



Chapter 1 Fundamentals of refrigeration

When studying refrigeration and air conditioning, it is important to master the fundamental principles of physics and thermodynamics explained in this chapter.

For those who are already familiar with these fundamentals, this chapter will serve as review or reference materials. Units are important subjects in this chapter. Various units are used depending on applications and districts and they are not unified throughout the world for the time being. The yard-pound system is still being used in quite a number of countries, and the metric system is used in the Japan Refrigeration and Air Conditioning Industries.

Furthermore, there are many kinds of systems in the metric - system. In order to settle the confusion caused by diversity of units, the international unit system (SI: Le Systeme International d'Unites) has been introduced, and it has been supported widely. In this textbook, however, the units of the metric system which are customarily used are mainly explained because we think it is too early to adopt the S.I. metric system fully in this textbook, as the system is not used in gauges, product catalogues, and technical materials which service technicians use daily.

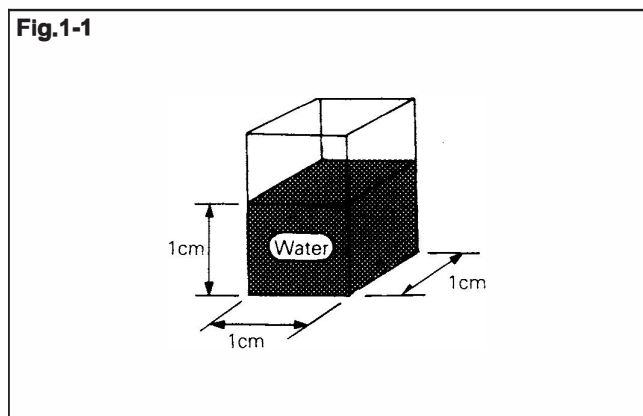
In order to make the persons who are familiar with the yard-pound system read this textbook easily, the conversion formulae from the units of the conventional metric system to those of the yard-pound system, and at the same time, the units of the S.I. metric system which will be necessary in near future are also explained.

1.1 Pressure

1.1.1 Mass

Mass..... Mass is the amount of material in a substance measured in grams and kilograms.

1 gram [g] A cubic centimeter [cm³] of water at a temperature of greatest density has a mass of 1g (See Fig. 1-1.)



The relations among grams, kilograms and other units are shown in Table 1-1.

Table 1-1

Conventional metric system and S.I. metric system		Yard-pound system	
g	kg	oz	lb
	0.001	0.03527	0.002205
1000	1	35.27	2.205
28.35	0.02835	1	0.0625
453.6	0.4536	16	

* The conventional metric units and the S.I. metric units of mass are the same.

To convert one unit to another, use the following formulae.

- (1) $[g \rightarrow kg]$ To convert grams into kilograms
 $kg = 0.001 \times g$
- (2) $[g \rightarrow oz]$ To convert grams into ounces
 $oz = 0.03527 \times g$
- (3) $[kg \rightarrow g]$ To convert kilograms into grams
 $g = 1000 \times kg$
- (4) $[kg \rightarrow lb]$ To convert kilograms into pounds
 $lb = 2.205 \times kg$
- (5) $[oz \rightarrow g]$ To convert ounces into grams
 $g = 28.35 \times oz$
- (6) $[oz \rightarrow lb]$ To convert ounces into pounds
 $lb = 0.0625 \times oz$
- (7) $[lb \rightarrow kg]$ To convert pounds into kilograms
 $kg = 0.4536 \times lb$
- (8) $[lb \rightarrow oz]$ To convert pounds into ounces
 $oz = 16 \times lb$

Example	: Convert 200g into kg
Solution	: $200g \times 0.001 = 0.2kg$
Example	: Convert 500g into oz
Solution	: $500g \times 0.03527 \approx 17.6oz$
Example	: Convert 4kg into g
Solution	: $4kg \times 1000 = 4000g$
Example	: Convert 4kg into lb
Solution	: $4kg \times 2.205 \approx 8.8lb$
Example	: Convert 50oz into g
Solution	: $50oz \times 28.35 = 1417.5g$
Example	: Convert 200oz into lb
Solution	: $200oz \times 0.0625 = 12.5lb$
Example	: Convert 80lb into kg
Solution	: $80lb \times 0.4536 \approx 36.3kg$
Example	: Convert 5lb into oz
Solution	: $5lb \times 16 = 80oz$



1.1.2 Force and weight

Force... A force is defined as a push or pull. It is anything that has a tendency to set a body in motion, to bring a moving body to rest, or to change the direction of motion. A force may also change the size or shape of a body.

Weight... Weight is the most familiar force. The weight of a body is a measure of the force exerted on the body by the gravitational pull of the earth. (See Fig. 1-2.)

The units of force are the kilogram force [kgf] in the conventional metric system, the newton [N] in the S.I. metric system and the pound force [lbf] in the yard-pound system.

Kilogram force [kgf] ...A kilogram force is the force of gravity of an object having a mass of 1kg. The force of gravity gives an acceleration of 9.807 meter per second per second to the object. [See Fig. 1-3 (a).]

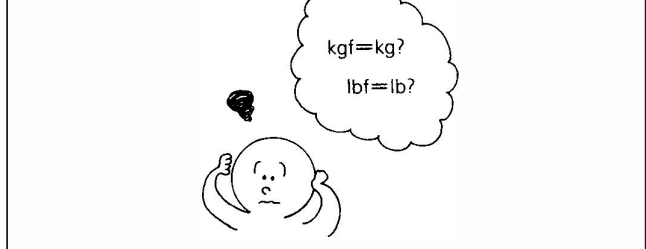
Newton [N]...A newton is that force which, when applied to a body having a mass of 1kg, gives it an acceleration of one meter per second per second. [See Fig. 1-3(b).]

The relations among kilogram force, newton and pound force are shown in Table 1-2.

Table 1-2

Conventional metric system	S.I. metric system	Yard-pound system
kgf	N	lbf
1	9.807	2.205
0.1020	1	0.2248
0.4536	4.448	1

Fig.1-4



* There is a custom to abbreviate kilogram force as kilogram or pound force as pound and, even their symbols, "kgf" as "kg" or "lbf" as "lb". Almost all weighing apparatus indicate the units of mass. In this chapter, grab the differences between weight and mass clearly.

1.1.3 What is "Pressure"?

Pressure... Pressure is the force per unit area. It may be described as a measure of the intensity of force at any given point on the contact surface. Whenever force is evenly distributed on a given area, pressure at any point on the contact surface is the same and can be calculated by dividing the total force exerted by the total area on which the force is applied. Such relationship is expressed by the following equation. (See Fig. 1-5.)

$$P = \frac{F}{A}$$

Where P = Pressure
 F = Total force
 A = Total area

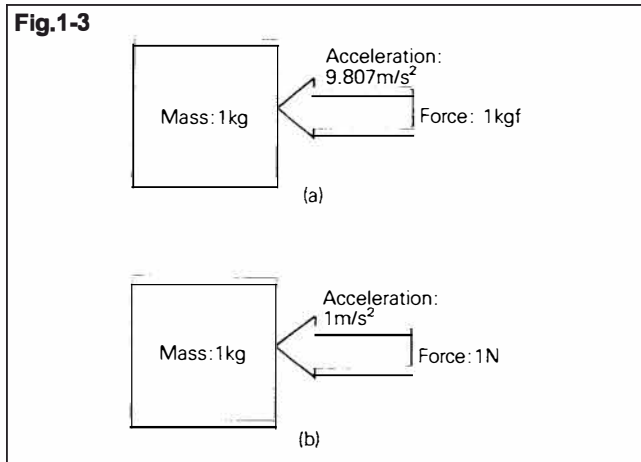
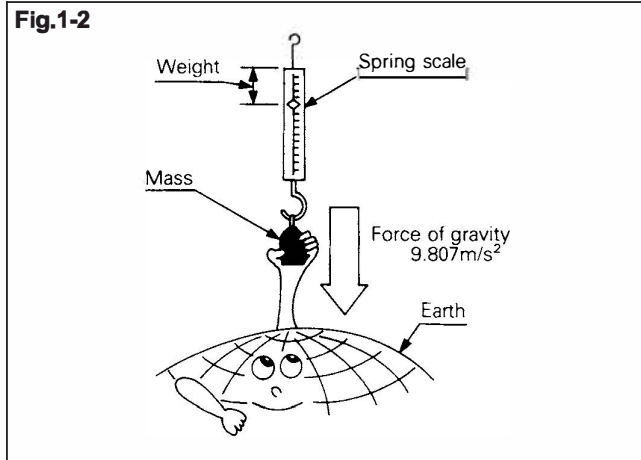
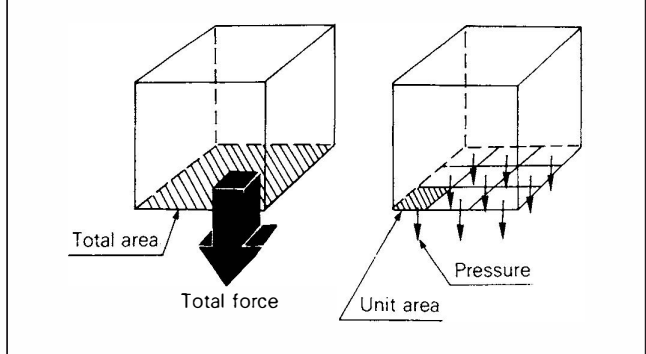


