving suits. Our following discussion on the use of compressed air as an aid in the control of submarines will help you understand the theory of pneumatics.

Submarines are designed with a number of tanks that may be used for the control of the ship. These tanks are flooded with water to submerge, or they are filled with compressed air to surface.

The compressed air for the pneumatic system is maintained in storage tanks (called banks) at a pressure of 4,500 psi. During surfacing, the pneumatic system delivers compressed air to the desired control tanks (the tanks filled with water). Because the pressure of the air is greater than the pressure of the water, the water is forced out of the tank. As a result, the weight of the ship decreases. The ship becomes more buoyant and rises to the surface.

METALS

As you look around, you see not only that your ship is constructed of metal, but also that the boilers, piping system, machinery, and even your bunk and locker are constructed of some type of metal. No one type of metal can serve all the needs aboard ship. Many types of metals or metal alloys must be used. A strong metal must be used for some parts of a ship, while a lightweight metal is needed for other parts. Some areas require special metal that can be shaped or worked very easily.

The physical properties of some metals or metal alloys make them more suitable for one use than for another. Various terms are used in describing the physical properties of metals. By studying the following explanations of these terms, you should have a better understanding of why certain metals are used on one part of the ship's structure and not on another part.

Brittleness is a property of a metal that will allow it to shatter easily. Metals, such as cast iron or cast aluminum and some very hard steels, are brittle.

Ductility refers to the ability of a metal to stretch or bend without breaking. Soft iron, soft steel, and copper are ductile metals.

Hardness refers to the ability of a metal to resist penetration, wear, or cutting action.

Malleability is a property of a metal that allows it to be rolled, forged, hammered, or shaped without cracking or breaking. Copper is a very malleable metal.

Strength refers to the ability of a metal to maintain heavy loads (or force) without breaking. Steel, for example, is strong, but lead is weak.

Toughness is the property of a metal that will not permit it to tear or shear (cut) easily and will allow it to stretch without breaking.

Metal preservation aboard ship is a continuous operation because the metals are constantly exposed to fumes, water, acids, and moist salt air. All of these elements will eventually cause corrosion. The corrosion of iron and steel is called rusting. This process results in the formation of iron oxide (iron and oxygen) on the surface of the metal. Iron oxide (or rust) can be identified easily by its reddish

color. (A blackish hue occurs in the first stage of rusting but is seldom thought of as rust.) Corrosion can be reduced or prevented by use of better grades of alloyed metals. Chromium and nickel are commonly used. Coating the surface with paint or other metal preservatives also helps prevent rust.

Metals and alloys are divided into two general classes: ferrous and nonferrous. Ferrous metals are those composed primarily of iron. Nonferrous metals are those composed primarily of some element or elements other than iron. One way to tell a common ferrous metal from a nonferrous metal is by using a magnet. Most ferrous metal is magnetic, and nonferrous metal is nonmagnetic.

Elements must be alloyed (or mixed) together to obtain the desired physical properties of a metal. For example, alloying (or mixing) chromium and nickel with iron produces a metal known as special treatment steel (STS). An STS has great resistance to penetrating and shearing forces. A nonferrous alloy that has many uses aboard ship is copper-nickel. It is used extensively in saltwater piping systems. Copper-nickel is a mixture of copper and nickel. Many other different metals and alloys are used aboard ship that will not be discussed here.

With all the different types of metals used aboard ship, some way must be used to identify these metals in the storeroom. The Navy uses two systems to identify metals: the continuous identification marking system and the color marking system. These systems have been designed so even after a portion of the metal has been removed, the identifying marks are still visible.

In the continuous identification marking system, the identifying information is actually painted on the metal with a heavy ink. This marking appears at specified intervals over the length of the metal. The marking contains the producer's trademark and the commercial designation of the metal. The marking also indicates the physical condition of the metal, such as cold drawn, cold rolled, and seamless.

In the color marking system, a series of color symbols with a related color code is used to identify metals. The term color symbol refers to a color marking actually painted on the metal. The symbol is composed of one, two, or three colors and is painted on the metal in a conspicuous place. These color symbols correspond to the elements of which the metal is composed.

For further information on the metals used aboard ship, their properties, and their identification systems, refer to the TRAMAN, Hull Maintenance Technician 3 & 2, NAVEDTRA 14119.

SUMMARY

In this chapter we have discussed some of the basic laws and principles of physics as they apply to the engineering ratings. We covered matter, magnetism, electricity, Ohm's law, Newton's laws, and mass and its different properties. Mechanical energy, thermal energy, and topics of energy transformations were described. We also provided you information on temperature, pressure definitions, principles of hydraulics, principles of pneumatics, and metals.

This chapter was provided to give you only the basis on which to expand your knowledge of electrical and mechanical fundamentals. It is important that you have a sound understanding of these laws and principles. The complex electrical and mechanical systems and the internal pressure-temperature relationships in an engineering plant make it imperative that you understand the material presented. If you have problems understanding this material, you should reread the pertinent portions until you have absorbed the basic concepts. You will use this information throughout your naval career. Study this information so you will have a good foundation of understanding within the engineering department of your ship.