Modern Refrigeration and air conditioning

ALTHOUSE AND TURNQUIST

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Refrigeration
and air conditioning

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INTRODUCTION

MODERN REFRIGERATION and AIR CONDITIONING covers the practical application of refrigeration in all of its branches.

The objective of this text is to give the refrigeration student a sound foundation in Air Conditioning and Refrigeration Principles, and at the same time acquaint him with Refrigeration Mechanisms and their Components.

MODERN REFRIGERATION was first published in 1933. Revisions were made in 1936, 1939, 1943 and 1950. To bring the text up to date (1956), it has been completely rewritten and much new material added. New colored inserts have been included to make refrigeration cycles of operation easy to understand.

The new page size was chosen to provide more space for illustrations, and for a better arrangement of the text material.

The acceptance of MODERN REFRIGERATION on an International basis seems to justify the work and expense of this new book.

Andrew D. Althouse

Carl H. Turnquist

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The McIntire Co.
Mechanical Refrigeration Enterprises
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National Cooler Corp.
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Studebaker-Packard Corp.
Sundstrand Hydraulic Div.
Sweden Freezer
Taylor Instrument Companies
Tecumseh Products Co.
Temprite Products Corp.
Tenney Engineering, Inc.
Timken Silent Automatic Div., Scaife Co.
The Torrington Mfg. Co.
Tranter Mfg. Inc.
Tubing Appliance Co., Inc.
Tyler Refrigeration Corp.
Ultra-Violet Products, Inc.
Wabash Corp.
Wagner Electric Corp.
The Warren Co.
Webster Electric Co.
Westinghouse Electric Corp.
White-Rodgers Electric Co.
Williams Oil-O-Matic Heating Corp.
Wilson Refrigeration Inc.
York Corp.

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Chapter 1

FUNDAMENTALS OF REFRIGERATION

1-1. HISTORY OF REFRIGERATION

As far back as history can be traced, snow, ice, and cold water have aided mankind in keeping his food supply in good condition. Even today in some areas porous vessels containing water are used to cool beverages and foods. Also, during the warmer months, food is kept in deep caves or just over the surface of water in deep wells.

Refrigeration, the industry of preserving food by cold, first became of commercial importance during the 18th century, when ice formed during the winter on the surface of lakes and ponds was cut and stored in insulated store rooms to be used during the summer. This practice was followed by shipping ice from the colder climates to the hotter zones, but this did not turn out successfully. The use of natural ice made necessary the building of insulated containers or ice boxes. These first appeared on a large scale during the 19th century.

Ice was first made artificially in about 1820, but it was not until 1834 that this was done successfully. Jacob Perkins, an American engineer, was the inventor of this apparatus, which was the forerunner of our modern compression systems. In 1855 a German produced the first absorption type of refrigerating mechanism, although Michael Faraday discovered the principle of the absorption type in 1824.

The production of artificial ice made very little progress until shortly after 1890. During that year a shortage of natural ice gave impetus to the mechanical ice-making industry. Since 1890, the growth of mechanical refrigeration in the United States has been phenomenal.

Domestic refrigeration first made its appearance about 1910. J. M. Larsen produced a manually operated household machine in 1913. It was not until 1918 that the first automatic refrigerator was available on the American market (the Kelvinator). The Kelvinator Company sold its first machine in 1918. Kelvinator sold sixty-seven machines that year. Between 1918 and 1920 two hundred units were sold. Freezing of meats was first studied in 1923 and was the origin of the frozen foods industry. The General Electric Monitor Top appeared in 1926 after eleven years of experimenting. The Monitor Top was the first of the "sealed" or hermetic automatic refrigerating units. Beginning with 1920, domestic refrigeration became one of our important industries. The Electrolux, which is an automatic domestic absorption unit, appeared on the American market in 1927. The use of automatic refrigeration units for comfort cooling appeared on the market in 1927.

1-2. SCOPE OF MECHANICAL REFRIGERATION

Mechanical Refrigeration is used for domestic refrigeration, commercial refrigeration, air conditioning, comfort cooling, dehumidifying, freezing foods, cooling in manufacturing processes, and numerous other applications.

1-3. HEAT

Heat is molecular motion. All substances are made up of tiny molecules which are in a state of rapid motion (vibration). As the temperature of a substance is increased the motion increases and as the temperature decreases, the molecules motion decreases. If all heat is extracted (absolute zero) from a substance, the molecular motion will cease.