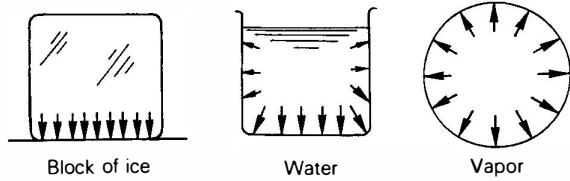
Fig.1-5



A block of ice (a solid) exerts pressure on its support. Water (liquid) exerts pressure on the sides and bottom of its container. Vapor (gas) exerts pressure on all surface of its container. (See Fig. 1-6.)



Fig.1-6



1.1.4 Units of pressure

Units of pressure are the kilogram force per square centimeter [kgf/cm²] in the conventional metric system, the pascal [Pa], the kilopascal [kPa] in the S.I metric system and the pound per square inch [psi] in the yard-pound system.

Kilogram force per square centimeter [kgf/cm²]...A solid weight of 1kgf with a bottom surface area of 1cm² would exert a pressure of 1kgf/cm² upon a flat surface. [See Fig. 1-7 (a).]

Pascal [Pa]...A pascal is a newton per square meter.
 [See Fig. 1-7(b).]
 1 kilopascal [kPa]=1000Pa

Pounds per square inch [psi]...A solid weight of 1 lb with a bottom surface area of 1 in² would exert a pressure of 1 psi upon a flat surface. [See Fig. 1-7(c).]

Fig.1-7

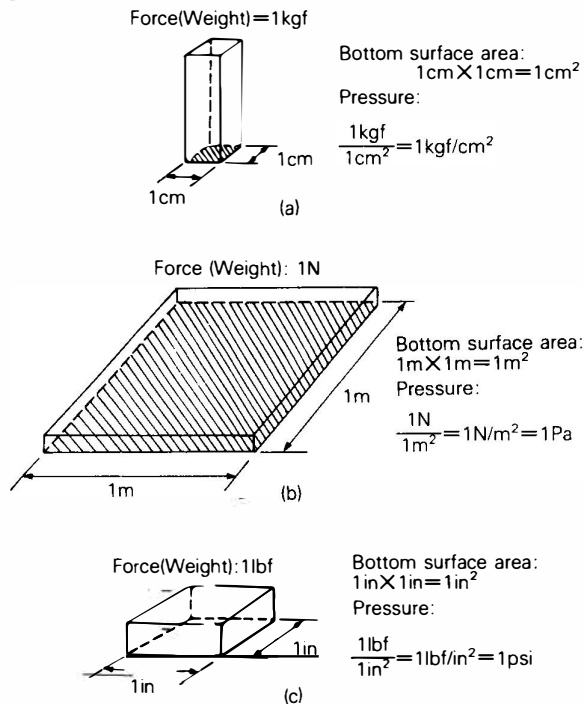
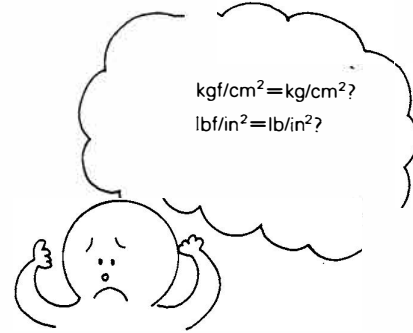


Fig.1-8



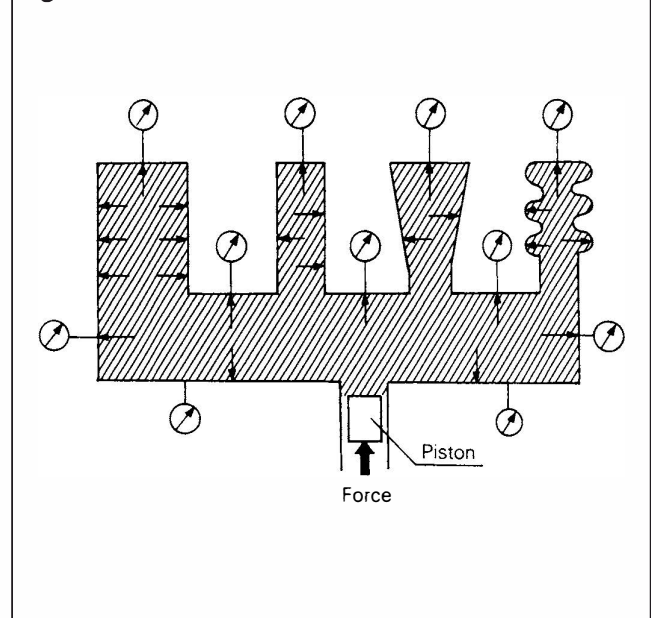
* Like the units of weight, the units of pressure are also abbreviated such as kilogram force per square centimeter as kilogram per square centimeter or pound force per square inch as pound per square inch and their symbols such as kgf/cm² as kg/cm² or lbf/in² as lb/in². On the gauges that servicemen normally use, only kg/cm² or lb/in² is indicated. There is no problem to think that kg/cm² or lb/in² is equal to kgf/cm² or lbf/in² respectively.

1.1.5 Pascal's Law

Pascal's Law...Pressure applied on a confined fluid is transmitted equally in all directions.

Fig. 1-9 illustrates Pascal's Law. It shows a fluid-filled cylinder with different shapes of chambers. A piston is fitted into a small cylinder which is connected to the larger cylinder. A force is applied to the piston in the small cylinder. The pressure gauges show the pressure transmitted equally in all directions and chambers regardless of the size and shape of chambers.

Fig.1-9



1.1.6 Atmospheric pressure

Atmospheric pressure...The earth is surrounded by an envelope of atmosphere or air. Air has weight and exerts a pressure on the surface of the earth. The pressure exerted by the atmosphere is known as atmospheric pressure.

The weight of a column of air having a cross section of 1 square cm and extending from the surface of the earth at the sea level to the upper limits of the atmosphere is 1.033kgf (14.70lbf). Therefore, the pressure on the surface of the earth at the sea level resulting from the weight of the atmosphere is 1.033kgf/cm² (14.70lbf/cm²) (See Fig. 1-10.)

Barometers...To measure the atmospheric pressure experimentally, a barometer is used. A simple barometer consists of glass tube sealed at one end and opens at the other end. Fill the tube with mercury, then, seal the open end with a finger, and invert it in a container of mercury. When the finger is removed, mercury will drop to the level corresponding with the atmospheric pressure. The height of mercury column will be 760mm (29.92 in.) at the sea level under the standard conditions. (See Fig. 1-11.)

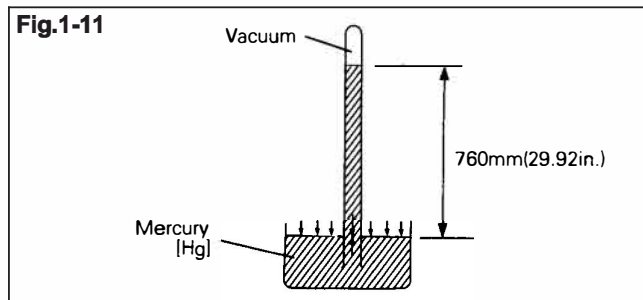
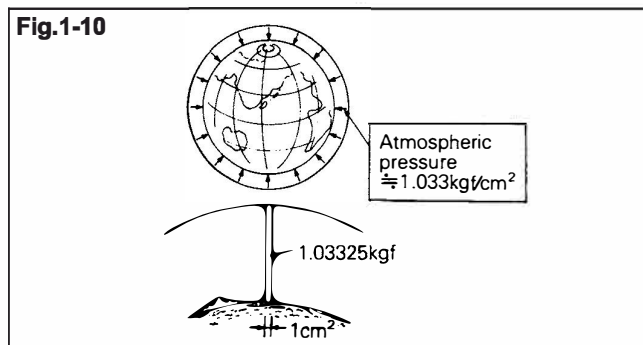


Table 1-3

Conventional metric systems			S.I metric system	Yard-pound system	
kgf/cm ²	atm	mmHg	kPa	psi	in.Hg
1	0.9678	735.6	98.07	14.22	28.96
1.033	1	760	101.3	14.70	29.92
0.001360	0.001316	1	0.1333	0.01934	0.03937
0.01020	0.009869	7.501	1	0.1450	0.2953
0.07031	0.06805	51.71	6.895	1	2.036
0.03453	0.03342	25.40	3.386	0.4912	1

Atmospheric pressure is expressed in many ways as shown below.

