Chapter 1

Air-Conditioning Fundamentals

Air conditioning may be defined as the simultaneous control of all (or at least the first three) of those factors affecting both the physical and chemical conditions of the atmosphere within any structure. These factors include *temperature, humidity, motion, distribution, dust, bacteria, odors,* and *toxic gases,* most of which affect human health and comfort to a greater or lesser degree.

Air that has been properly conditioned has had one (or a combination) of the foregoing processes performed on it. For example, it has been heated or cooled; it has had moisture removed from it (dehumidified); it has been placed in motion by means of fans or other apparatus; and it has been filtered and cleaned. These processes may be placed in the following order for ready reference:

1. Heating.
2. Cooling.
3. Humidifying.
4. Dehumidifying.
5. Circulating.
6. Cleaning and filtering.

The impression prevailing in many instances is that refrigerating or heating equipment cools or heats a room. This is only partly true since all the work performed by the equipment is on the *air* within the room, not on the room itself. In this connection, it is good to remember that air is only a vehicle or conveyance used to transport heat and moisture from one point to another. Air is a tangible item, and every cubic foot of air surrounding a person has a certain weight, depending on its temperature, the amount of moisture it is carrying, and its altitude above sea level.

Properties of Air

Air is a mixture made up primarily of two gases, being approximately 23 parts oxygen and 77 parts nitrogen by weight. Other gases in air include carbon dioxide, carbon monoxide, ozone, neon (in small quantities), and certain gases that are of no particular interest in the field of air conditioning.

Ozone is produced by sparks around electrical equipment and by the discharge of atmospheric electricity or lightning. *Neon* is a gas in its normal form and is used in signs for advertising.

Carbon monoxide is not present in the atmosphere except in congested motor traffic. It is dangerous, being produced by the incomplete combustion of carbon. It is also given off by stoves, furnaces, and cigarettes. Air containing carbon monoxide in excess of $^1/_{10}$ of 1 percent is fatal to human beings.

Oxygen, the most important constituent of air, constitutes about one-fourth of the air by weight and one-fifth of the air by volume, and on it depends the existence of all animal life. *Nitrogen* is a relatively inert gas whose principal function is to dilute oxygen.

Air Circulation

Air-conditioning equipment must circulate a sufficient volume of air at all times for two main reasons:

- The air must be constantly moving to carry away the moisture and heat immediately surrounding the body. If this is not done, the occupants soon become uncomfortable, even though the relative humidity of the room as a whole is comparatively low.
- The air must be constantly drawn into the conditioner and passed out over the cool evaporator so that the moisture it absorbs from the room may be condensed and eliminated through the drain.

Although the movement of a sufficient volume of air at all times is most essential, direct drafts must be prevented. The condensation of moisture on the evaporator surface during summer operation produces a measure of cleaning because this moisture absorbs a considerable amount of impurities from the air passing over the moist evaporator surfaces. As the condensation of moisture continues, it drips off the evaporator and is carried off to the drain, taking the impurities with it. For very dirty air, special provision must be made by installing air filters.

Cleaning and Filtering

There are numerous air-cleaning and filtering devices on the market. Such devices serve to eliminate particles carried in the air that are detrimental to health and comfort and that cause property damage. These may be classified as *dust, fumes,* and *smoke.* Dust and fumes will settle in still air, whereas smoke is actuated by motion rather than by gravity and, if not removed, will remain in motion in the air.

Air washing is effective in removing dust and fumes such as smoke because they are soluble in water, but carbons, soot, and similar

P1: GDZ/FFX P2: GDZ/FFX QC: GDZ/FFX T1: GDZ
GB076-01 GB076-Miller-Sample July 14, 2004 22:26 Char Count= 0

substances are not removed by this method of cleaning. Dry and viscous filters have been developed to make it possible to cleanse air of these substances. To fulfill the essential requirements of clean air, an air cleaner should have the following qualifications:

- It should be efficient in the removal of harmful and objectionable impurities in the air (such as dust, dirt, pollens, bacteria, and so on).
- It should be efficient over a considerable range of air velocities.
- It should have a large dust-holding capacity without excessive increase of resistance.
- It should be easy to clean and handle, or be able to clean itself automatically.
- It should leave the air passage through the filter or cleaner free from entrained moisture or charging liquids used in the cleaner.

Basic Information

To obtain a clear concept of the functioning of air-conditioning systems, you must understand the physical and thermal properties underlying the production of artificial cold. Since air conditioning deals largely with the problem of removal of heat from a room or space, the following definitions should be understood.