1-4. COLD

Cold is a relative term used to denote a low temperature. Cold is not something which is produced, but rather heat is extracted and the resulting condition is called cold. A refrigerator produces a condition called "cold" by the process of extracting heat from the interior of the refrigerator cabinet. The refrigerator does not destroy the heat, but rather pumps the heat from the inside of the box to the outside. Heat and cold are opposite ends of the same thing. It may be pointed out here that heat cannot travel from a cold body to a hot body, but always travels from the body of a higher temperature to a colder one. (Second law of Thermodynamics.)

1-5. HOW COLD PRESERVES FOOD

As the molecules move slower, there is an important effect on the bacteria that are present in most foods. Cold, or low temperatures, slows up the growth of these bacteria and foods do not spoil as fast. Slowing the movement or cooling of the molecules tends to make all organisms more sluggish. Spoiling of food is actually the growth of bacteria in the food. If these bacteria can be kept from increasing, the food will be edible for a longer period of time. Since most foods have a considerable water content, the food must be kept just above freezing temperatures.

If food is frozen slowly at near the freezing temperature the ice crystals formed are large and their growth ruptures the food tissues. When the food melts it spoils rapidly and its appearance and taste are ruined. Fast freezing at very low temperatures forms small crystals and the food tissues are not injured.

1-6. REMOVING HEAT

Heat always flows from hot to cold, that is from higher temperatures to lower temperatures. Faster moving molecules impart some of their energy to slower moving molecules. Therefore, the faster molecule slows a little and the slower one moves a little faster. Sometimes, however, the molecules instead of moving slower or faster, change their shape. The change in shape is caused by one or more of the atoms in the molecules shifting to a different position and the molecule will change from a gas to a liquid, or vice versa.

1-7. BASIS OF MECHANICAL REFRIGERATION

In order to understand the operation of the mechanical refrigerator, it is important to understand the physical and thermal properties of the mechanisms and of the substances used to produce cold. A study of elementary physics is needed in order that all the explanations may be well understood. A leaking canoe can be kept afloat by means of bailing the craft with a sponge. If the sponge is used to soak up the water and is then squeezed over the side and the process repeated the canoe will be freed from the water. The water has not been destroyed, but merely conveyed from inside the canoe into the lake.

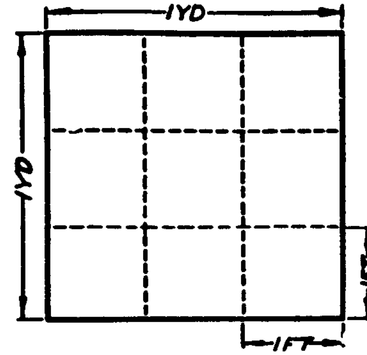
A refrigerator operates in a similar manner. A substance (refrigerant) is piped into the refrigerator in such a way that it soaks up heat from the box and is then passed to the outside of the box where the heat is squeezed out. The repetition of this cycle on the part of the refrigerant produces a condition in the box called cold. It should be noted that some of the heat has been removed, not all of it. Service managers of refrigerator companies prefer service and installation mechanics who are well grounded in the essential principles of physics as it pertains to refrigeration.

1-8. DIMENSIONS

All measurement of dimensions in this text are based on the English units such as, inches, feet, and yards. One must be able to accurately measure cabinet sizes and volumes. One must be able to measure tubing sizes, piston, cylinder, journal sizes and the like to very accurate dimensions.

12 inches	(in.) = 1	foot (ft.)
3 feet	(ft.) = 1	yard (yd.)
5280 feet	(ft.) = 1	mile (mi.)
6080 feet	(ft.) = 1	nautical (mi.)

Two dimensional space (area) is also measured in feet and inch units; that is, a square inch or a square foot. 1 square inch is a square area with a 1 inch measurement on each side, Figure 1-1.

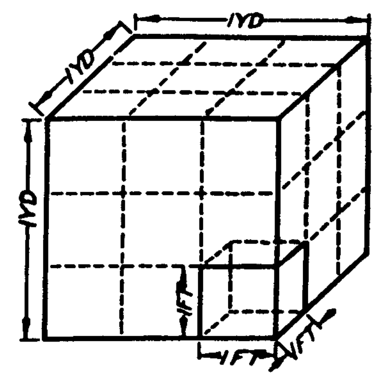


1-1. The relation of standard areas.

144 square inches (sq. in.) = 1 square foot (sq. ft.)