- Atmospheric pressure =1.033kgf/cm²
- =1atm
- =760mmHg
- =101.3kPa
- =14.70lbf/in² [psi]
- =29.92in.Hg

1.1.7 Vacuum

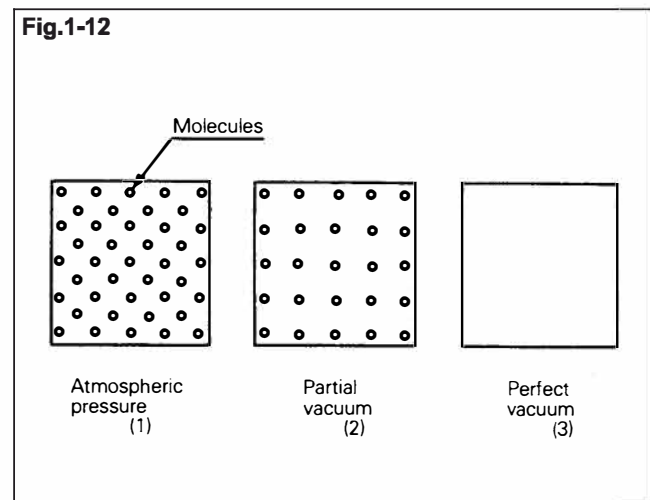
Vacuum...Pressures lower than atmospheric pressure are called vacuum.

Perfect vacuum...A pressure which cannot be reduced any further is called perfect vacuum. (Absolute vacuum)

Partial vacuum...A pressure lower than atmospheric pressure, but not a perfect vacuum, is called partial vacuum.

A perfect vacuum is expressed in many ways as shown below.

- Perfect vacuum=0kgf/cm²
- =0mmHg
- =0Pa
- =0psi
- =0in.Hg



1.1.8 Conversion of pressure units

The relations among kgf/cm², kPa, psi and other units are shown in Table 1-3.



To convert one unit to another, use the following formulae.

- | | | | |
|------|---|---|---|
| (1) | $\text{kgf/cm}^2 \rightarrow \text{atm}$ | To convert kgf/cm^2 into atm
$\text{atm} = 0.9678 \times \text{kgf/cm}^2$ | Example : Convert 20kgf/cm^2 into atm
Solution : $20 \text{kgf/cm}^2 \times 0.9678 \doteq 19.36 \text{atm}$ |
| (2) | $\text{atm} \rightarrow \text{kgf/cm}^2$ | To convert atm into kgf/cm^2
$\text{kgf/cm}^2 = 1.033 \times \text{atm}$ | Example : Convert 2atm into kgf/cm^2
Solution : $2 \text{atm} \times 1.033 = 2.066 \text{kgf/cm}^2$ |
| (3) | $\text{kgf/cm}^2 \rightarrow \text{mmHg}$ | To convert kgf/cm^2 into mmHg
$\text{mmHg} = 735.6 \times \text{kgf/cm}^2$ | Example : Convert 1.5kgf/cm^2 into mmHg
Solution : $1.5 \text{kgf/cm}^2 \times 735.6 \doteq 1103 \text{mmHg}$ |
| (4) | $\text{mmHg} \rightarrow \text{kgf/cm}^2$ | To convert mmHg into kgf/cm^2
$\text{kgf/cm}^2 = 0.001360 \times \text{mmHg}$ | Example : Convert 745mmHg into kgf/cm^2
Solution : $745 \text{mmHg} \times 0.001360 \doteq 1.013 \text{kgf/cm}^2$ |
| (5) | $\text{kgf/cm}^2 \rightarrow \text{MPa}$ | To convert kgf/cm^2 into MPa
$\text{MPa} = 0.098 \times \text{kgf/cm}^2$ | Example : Convert 12kgf/cm^2 into MPa
Solution : $12 \text{kgf/cm}^2 \times 0.098 \doteq 1.176 \text{MPa}$ |
| (6) | $\text{MPa} \rightarrow \text{kgf/cm}^2$ | To convert MPa into kgf/cm^2
$\text{kgf/cm}^2 = 10.2 \times \text{MPa}$ | Example : Convert 105 MPa into kgf/cm^2
Solution : $105 \text{MPa} \times 10.2 = 1071 \text{kgf/cm}^2$ |
| (7) | $\text{kgf/cm}^2 \rightarrow \text{psi}$ | To convert kgf/cm^2 into psi
$\text{psi} = 14.22 \times \text{kgf/cm}^2$ | Example : Convert 20kgf/cm^2 into psi
Solution : $20 \text{kgf/cm}^2 \times 14.22 = 284.4 \text{psi}$ |
| (8) | $\text{psi} \rightarrow \text{kgf/cm}^2$ | To convert psi into kgf/cm^2
$\text{kgf/cm}^2 = 0.07031 \times \text{psi}$ | Example : Convert 300psi into kgf/cm^2
Solution : $300 \text{psi} \times 0.07031 \doteq 21.09 \text{kgf/cm}^2$ |
| (9) | $\text{MPa} \rightarrow \text{psi}$ | To convert MPa into psi
$\text{psi} = 145.0 \times \text{MPa}$ | Example : Convert 15 MPa into psi
Solution : $15 \text{MPa} \times 145.0 = 2175 \text{psi}$ |
| (10) | $\text{psi} \rightarrow \text{MPa}$ | To convert psi into MPa
$\text{MPa} = 0.00689 \times \text{psi}$ | Example : Convert 40psi into MPa
Solution : $40 \text{psi} \times 0.00689 = 0.275 \text{MPa}$ |
| (11) | $\text{psi} \rightarrow \text{in.Hg}$ | To convert psi into in.Hg
$\text{in.Hg} = 2.036 \times \text{psi}$ | Example : Convert 28psi into in.Hg
Solution : $28 \text{psi} \times 2.036 \doteq 57 \text{in.Hg}$ |
| (12) | $\text{in.Hg} \rightarrow \text{psi}$ | To convert in.Hg into psi
$\text{psi} = 0.4912 \times \text{in.Hg}$ | Example : Convert 62in.Hg into psi
Solution : $62 \text{in.Hg} \times 0.4912 \doteq 30.45 \text{psi}$ |



1.1.9 Absolute pressure and gauge pressure

Gauge pressure...Gauge pressure is the pressure as indicated by a gauge. It is important to understand that gauges are calibrated to read zero at atmospheric pressure. Gauges measure only the difference in pressure between the total pressure of the fluid in the vessel and the atmospheric pressure.

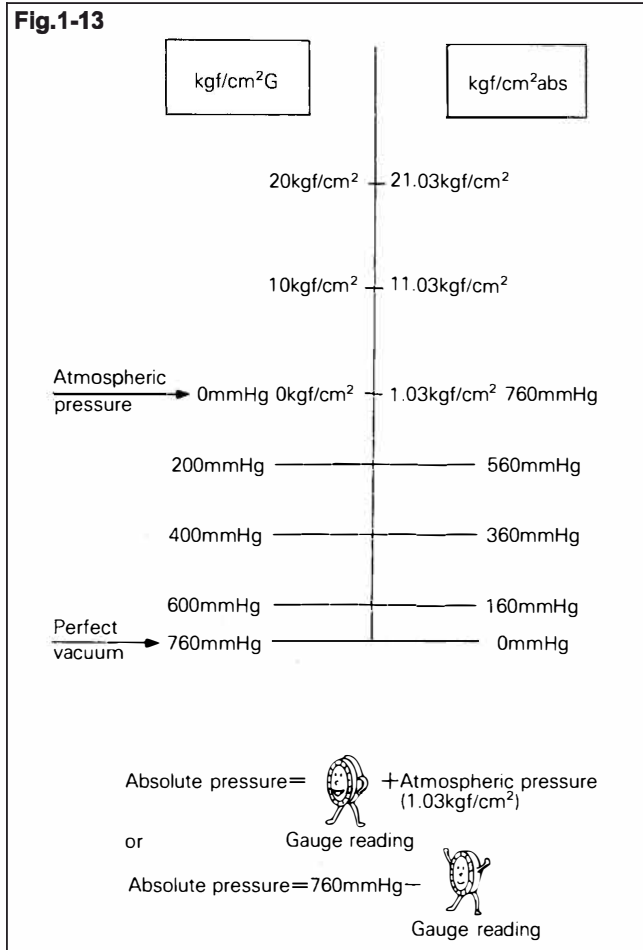
Gauge pressures are expressed as "kgf/cm²G", "psig" or "kPa(G)".