Heat Transfer

First, it should be noted that heat is an active form of energy, much the same as mechanical and electrical energy. Heat may be transferred by three methods: conduction, convection, and radiation.

- *Conduction* is heat transfer that takes place chiefly in solids, wherein the heat is passed from one molecule to another without any noticeable movement of the molecules.
- *Convection* is heat transfer that takes place in liquids and gases, where the molecules carry the heat from one point to another.
- *Radiation* is heat transfer in wave motion (such as light and radio waves) that takes place through a transparent medium without affecting that medium's temperature. An illustration of this is the sun's rays passing through air. The air temperature is noticeably affected. Radiant heat is not apparent until it strikes an opaque surface, where it is absorbed and manifests itself in a temperature rise.

Sensible Heat

Sensible heat is that form of heat that causes a change in the temperature of a substance. This heat can be measured by a thermometer. For example, when the temperature of water is raised from 32°F to 212°F, an increase in the sensible-heat content is taking place.

Specific Heat

The British thermal unit (Btu) required to raise the temperature of one pound of a substance 1°F is termed its *specific heat*. (The Btu is discussed later in this chapter.) By definition, the specific heat of water is 1.00, but the amount of heat required to raise the temperature of various substances through a given temperature range will vary. Since water has a very large heat capacity, it has been taken as a standard; and since 1 pound of water requires 1 Btu to raise its temperature 1°F, its rating on the specific heat scale is 1.00. Iron has a lower specific heat—its average rating is 0.130; ice is 0.504, and air is 0.238. The more water an object contains (as in the case of fresh food or air), the higher the specific heat.

Latent Heat

Latent heat (meaning hidden heat) is a form of heat that causes a substance to change its physical state from a solid to liquid, a liquid to vapor, or vice versa. For example, when a liquid is evaporated to a gas, the change of physical state is always accompanied by the absorption of heat. Evaporation has a cooling effect on the surroundings of the liquid since the liquid obtains from its surroundings the necessary heat to change its molecular structure. This action takes place in the evaporator of an air-conditioning system. Any liquid tends to saturate the surrounding space with its vapor. This property of liquids is an important element in all air-conditioning work.

On the other hand, when a gas is condensed to a liquid, the change of physical state is always accompanied by the giving up of heat. This action takes place in the condensing unit of an air-conditioning system because of the mechanical work exerted on the gas by the compressor.

Latent Heat of Fusion

The change of a substance from a solid to a liquid, or from a liquid to a solid, involves the latent heat of fusion. One pound of water at a temperature of 32°F requires the extraction of 144 Btu to cause it to freeze into solid ice at 32°F. Every solid substance has a latent-heat value in varying degrees, and that amount required to convert it, or bring about a change of state, is termed the *latent heat of fusion*. This heat, assimilated or extracted, as the case may be, is not

P1: GDZ/FFX P2: GDZ/FFX QC: GDZ/FFX T1: GDZ
GB076-01 GB076-Miller-Sample July 14, 2004 22:26 Char Count= 0

measurable with a thermometer because the heat units are absorbed or expanded in intermolecular work, separating the molecules from their attractive forces so that a change of state is effected.

Latent Heat of Evaporation

The change of a substance from a liquid to a vapor or from a vapor back to a liquid involves the *latent heat of evaporation*. Careful measurements have determined that the conversion of 1 pound of pure water at 212°F to steam at 212°F requires 970 Btu when carried out at the normal pressure of the atmosphere encountered at sea level. If heat is added and a count is kept of the Btu expended, it will be found that when all the water has been changed to steam, 970 heat units will have been used. The further addition of heat would serve only to heat the steam, such as would be possible if it had been trapped or the experiment performed in a closed vessel so that heat could be applied to it.

Superheat

Superheat is a term used frequently, especially for refrigerant control adjustment. *Superheat* is sensible heat absorbed by a vapor or gas not in contact with its liquid, and consequently it does not follow the temperature–pressure relationship. Therefore, superheat is sensible heat absorbed by the vapor raising the temperature of the vapor or gas without an appreciable change in pressure.

A gas is usually considered a vapor in a highly superheated state, or a vapor not near its condensing point. Water in the air that is close to the condensing point is termed *water vapor.* Inasmuch as superheat is sensible heat, its effect can be measured with a thermometer and is merely the temperature rise in degrees Fahrenheit. Therefore, a 10°F superheat means a vapor that has absorbed sufficient heat to raise the vapor temperature 10°F above the temperature of the vaporizing liquid.