9 square feet (sq. ft.) = 1 square yard (sq. yd.)

Three dimensional space (volume) is also measured in English units. All substances must be of three dimensions. These measurements are the cubic inch, the cubic foot, and the cubic yard, Figure 1-2. 1 cubic inch (cu. in.) is a cube, 1 inch (in.) on each dimension.



1-2. The relation of standard volumes.

1728 cubic inches (cu. in.) = 1 cubic foot (cu. ft.)

27 cubic feet (cu. ft.) = 1 cubic yard (cu. yd.)

1-9. PROBLEMS

1. How many square inches are equal to 4 square feet? Ans. 576
2. How many square feet are equal to 1440 square inches? Ans. 10
3. How many square yards are equal to 1296 square inches? Ans. 1
4. How many cubic inches are equal to 10 cubic feet? Ans. 17280
5. How many cubic feet are equal to 6 cubic yards? Ans. 162

1-10. MASS AND WEIGHT

Mass is a property of all matter, for everything has mass. Gas has mass, water has mass, and metals have mass. The mass is indication of the number of molecules present in a unit quantity of a substance. The weight of a substance is due to the earth's attraction on the substance (gravity). The only condition in which a substance has no weight is when it is falling in a vacuum under the influence of gravity. At all other times it has weight. Therefore, weight divided by acceleration due to gravity is mass. Ordinarily gravity pull on an object will give the object a falling acceleration of 32.2 ft./sec/sec.

Therefore:

$$\text{mass} = \frac{\text{Weight}}{32.2\ \text{ft. per sec. per sec.}} = \text{slugs}$$

The unit of mass is the slug.

It is important to know this slug value because all mass obeys the following rule:

Force = mass x acceleration.

The English units for weight are the ounce, the pound, and the ton.

16 ounces (oz.) = 1 pound (lb.)
2000 pounds (lb.) = 1 ton (ton)

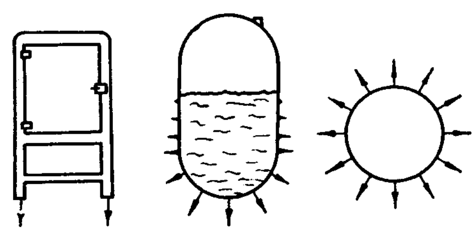
Example: What is the mass of a 10 lb. substance:

$$\text{Mass is } \frac{W}{g} = \frac{10}{32.2} = .3106 \text{ slugs}$$

W = Weight of substance
g = 32.2 feet per second per second

1-11. SOLIDS

Substances exist in three physical forms: The solid, the liquid, and the gaseous. Water, for example, may exist in any one of the above physical forms. If it is ice, it is a solid; if it is water, it is a liquid; while as steam, it is a gas. Three different methods are used to express physical properties of substances or materials corresponding to the three states of matter.



1-3. The various ways materials exert pressure. The arrows represent the direction of and the relative amount of the pressures.

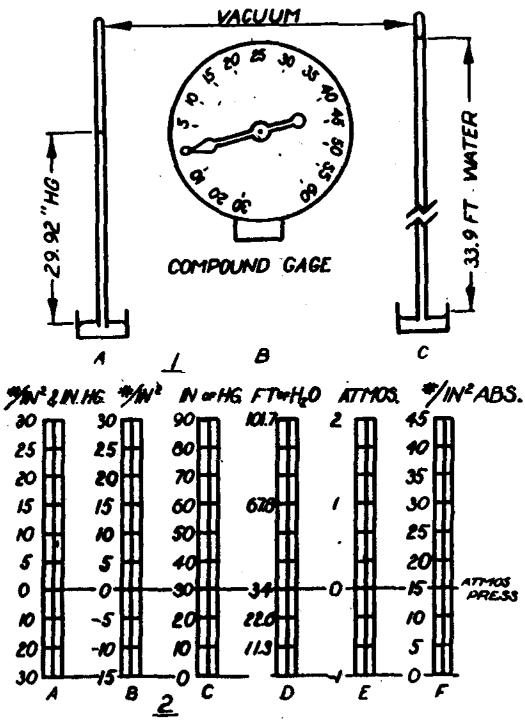
A solid is any physical substance which retains a certain shape. It is made of untold billions of molecules, all exactly the same, that stay in the same place relative to each other, and vibrate back and forth. The lower the temperature, the slower the molecules vibrate, and the higher the temperature, the faster the molecules vibrate. These molecules are strongly attached to each other and considerable force is necessary to move them.