Absolute pressure...Absolute pressure is the "total" or "true" pressure of a fluid. When the fluid pressure is greater than the atmospheric pressure, the absolute pressure of the fluid is determined by adding the atmospheric pressure to the gauge pressure, and when the fluid pressure is less than the atmospheric pressure, the absolute pressure of the fluid is found by subtracting the gauge pressure from the atmospheric pressure.

In solving most pressure and volume problems or using the Mollier chart, it is necessary to use absolute pressures.

Absolute pressures are expressed as "kgf/cm²abs", "psia" or "MPa".

However, it is normal to omit "G", "g", "abs" or "a" except when it is necessary to discriminate gauge pressure from absolute pressure.



Example : A pressure gauge reads 1.8MPa (18kgf/cm²).
 What is the absolute pressure in this case?

Solution : Absolute pressure=[1.8+0.1] MPa; (18+1.03) kgf/cm²
 =1.9MPa; (19.03kgf/cm²)

Example : A compound gauge on the suction pipe reads 200mmHg.
 What is the absolute pressure?

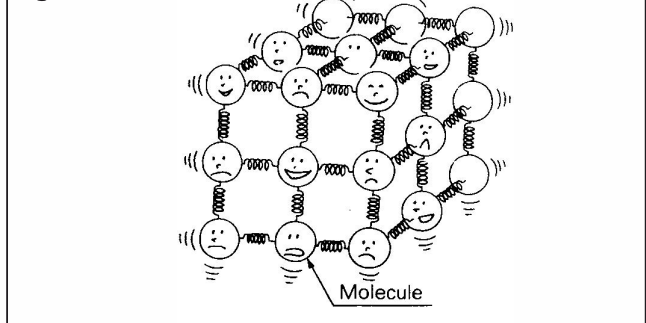
Solution : Absolute pressure=760-200=560mmHg

1.2 Heat and temperature

1.2.1 What is "Heat"?

Heat is a form of energy. It is related to the molecular motion or vibration. A molecule is the smallest particle in which any substance can be broken down and still retain its chemical identity. As a substance is warmed, molecules move more rapidly. As a substance is cooled, they slow down. If all heat is removed from a substance, all molecular motion stops. In other words, if a substance is warmed, heat is added, if cooled, heat is removed. (See Fig. 1-14.)

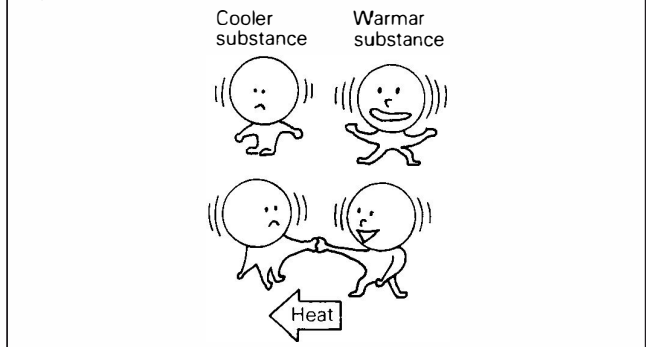
Fig.1-14



1.2.2 Heat flow

Heat always flows from a warmer substance to a cooler one. What happens is that the faster moving molecules give out some of their energy to slower moving molecules. Therefore, the faster molecules slow down a little and the slower ones move a little faster. (See Fig. 1-15.)

Fig.1-15



1.2.3 Heat transfer

Heat may be transferred from one body to another by one of the following methods.

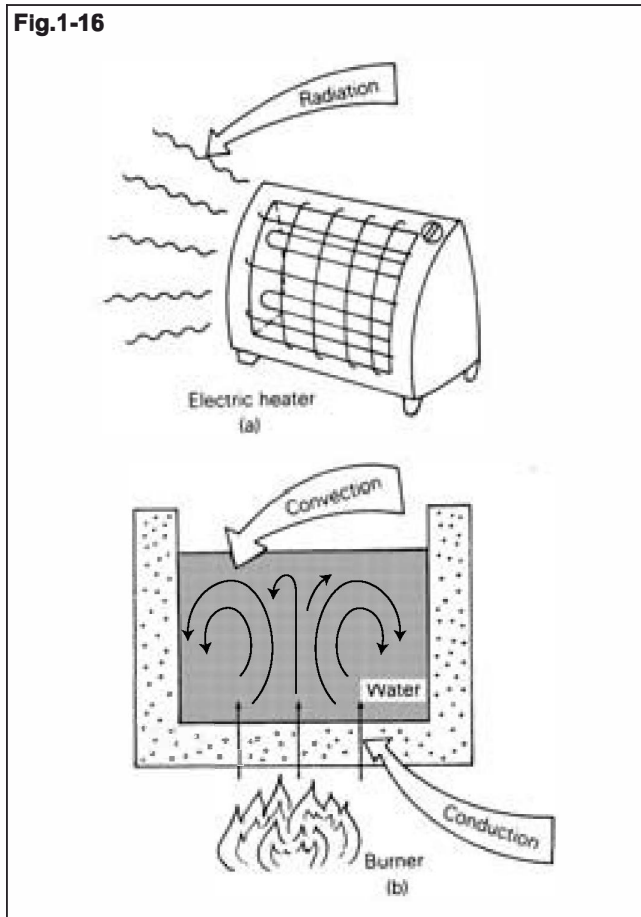
Radiation...The heat transfer in the form of a wave motion similar to light waves in which the energy is transmitted from one body to another without the need for intervening matter. [See Fig. 1-16(a).]

Conduction...The flow of heat among parts of a substance. The flow can also be from one substance to another substance in direct contact. [See Fig. 1-16(b).]

Convection...The moving of heat from one place to another by way of fluid or air. [See Fig. 1-16(b).]

Some systems of heat transfer use a combination of these three methods.

Fig.1-16

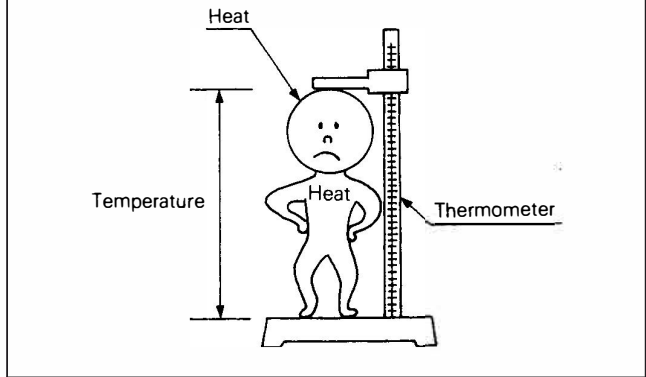


1.2.4 What is "Temperature"?

Temperature...Temperature measures the heat intensity or heat level of a substance. Temperature alone does not give the amount of heat in a substance. It indicates the degree of warmth or how hot or cold a substance or body is.

It is important not to use the words "heat" and "temperature" carelessly.

Fig.1-17



1.2.5 Thermometric scales

The most common thermometer scale in the metric system is the Celsius, sometimes called the Centigrade scale. Other common thermometer scale in the yard-pound system is the Fahrenheit. The S.I metric system uses the Kelvin which is explained in 1.2.7.

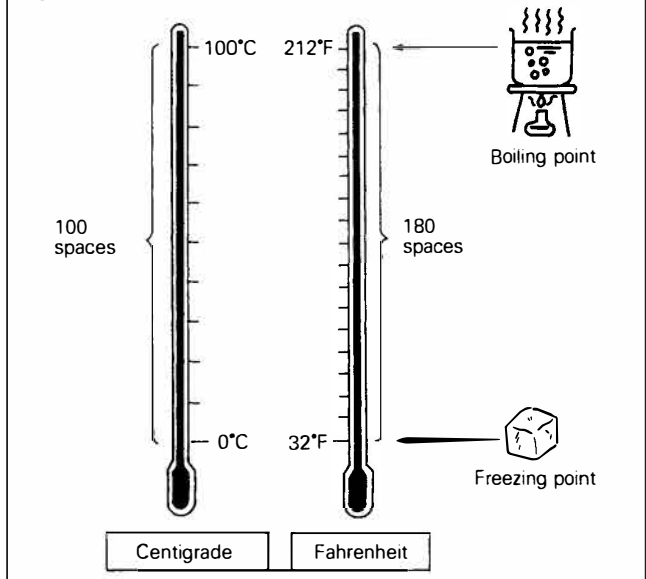
The calibration of thermometers for these two scales are determined by the temperature of melting ice and boiling water.