Pressure–Temperature Relationship

Extensive investigation of gases and their behavior has shown that a given weight expands or contracts uniformly $^1/_{459}$ of its original volume for each degree it is raised or lowered in temperature above or below 0°F, provided the pressure on the gas remains constant. This fact is known as the *law of Charles*. Following this same reasoning, assume −459°F as absolute zero.

Actually, this temperature or condition has never been attained. The *law of conservation of matter* states that matter can be neither created nor destroyed, although it can be changed from one form into another. Temperature within a few degrees of absolute zero has been reached by liquefying oxygen, nitrogen, and hydrogen, but these (like other gases) change their physical state from gas into liquid and fail to disappear entirely at these low temperatures. The fact that absolute zero has never been reached is also explained by another law, known as the *law of conservation of energy.* It has already been explained that heat is a form of energy. This law states that energy can be neither created nor destroyed, although it can be changed from one form into another.

Having considered the effect of temperature on a gas, the next step is the effect of pressure on gases to aid the study of refrigeration. In 1662, Robert Boyle announced a simple relation existing between the volume of a gas and the pressure applied to it, which has since become known to scientists as *Boyle's law:*

> *At constant temperature, the volume of a given weight of gas varies inversely as the pressure to which it is subjected. The more pressure applied to a gas, the smaller its volume becomes if the temperature remains the same; likewise, if the pressure is released or reduced, the volume of the gas increases.*

Mathematically, this might be expressed:

$$P \times V = p \times v$$

where P is the pressure on the gas at volume V, and p is the pressure on the same weight of gas at volume v.

Boyle's law has been found to be only approximately true, especially for the refrigerant gases, which are more easily liquefied. The variations from the law are greater as the point of liquefaction or condensing of any gas is reached, although the material movement of air is determined by this law. It will be found that if the temperature is held constant and sufficient pressure is applied to a given weight of gas, it will change from the gaseous state into the liquid state. The point at which this change of state takes place is known as the *point of liquefaction or condensing.*

There is a definite relationship existing between the pressure, temperature, and volume at which a given weight of gas may exist. The relationship is used extensively in scientific work and is known as the *combined law of Boyle and Charles*. It may be expressed mathematically as follows:

$$\frac{P \times V}{T} = \frac{p \times v}{t}$$

where P and p are expressed in the absolute pressure scale in pounds per square foot; V and v are expressed in cubic feet; and T and t are expressed in degrees on the absolute-temperature scale.

When the pressure, temperature, or volume of a gas is varied, a new set of conditions is created under which a given weight of gas exists in accordance with the preceding mathematical equation. If a gas is raised to a certain temperature (which varies with each individual gas), no matter how much pressure is applied to it, it will be found impossible to condense. This temperature is known as the *critical temperature*. The pressure corresponding to the critical temperature is termed the *critical pressure*. Above the critical points, it is impossible to vaporize or condense a substance.

Measurements and Measuring Devices

The instrument commonly used for measuring temperature is known as the *thermometer,* which operates on the principle of the expansion and contraction of liquids (and solids) under varying intensities of heat. The ordinary thermometer charged with mercury operates with a fair degree of accuracy over a wide range. It becomes useless, however, where temperatures below −38°F (38 degrees below zero Fahrenheit) are to be indicated, because mercury freezes at this point; and another liquid, such as alcohol (usually colored for easy observation), must be substituted. The upper range for mercurial thermometers is quite high (about 900°F) so it is at once apparent that for ordinary service and general use the mercury thermometer is usually applicable.

Thermometer

In operation, the thermometer depends on the effect of heat on the main body of mercury or alcohol that expands or contracts in a bulb or reservoir. This action raises or lowers the height of the liquid in the capillary tube forming the thermometer stem. Several thermometer scales are in existence and are used in various countries. The *English* (or *Fahrenheit)* scale is commonly used in the United States, the *Celsius* in France, and the *Reamur* in Germany. Since the Celsius scale is so widely used in scientific work in all countries, an illustration of the comparison of thermometers is shown in Figure 1-1 so that any one scale may be converted to another. The freezing point on the Fahrenheit scale is fixed at 32°, and on both the Celsius and Reamur scales it is placed at 0°. On the Fahrenheit scale, the boiling point of pure water under the normal pressure encountered at sea level is 212°; on the Celsius scale, it is 100°; and in the case of the Reamur, it is 60°.