1-12. LIQUIDS

A liquid is any physical substance which will assume the shape of its container but which has the molecules strongly attached to each other. One could imagine the molecules swimming amongst its fellow molecules but never leaving them. As the temperature rises, the molecules will swim faster and vice versa.

1-13. GASES

A gas is any physical substance which must be contained in sealed container or it will soon dissipate. These molecules have little attraction



1-4. The standard pressure scales and the different ways of registering atmospheric pressure.
1. A simple mercury barometer is shown at (A). The compound gauge (B) is calibrated in inches of mercury for pressures below atmospheric, and in pounds per square inch gauge for pressures above atmospheric. The water column (C) illustrates the water equivalent of the mercury barometer.
2. This illustrates pressures of from 0 pounds per square inch to 30 pounds per square inch gauge expressed in common units. It may be noticed that all values, reading horizontally, are equal. The apparent difference in readings is due to the scale used.

for each other and travel in a straight line (fly) and will ricochet or rebound from any other molecules they contact. They have no attraction for each other or any other substance.

Any particular substance can be made to exist in any of these three forms. Any molecule can be made to vibrate, or swim or fly depending on two things: temperature and pressure. Before one can understand this change of state, he must study temperature and pressure.

Comparative weights of solids and liquids may be expressed by either density or specific gravity. Density is defined as the weight per unit volume.

Specific gravity is defined as the ratio of the weight of a certain volume of a substance to the weight of an equal volume of water.

Comparative densities of gases are expressed by specific volumes. Specific volume is the volume of one pound of a gas at standard conditions. Standard conditions are considered to be 68 F. and 29.92 inches of mercury column pressure. See Figures 1-4 & 1-5.

1-14. SYMBOLS

F = Degrees Fahrenheit
C = Degrees Centigrade
F_A = Degrees Fahrenheit Absolute
C_A = Degrees Centrigrade Absolute

p = pounds = lbs.
psi = pounds per square inch = lbs. per sq. in.
i = inches = in.
f = foot or feet = ft.
si = square inch = sq. in.
sf = square feet or foot = sq. ft.
pcf = pounds per cubic foot = lbs. per cu. ft.

Example: What is the specific volume of air if 10 cubic feet of it weighs .75 pounds?

Specific Volume $= \frac{\text{Volume in cu. ft.}}{\text{Weight in lbs.}} =$

$\frac{10}{.75} = 13.3$ cfp

Example: If 1 cubic foot of iron weighs 490 pounds what is its specific gravity? Density of water - 62.4 pcf. Specific gravity of iron =

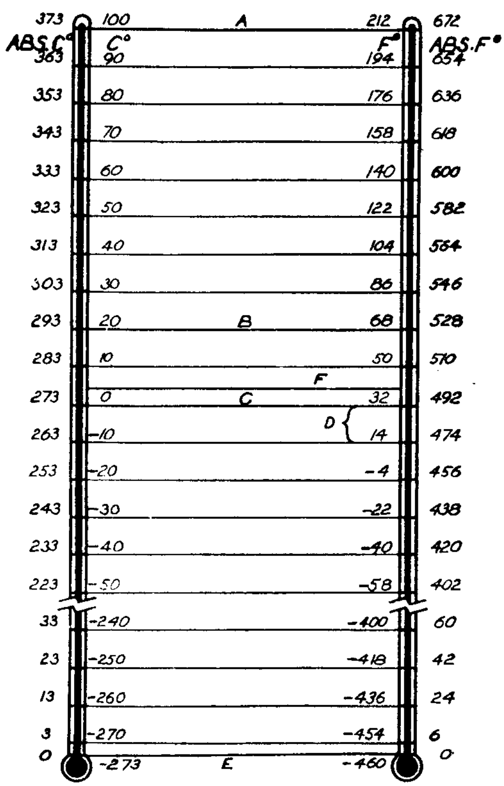
$\frac{\text{490 pounds per cubic foot}}{\text{62.4 pounds per cubic foot}} = 62.4$

Examples: What is the density of a liquid if 3000 cubic inches of it weighs 108.5 pounds?