Centigrade...On the Centigrade scale, the temperature of melting ice or the freezing temperature of water is 0°C. The temperature of boiling water is 100°C. There are 100 spaces or degrees on the scale between freezing and boiling temperatures.

Fahrenheit...On the Fahrenheit thermometer, the temperature of melting ice or the freezing temperature of water is 32°F. The temperature of boiling water is 212°F. This provides 180 spaces or degrees between the freezing and boiling temperature.

* The freezing and boiling points are based on freezing and boiling temperatures of water at the standard atmospheric pressure.

Fig.1-18



1.2.6 Absolute zero

Absolute zero... Absolute zero is that temperature at which molecular motion stops. It is the lowest temperature possible. There is no more heat remaining in the substance at this point.

Fig.1-19



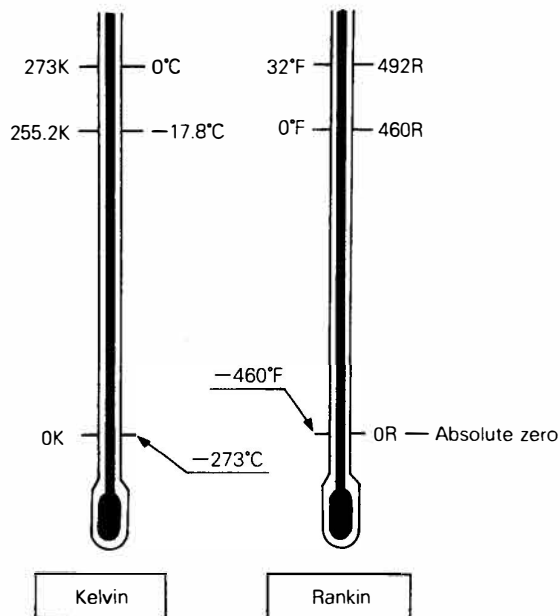
1.2.7 Absolute temperature scales

Two absolute temperature scales are used with very low temperature work or in solving thermodynamic problems. Both conventional metric and S.I metric system use the Kelvin scale and the yard-pound system uses the Rankine.

Kelvin [K]...The kelvin scale uses the same divisions as the Celsius scale. Zero on the Kelvin scale (0K) is 273 degrees below 0°C.

Rankin [R]...The Rankine scale uses the same divisions as the Fahrenheit scale. Zero on the Rankine scale (0R) is 460 degrees below 0°F.

Fig.1-20





1.2.8 Temperature conversion formulae

It is sometimes necessary to convert a temperature from one scale to another. Formulae are provided below.

- (1) $^{\circ}\text{C} \rightarrow ^{\circ}\text{F}$ To convert Celsius degrees into Fahrenheit degrees.

$$\begin{aligned}\text{Temp.}^{\circ}\text{F} &= \left(\frac{180}{100} \times \text{Temp.}^{\circ}\text{C}\right) + 32 \\ &= \left(\frac{9}{5} \times \text{Temp.}^{\circ}\text{C}\right) + 32\end{aligned}$$

Example : Convert 40°C into Fahrenheit

Solution : $\text{Temp.}^{\circ}\text{F} = \left(\frac{9}{5} \times 40\right) + 32 = 104^{\circ}\text{F}$

- (2) $^{\circ}\text{F} \rightarrow ^{\circ}\text{C}$ To convert Fahrenheit degrees into Celsius degrees.

$$\begin{aligned}\text{Temp.}^{\circ}\text{C} &= \frac{100}{180} \times (\text{Temp.}^{\circ}\text{F} - 32) \\ &= \frac{5}{9} \times (\text{Temp.}^{\circ}\text{F} - 32)\end{aligned}$$

Example : Convert 50°F into Celsius

Solution : $\text{Temp.}^{\circ}\text{C} = \frac{5}{9} \times (50 - 32) = 10^{\circ}\text{C}$

- (3) $^{\circ}\text{C} \rightarrow \text{K}$ To convert Celsius degrees to Kelvin degrees.

$$\text{Temp. K} = \text{Temp.}^{\circ}\text{C} + 273$$

Example : Convert -20°C to Kelvin

Solution : $\text{Temp. K} = (-20) + 273 = 253\text{K}$

- (4) $\text{K} \rightarrow ^{\circ}\text{C}$ To convert Kelvin degrees to Celsius degrees.

$$\text{Temp.}^{\circ}\text{C} = \text{Temp. K} - 273$$

Example : Convert 400K to Celsius

Solution : $\text{Temp.}^{\circ}\text{C} = 400 - 273 = 127^{\circ}\text{C}$

- (5) $^{\circ}\text{F} \rightarrow \text{R}$ To convert Fahrenheit degrees to Rankine degrees.

$$\text{Temp. R} = \text{Temp.}^{\circ}\text{F} + 460$$

Example : Convert 20°F to Rankine

Solution : $\text{Temp. R} = 20 + 460 = 480\text{R}$

- (6) $\text{R} \rightarrow ^{\circ}\text{F}$ To convert Rankine degrees to Fahrenheit degrees.

$$\text{Temp.}^{\circ}\text{F} = \text{Temp. R} - 460$$

Example : Convert 200R to Fahrenheit

Solution : $\text{Temp.}^{\circ}\text{F} = 200 - 460 = -260^{\circ}\text{F}$

1.2.9 Units of heat

As explained already, a thermometer measures only the intensity of heat but not a quantity. However, in working with heat, it is often necessary to determine heat quantities. Obviously, certain units of heat are required. There are several units of heat. The conventional metric system uses the calorie [cal] or the kilocalorie [kcal]. The S.I metric system uses the joule [J] or the kilojoule [kJ]. The yard-pound system uses the British thermal unit [Btu].

Calorie [cal]...The amount of heat required/removed to raise/lower the temperature of 1g water 1°C is equal to 1cal. [See Fig. 1-22(a).]

Kilocalorie [kcal]...The amount of heat required/removed to raise/lower the temperature of 1kg water 1°C is equal to 1kcal. [See Fig. 1-22(b).]

Joule [J]...The amount of heat required to raise the temperature of 1g water 1°C is equal to 4.187J. On the contrary, the amount of heat removed to lower the temperature of 1g water 1°C is also equal to 4.187J. [See Fig. 1-22(a).]

Kilojoule [kJ]...The amount of heat required/removed to raise/lower the temperature of 1kg water 1°C is equal to 4.187kJ. [See Fig. 1-22(b).]

British thermal unit [Btu]...The amount of heat required/removed to raise/lower the temperature of 1lb water 1°F is equal to 1Btu. [See Fig. 1-22(c).]

The relations among cal, kcal and other units are shown in Table 1-4.