If it is desired to convert 50° Celsius to Fahrenheit, the method would be in accordance with the following formula:

$$°F = \frac{9}{5}°C + 32$$

P1: GDZ/FFX P2: GDZ/FFX QC: GDZ/FFX T1: GDZ
GB076-01 GB076-Miller-Sample July 14, 2004 22:26 Char Count= 0

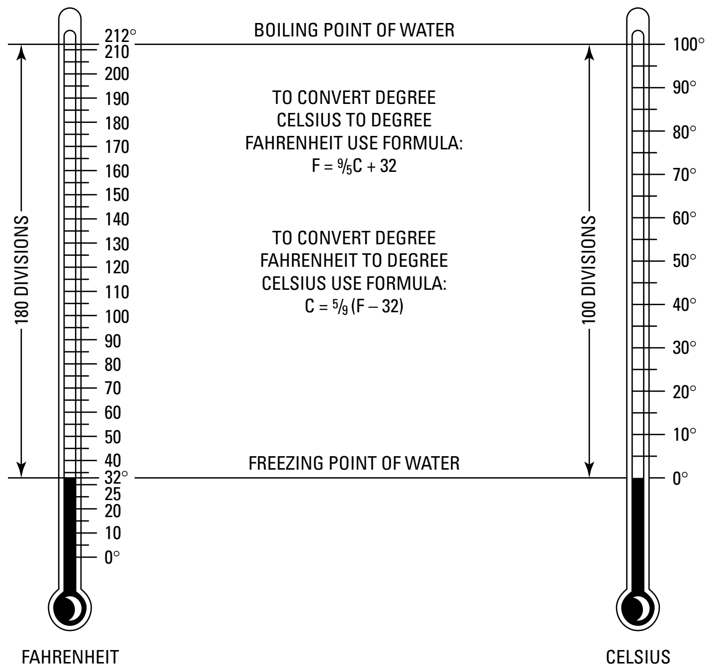

Figure 1-1 Relationship between Fahrenheit and Celsius temperature scales.

Therefore,

$$50 \times {}^{9}/_{5} + 32 = 122°\text{F}$$

Or, using a calculator, it becomes

$$50 \times 1.8 + 32 = 122°\text{F (since } {}^{9}/_{5} = 1.8\text{)}$$

To convert 50°F to Celsius:

$$°\text{F} = {}^{5}/_{9} \times (°\text{C} - 32)\text{, or } 0.5555555 \times °\text{C} - 32$$

Therefore,

$$0.5555555 \times 50 - 32 = 10°\text{F (since } {}^{5}/_{9} = 0.5555555\text{)}$$

Barometer

The *barometer* is an instrument for the measurement of atmospheric pressure. In its earliest form, it consisted simply of a glass tube somewhat in excess of 30 inches in length filled with mercury. This tube

P1: GDZ/FFX P2: GDZ/FFX QC: GDZ/FFX T1: GDZ
GB076-01 GB076-Miller-Sample July 14, 2004 22:26 Char Count= 0

was inverted in a cup partially filled with mercury, as shown in Figure 1-2. The height of the mercury column in the tube is a measure of the existing atmospheric pressure.

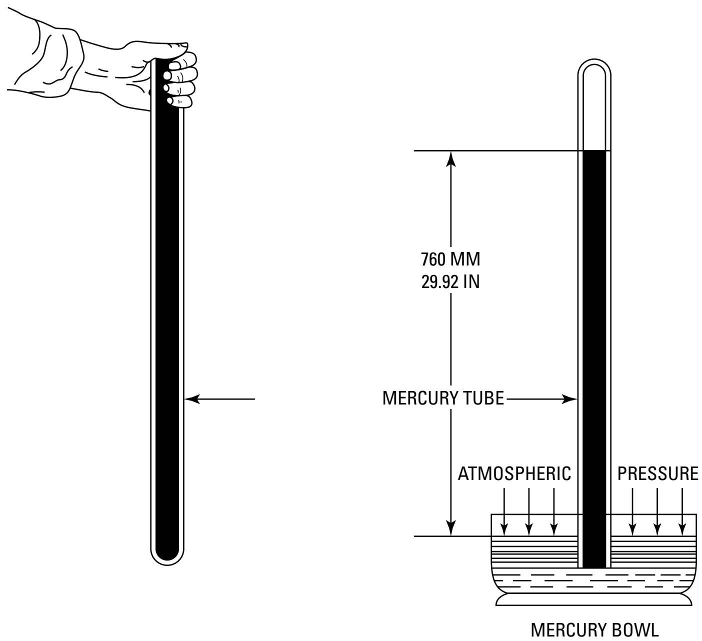

Figure 1-2 Method of obtaining barometric pressure.