$\frac{\text{108.5 pounds x 1728 cubic inches per cubic foot}}{\text{3000 cubic inches}} =$

$\frac{108.5 \times 1728}{3000}$

Density of the liquid = 62.4 pounds per cubic foot



1-5. The four standard temperature scales and their relationship. A. Boiling temperature of water at atmospheric pressure; B. Average room temperature; C. Freezing temperature of water at atmospheric pressure; D. Cooling unit temperature range; E. Absolute zero temperature; F. Average refrigerator box temperature.

1-15. PRESSURE

As the operation of a refrigerator depends mainly on pressure differences in the system, a basic understanding of pressure and of the laws of pressures is very important.

Pressure is defined as the weight per unit area, and it is expressed in pounds per square inch and pounds per square foot. The normal pressure of the air on the body averages about 14.7 pounds per square inch, or 2117 pounds per square foot. Note: There are 144 square inches in 1 square foot; therefore to get the pressure per square foot, 14.7 must be multiplied by 144.

Substances always exert a pressure upon the surfaces supporting them. That is, an ice-box (a solid) exerts a pressure on its legs because if they were removed the box would move; a liquid always exerts a pressure on the sides and bottom of its container, such as a bottle; and a gas always exerts a pressure on all the surfaces of its container, such as a balloon. See Figure 1-3.

If a solid weight of 1 pound were made with its bottom surface area 1 inch square, it would exert a pressure of 1 pound per square inch upon a flat surface.

A liquid in a container maintains an increasing pressure on the sides as the liquid depth increases and a constant pressure on the bottom of the container. Gases, however, do not always exert a constant pressure on the container because the pressure is determined by the temperature and the quantity in the container.

1-16. PRESSURES, GAGE AND ABSOLUTE

Pressures are expressed in pounds per unit of area or in inches of static pressure of liquids. The most popular pressure indicating instruments register in pounds per square inch ABOVE the atmospheric pressure. The pressure of zero pounds per square inch gauge is equal to the atmospheric pressure (approximately 14.7 pounds per square inch; 15 pounds per square inch is usually used for computation purposes). Pressures below atmospheric pressure are termed vacuums and a perfect vacuum may be described as - 14.7 pounds per square inch gauge or 0 pounds per square inch absolute. Therefore, the absolute pressure scale has its zero at a pressure which cannot be further reduced. Pressure is also indicated in inches of mercury or water column and may be either above atmospheric pressure or absolute pressure depending on the construction of the gauge. Mercury is usually used for measuring pressures below atmospheric pressure and water for SMALL PRESSURES above. (GAS LINES, ETC.)

The barometer, Figure 1-4, is an example of a mercury gauge. With a vacuum in one end of the tube, it is found that the atmospheric pressure will support a mercury column 29.92 in. in height at sea level under standard conditions.

1-17. BOYLE'S LAW

Boyle's Law expresses a very interesting relation between the pressure and volume of a gas. It is stated as follows:

"The volume of a gas varies inversely as the pressure provided the temperature remains constant."

This means if a certain quantity of gas has its pressure doubled, the volume becomes one-half that of the original. Or, if the volume becomes doubled, the gas has its pressure reduced by one-half. If a perfect gas is considered, Boyle's Law may be expressed as a formula:

Pressure x Volume = A constant number.

This being true, one can say that when either the pressure or the volume is changed, the corresponding pressure or volume is changed in the opposite direction. Therefore, Old Pressure x Old Volume = the New Pressure x the New Volume. THIS FORMULA WILL HOLD TRUE ONLY IF THE PRESSURES ARE EXPRESSED AS ABSOLUTE PRESSURES. Expressed in letter form:

$$Po \times Vo = Pn \times Vn$$

Example:

What is the new volume, if 5 cubic feet of gas at 20 pounds per square inch gauge are compressed to 60 pounds per square inch providing the temperature remained constant? Consider atmospheric pressure = 15 pounds per square inch.

$$Po \times Vo = Pn \times Vn$$

Po = 20 pounds per sq. in. gauge = (20 + 15) = 35 pounds per sq. in. abs.

Vn = 60 pounds per sq. in. gauge = (60 + 15) = 75 pounds per sq. in. abs.

$$35 \times 5 = 75 \times Vn$$

$$\frac{35 \times 5}{75} = Vn$$

$$\frac{35}{15} = Vn$$

$$\frac{7}{3} = Vn$$

2.33 cubic feet = Vn = New Volume

1-18. DALTON'S LAW

Dalton's Law of partial pressures is the foundation of the principle of operation of one of the absorption type refrigerators. The law may be stated as follows:

"The total pressure of a mixture of gases is the sum of the partial