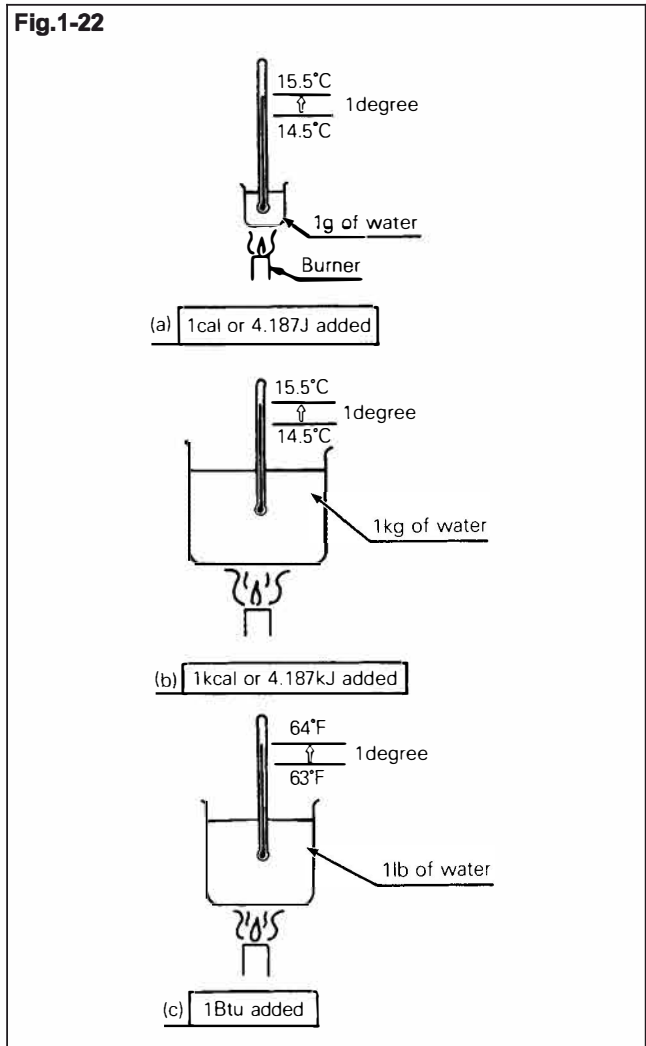
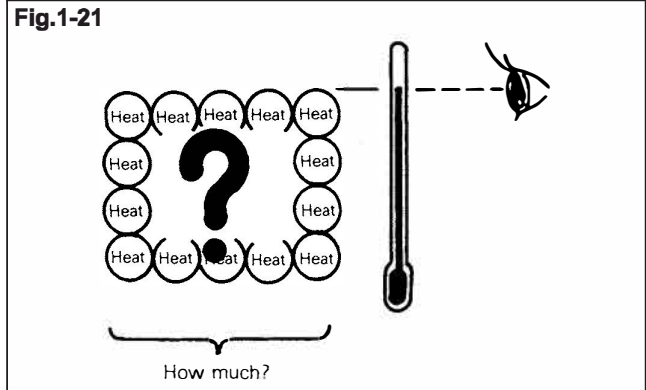


Table 1-4

Conventional metric systems		S.I metric system		Yard-pound system
cal	kcal	J	kJ	Btu
1	0.001	4.186	0.004186	0.003968
1000	1	4186	4.186	3.968
0.2389	0.0002389	1	0.001	0.000948
238.9	0.2389	1000	1	0.9480
252	0.2520	1055	1.055	1



To convert one unit to another, use the following conversions.

- (1) **cal → kcal** To convert calories into kilocalories
 $kcal = 0.001 \times cal$
Example : Convert 2500cal into kcal
Solution : $2500cal \times 0.001 = 2.5kcal$
- (2) **kcal → cal** To convert kilocalories into calories
 $cal = 1000 \times kcal$
Example : Convert 5kcal into cal
Solution : $5kcal \times 1000 = 5000cal$
- (3) **kcal → kJ** To convert kilocalories into kilojoules
 $kJ = 4.186 \times kcal$
Example : Convert 5kcal into kJ
Solution : $5kcal \times 4.186 \approx 20.93kJ$
- (4) **kJ → kcal** To convert kilojoules into kilocalories
 $kcal = 0.2389 \times kJ$
Example : Convert 100kJ into kcal
Solution : $100kJ \times 0.2389 = 23.89kcal$
- (5) **kcal → Btu** To convert kilocalories into British thermal units
 $Btu = 3.968 \times kcal$
Example : Convert 2500kcal into Btu
Solution : $2500kcal \times 3.968 = 9920Btu$
- (6) **Btu → kcal** To convert British thermal units into kilocalories
 $kcal = 0.2520 \times Btu$
Example : Convert 20000Btu into kcal
Solution : $20000Btu \times 0.2520 = 5040kcal$
- (7) **Btu → kJ** To convert British thermal units into kilojoules
 $kJ = 1.055 \times Btu$
Example : Convert 25000Btu into kJ
Solution : $25000Btu \times 1.055 = 26375kJ$
- (8) **kJ → Btu** To convert kilojoules into British thermal units
 $Btu = 0.9480 \times kJ$
Example : Convert 500kJ into Btu
Solution : $500kJ \times 0.9480 = 474Btu$
- (9) **J → kJ** To convert joules into kilojoules
 $kJ = 0.001 \times J$
Example : Convert 8000J into kJ
Solution : $8000J \times 0.001 = 8kJ$
- (10) **kJ → J** To convert kilojoules into joules
 $J = 1000 \times kJ$
Example : Convert 2kJ into J
Solution : $2kJ \times 1000 = 2000J$



1.2.10 Work, energy and power

Work...Work is force multiplied by the distance through which it travels.

The units of work are the kilogram force meter [kgf·m] in the conventional metric system, the joule [J] in the S.I metric and the foot-pound force [ft·lbf] in the yard-pound system.

Kilogram force meter [kgf·m]...Kilogram force meter is the amount of work done by a force of 1kgf moving its point of application a distance of 1m. [See Fig. 1-23(a).]

Joule [J]...Joule is the amount of work done by a force of 1N moving its point of application a distance of one meter. [See Fig. 1-23(b).]

Energy...Energy is the capacity or ability to do work.

In the refrigeration work, three common, related forms of energy must be considered; i.e. mechanical, electrical and heat. The study of refrigeration deals mainly with heat energy, but the heat energy is usually produced by a combination of electrical and mechanical energy. In a refrigerating unit, electrical energy flows into an electric motor, and this electrical energy is turned into mechanical energy, which is used to turn a compressor. The compressor compresses the vapor to a high pressure and high temperature, transforming mechanical energy into heat energy. (See Fig. 1-24.)

Various units are used for measuring mechanical, heat and electrical energy. Table 1-5 shows the relations among these units.

Power...Power is the time rate of doing work.

The units of power are kilogram force meter per second [kgfm/s] in the conventional metric system, kilowatt [kw] in the S.I metric and foot-pound force per second [ft.lbf/s] in the yard-pound system.

There are also various units other than above mentioned. Table 1-6 shows the relation among these units.

Fig.1-23

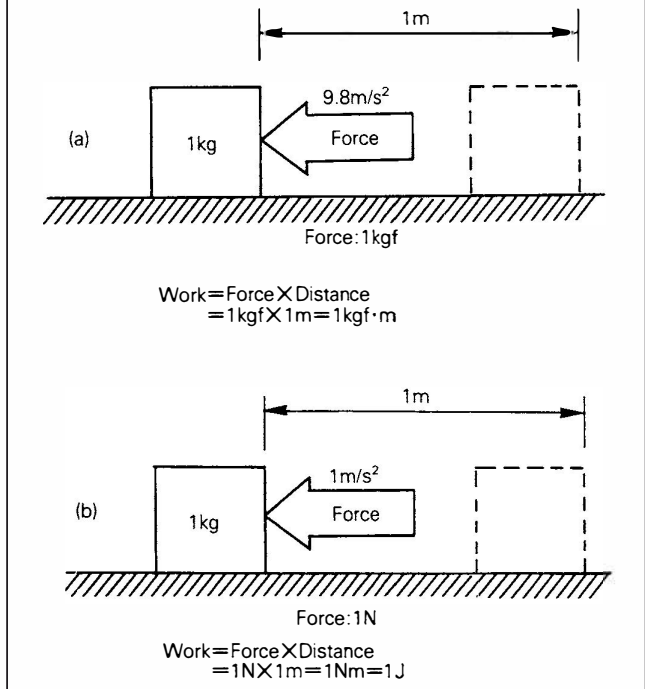


Fig.1-24

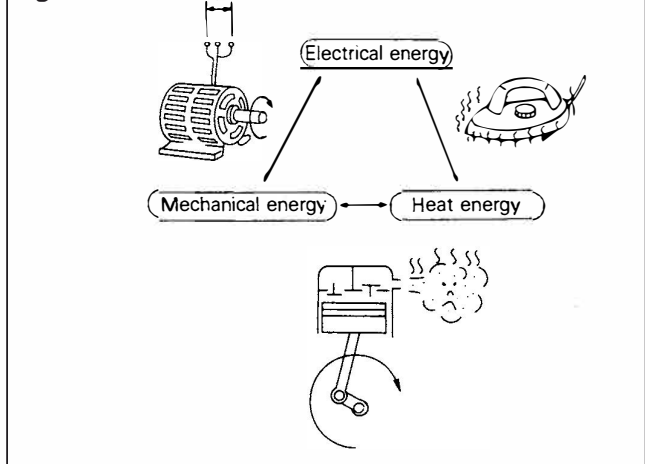


Table 1-5

Conventional metric system				S.I metric system	Yard-pound system		
Mechanical energy		Electrical energy	Heat energy	Mechanical electrical and heat energy	Mechanical energy		Heat energy
kgf·m	PS·h	kW·h	kcal	J	ft·lbf	HP·h	Btu
1	0.000003704	0.000002724	0.002343	9.807	7.233	0.000003652	0.009297
270000	1	0.7355	632.5	2648000	1953000	0.9859	2510
367100	1.3596	1	860.0	3600000	2655000	1.3405	3413
426.9	0.001581	0.001163	1	4186	3087	0.001559	3.968
0.1020	0.0000003777	0.0000002778	0.0002389	1	0.7376	0.0000003724	0.0009480
0.1383	0.0000005121	0.0000003766	0.0003289	1.356	1	0.0000005049	0.001285
273900	1.014	0.746	641.6	2686000	1981000	1	2546
107.6	0.0003984	0.0002930	0.2520	1056	778.0	0.0003928	1