Standard atmospheric pressure at sea level is 29.921 inches of mercury. Most of the pressure gages used in engineering calculations indicate gage pressure, or *pounds per square inch* (psi). Barometer readings may be converted into gage pressure by multiplying inches of mercury by 0.49116. Thus, if the barometer reads 29.921 inches, the corresponding gage pressure equals 0.49116 × 29.921, or 14.696 psi. Table 1-1 is a convenient conversion table based on the standard atmosphere, which, by definition, equals 29.921 inches of mercury (in Hg), or 14.696 psi.

Sling Psychrometer

Relative humidity is measured by an instrument known as the *sling psychrometer,* which uses two mercury thermometers mounted side by side (see Figure 1-3). One of the thermometers is the same type used to measure the temperature of the air; it is called the

Table 1-1 Atmospheric Pressure for Various Barometer Readings

Barometer (in Hg)	*Pressure (psi)*	*Barometer (in Hg)*	*Pressure (psi)*
28.00	13.75	29.75	14.61
28.25	13.88	**29.921**	**14.696**
28.50	14.00	30.00	14.74
28.75	14.12	30.25	14.86
29.00	14.24	30.50	14.98
29.25	14.37	30.75	15.10
29.50	14.49	31.00	15.23

dry-bulb thermometer. The other, called the *wet-bulb thermometer,* has a small wick saturated with water attached to its bulb. If the air is dry (less humid), the evaporation from the saturated wick will be faster and consequently the temperature will be lower.

Pressure Gages

Pressure gages, as the name implies, are used for pressure measurements on refrigeration systems as a means of checking performance. Gages for the high-pressure side of the system have scales reading from 0 to 300 pounds per square inch gage (psig), or for higher pressures, from 0 to 500 psig (Figure 1-4). Gages for the low-pressure part of the system are termed *compound gages* since their scales are graduated for pressures above atmospheric pressure in pounds per square inch gage and for pressures below atmospheric pressure (vacuum) in inches of mercury. The compound gage is calibrated from 30 inches of vacuum to pressures ranging from 60 to 150 psig, depending on gage design.

British Thermal Unit

The unit of measuring the quantity of heat is the *British thermal unit* (Btu) and is the heat required to raise the temperature of 1 pound of pure water (at its greatest density) 1°F.

Refrigeration Capacity Measurements

The cooling effect is measured by a unit known as a *ton of refrigeration.* A ton of refrigeration is obtained when 1 ton (2000 lb) of ice at 32°F is melted to water at 32°F in 24 hours. If it is remembered that the latent heat of fusion is 144 Btu/lb, it follows that the ton represents a unit cooling effect of 144 $\times$ 2000, or 288,000 Btu/24 hr, 12,000 Btu/hr, or 200 Btu/min. Thus, for air-conditioning

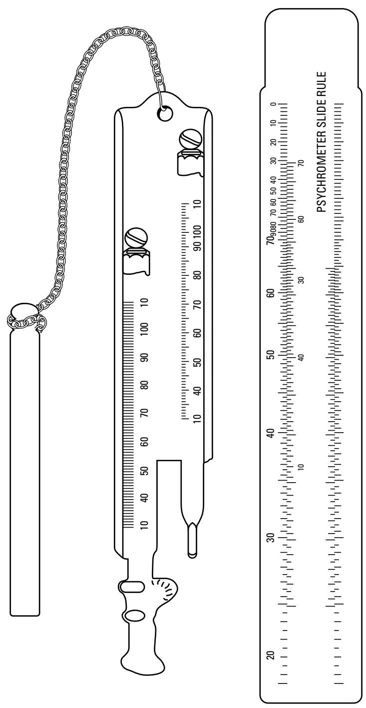

Figure 1-3 Sling psychrometer. Note the thermometers plus a slide rule for obtaining relative humidity.