Table 1-6

Conventional metric system			S.I metric system	Yard-pound system		
kgf-m/s	PS	kcal/s	kW	ft-lbf/s	HP	Btu/s
1	0.01333	0.002343	0.009807	7.233	0.01315	0.009297
75	1	0.1757	0.7355	542.5	0.9859	0.6973
426.9	5.691	1	4.186	3087	5.611	3.968
102	1.360	0.2389	1	737.6	1.340	0.9180
0.1383	0.001843	0.003239	0.001356	1	0.001817	0.001285
76.07	1.014	0.1782	0.746	550.2	1	0.7072
107.6	1.434	0.2520	1.055	778.0	1.414	1

* One must understand through this section that heat is one of energy forms and can be converted into other forms and vice versa. Many conversion units represented in this section are used for calculating loads and determining the capacity of an equipment required for specific refrigeration applications.

1.3 Sensible heat and latent heat

1.3.1 Three physical states (phases)

Substances exist in three states depending on their temperature, pressure and heat content. For example, water under the standard atmospheric pressure is a solid (ice) at temperature below 0°C (32°F), and liquid (water) from 0°C (32°F) to 100°C (212°F). At 100°C (212°F) and above, it becomes gas (vapor). (See Fig. 1-25.)

Solids...A solid is any physical substance which keeps its shape even when not contained. It consists of billions of molecules, all exactly the same size, mass and shape.

These stay in the same relative position to each other, and yet, they are in the condition of rapid vibration. The rate of vibration will depend upon temperature. The lower the temperature, the slower molecules vibrate, the higher the temperature, the faster the vibration. The molecules are strongly attracted to each other. Considerable force is necessary to separate them. [See Fig. 1-26(a).]

Liquids...A liquid is any physical substance which will freely take on the shape of its container. Yet, its molecules strongly attract each other. Think of the molecules as swimming among their fellow molecules without ever leaving them. The higher the temperature, the faster the molecules swim. [See Fig. 1-26(b).]

Gases...A gas is any physical substance which must be enclosed in a sealed container to prevent its escape into the atmosphere. The molecules, having little or no attraction for each other, fly in a straight line. They bounce off each other, off molecules of other substances, or off the container walls. [See Fig. 1-26(c).]

Most substances change their physical state with the addition or removal of heat.

Adding heat causes

- solids to become liquids...Fusion
- solids to become gases...Sublimation
- liquids to become gases...Vaporization

Removing heat causes

- gases to become liquids...Condensation
- liquids to become solids...Solidification

(See Fig. 1-27.)

Fig.1-25

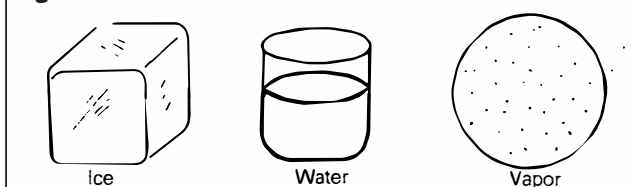


Fig.1-26

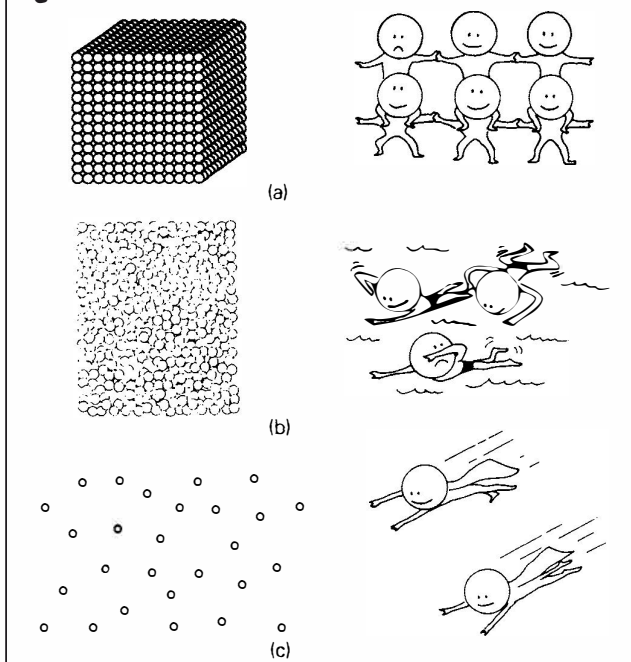
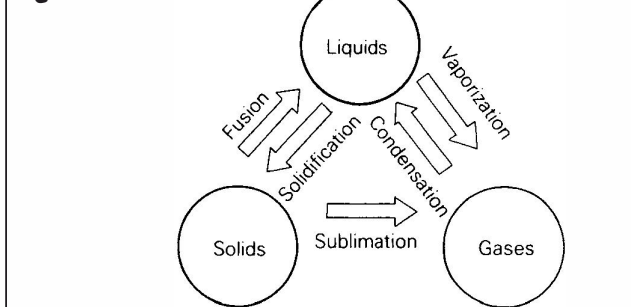


Fig.1-27



These changes of state occur at the same temperature and pressure combinations for any given substance.



1.3.2 Phase change of water

Suppose chipped ice of -50°C is to be heated in an vessel over gas flame. As the heat is applied, the temperature of the chipped ice will rise until the ice begins to melt. Then the temperature will stop rising and will remain at 0°C as long as there is any amount of ice left. Finally all the chipped ice becomes 0°C water.

Obviously, the burning gas is supplying heat to the ice. But if the ice temperature ceases to rise, where is this heat going? The answer is that the ice is melting; it is changing from solid to liquid. Now, to change any substance from solid to liquid requires the application of heat.

When the chipped ice has melted completely, further application of heat will raise the temperature until the water begins to boil. Then the temperature will stop rising and will remain at 100°C as long as the water is boiling. Finally all the water becomes 100°C vapor.

To change any substance from liquid to vapor also requires the application of heat.

When the water has vaporized completely, further application of heat to the 100°C vapor will raise the temperature of the vapor.

Melting temperature...The temperature at which a solid will change into the liquid phase is called the "melting temperature" or "melting point".

Boiling temperature...The temperature at which a liquid will change into the vapor phase is called the "boiling temperature" sometimes referred to as "boiling point", "evaporation temperature", "vaporizing temperature" or "saturation temperature".

The above explanation is the case of adding heat to the substance. If heat is removed from the substance, the process is reversed. For instance, the vapor will be condensed and the liquid will be solidified by removing heat.

Condensing temperature...The temperature at which a vapor will change into the liquid phase is called the "condensing temperature" or "saturation temperature".

Solidification temperature...The temperature at which a liquid will change into the solid phase is called the "solidification temperature".

Fig.1-28

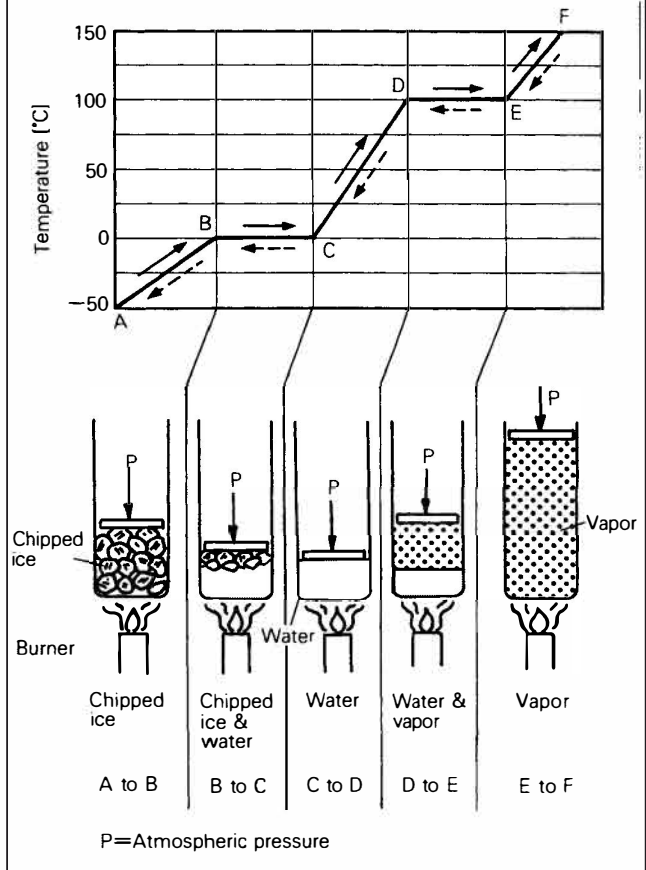
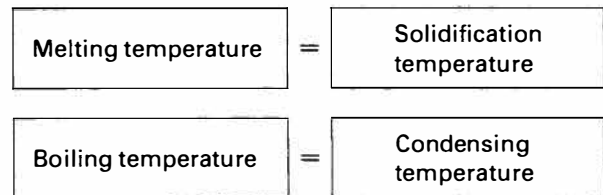


Fig.1-29



* At the constant pressure



1.3.3 Saturation, super-heating and subcooling

Saturated liquid...When the temperature of a liquid is raised to the saturation temperature, that is, any additional heat applied to the liquid will cause a part of the liquid to vaporize, the liquid is said to be saturated. Such liquid is called a "saturated liquid".