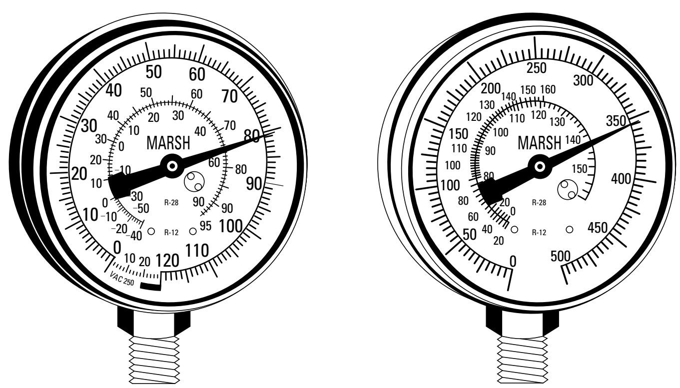

Figure 1-4 Compound (left) and high-pressure (right) gages.
(Courtesy Marsh Instrument Co., Inc.)

calculation, the size of the required condensing unit (expressed in tons) can be obtained by dividing the heat gain of the structure (expressed in Btu/hr) by 12,000. The foregoing may be written as follows:

$$\text{Refrigeration (in tons)} = \frac{\text{Btu/hr heat gain}}{12{,}000}$$

Summary

Factors affecting both physical and chemical conditions of the atmosphere are temperature, humidity, motion, distribution, dust, bacteria, odor, and toxic gases. Air is a mixture of two gases: oxygen and nitrogen. There are still other gases in the air, such as carbon dioxide, carbon monoxide, ozone, and neon in small quantities. The air must be constantly moving to carry away the moisture and heat.

Air filters are used to eliminate particles of dirt or dust carried in the air that are detrimental to health and comfort. Water filters are effective in removing dust and some fumes and smoke, but carbon and soot are not removed by this method. Dry filters and electronic filters make it possible to clean the air of most harmful dust and pollen.

Heat is an active form of energy much the same as mechanical and electrical energy. Heat is transferred by three methods: conduction, convection, and radiation. Conduction means the flow of heat through a solid substance (such as iron). The transfer of heat by convection means the carrying of heat by air rising from a heated surface. Radiation takes place in the absence of matter, as in the passage of heat through the vacuum inside the bulb of an incandescent lamp.

Sensible heat is a form of heat that causes a change in the temperature of a substance. Specific heat is the Btu required to raise the temperature of one pound of substance one degree Fahrenheit. Latent heat is the form of heat that changes the physical state of a substance, such as solid to liquid or liquid to a vapor. Latent heat of fusion is the point at which a substance changes from a solid to a liquid or from a liquid to a solid.

Latent heat of evaporation is the point at which a substance changes from a liquid to a vapor or from a vapor back to a liquid. It takes 970 Btu to change 1 lb of pure water at 212°F to steam when atmospheric pressure is at sea level. Superheat is sensible heat absorbed by a vapor or gas not in contact with its liquid and consequently does not follow the temperature–pressure relationship.

A thermometer is an instrument used for determining the temperature of a body or space. The barometer is an instrument used for

P1: GDZ/FFX P2: GDZ/FFX QC: GDZ/FFX T1: GDZ
GB076-01 GB076-Miller-Sample July 14, 2004 22:26 Char Count= 0

measuring the atmospheric pressure. Standard atmospheric pressure at sea level is 29.921 in Hg, or 14.696 psi.

Review Questions

1. Name the three most important factors that affect human health and comfort.
2. What factors besides heating and cooling are necessary in an air-conditioning system?
3. What are the chemical constituents of air?
4. Why is air movement a necessary part of air conditioning?
5. What are the devices used for cleaning and filtering air?
6. What are the three principal methods by which heat may be transferred through space?
7. If the specific heat of water is taken as 1.00, what is the specific heat of iron?
8. How does latent heat affect the change of state in various substances?
9. What is meant by "the latent heat of evaporation"?
10. What is superheat?
11. State the relations between pressure, temperature, and volume for a given weight of gas.
12. How many Btus are required to convert 1 pound of water at 32°F to 1 pound of ice at the same temperature?
13. Define the law of conservation of matter.
14. Define Boyle's law.
15. State the relations between the various temperature scales.
16. What instrument is commonly used for measurement of atmospheric pressure?
17. State the relations between absolute and gage pressure.
18. What is a British thermal unit?
19. What is a ton of refrigeration, and what is the Btu equivalent?
20. What is the old name used for degrees Celsius?

P1: GDZ/FFX P2: GDZ/FFX QC: GDZ/FFX T1: GDZ
GB076-01 GB076-Miller-Sample July 14, 2004 22:26 Char Count= 0