Saturated vapor...When the temperature of a vapor is decreased to the saturation temperature, that is, any further cooling of the vapor will cause a portion of the vapor to condense, the vapor is said to be saturated. Such a vapor is called a "saturated vapor".

A saturated vapor may be described also as a vapor ensuring from the vaporizing liquid as long as the temperature and pressure of the vapor are the same as those of the saturated liquid from which it came.

Superheated vapor...When the temperature of a vapor is so increased above the saturation temperature, the vapor is said to be superheated and is called a "superheated vapor".

In order to superheat a vapor it is necessary to separate the vapor from the vaporizing liquid. As long as the vapor remains in contact with the liquid it will be saturated. This is because any heat added to a liquid-vapor mixture will merely vaporize more liquid and no superheating will occur.

Sub-cooled liquid...If, after condensation, a liquid is cooled so that its temperature is reduced below the saturation temperature, the liquid is said to be "sub-cooled". A liquid at any temperature and above the melting temperature is a sub-cooled liquid.

Amount of superheat and subcool are determined by applying the following equation:

Amount of superheat (S.H.)=temperature of the superheated vapor-saturation temperature corresponding to the pressure

Amount of subcool (S.C.)=saturation temperature corresponding to the pressure-temperature of the sub-cooled liquid

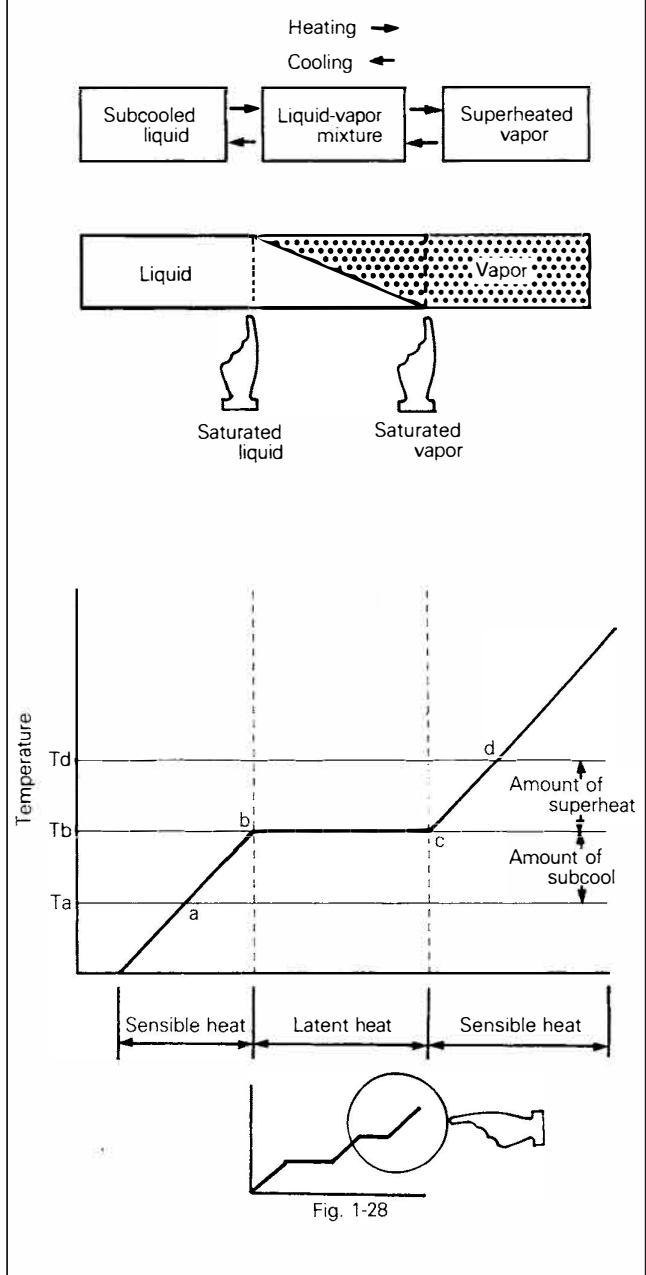
Example : Give the amount of superheat of a steam (water) at 120°C, 1 atm.

Solution : Saturation temperature=100°C
 S.H.=120°C-100°C=20°C

Example : Give the amount of subcool of water at 60°C, 1 atm.

Solution : S.C.=100°C-60°C=40°C

Fig.1-30



1.3.4 Saturation temperature

The saturation temperature of substances differs from one to others. Water boils at 100°C, alcohol vaporizes at 78°C and R-22 at -40.8°C under the atmospheric pressure.

The saturation temperature of a liquid or a vapor varies with the pressure. Increasing the pressure raises the saturation temperature and decreasing the pressure lowers the saturation temperature.

For example, the saturation temperature of water at atmospheric pressure 0.1MPa (1.03kgf/cm²abs) is 100°C. If the pressure over the water is increased from 0.1MPa (1.03kgf/cm²abs) to 0.2MPa (2.0kgf/cm²abs), the saturation temperature of the water increases from 100°C to 119°C. On the other hand, if the pressure over the water is reduced from 0.1MPa (1.03kgf/cm²abs) to 0.05MPa (0.5kgf/cm²abs), the new saturation temperature of the water will be 81°C.

Saturation chart...Fig. 1-31 shows the relationship between the pressure and the temperature of water and R-22. Such graph is called a "saturation chart".

The saturation chart is very useful to obtain the followings.

- (1) To know the physical state of a substance
 - If the intersection of temperature and pressure lines of a substance are on the left to the saturation curve, this substance is said to be sub-cooled.
 - If the intersection is on the right to the curve, this substance is said to be superheated.
 - If the intersection is exactly on the curve, this substance is said to be saturated. [See Fig. 1-32(a).]
- (2) To obtain the saturation temperature corresponding to the pressure
 - The saturation temperature is the temperature at which the pressure line and the saturation curve intersect. [See Fig. 1-32(b).]
- (3) To obtain the saturation pressure corresponding to the temperature
 - The saturation pressure is the pressure at which the temperature line and the saturation curve intersect. [See Fig. 1-32(b).]
- (4) To find the amount of S.H. and S.C.
 - The distance between the state point and the saturation curve represents the amount of S.H. or S.C. [See Fig. 1-32(c).]

Use the saturation table shown in Fig 362 instead of the saturation chart described previously, and reading accuracy is improved, which is very convenient for after-sales services.

Fig.1-31

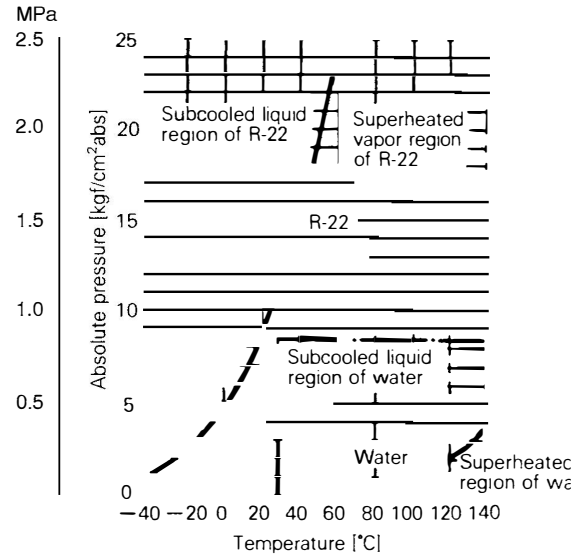
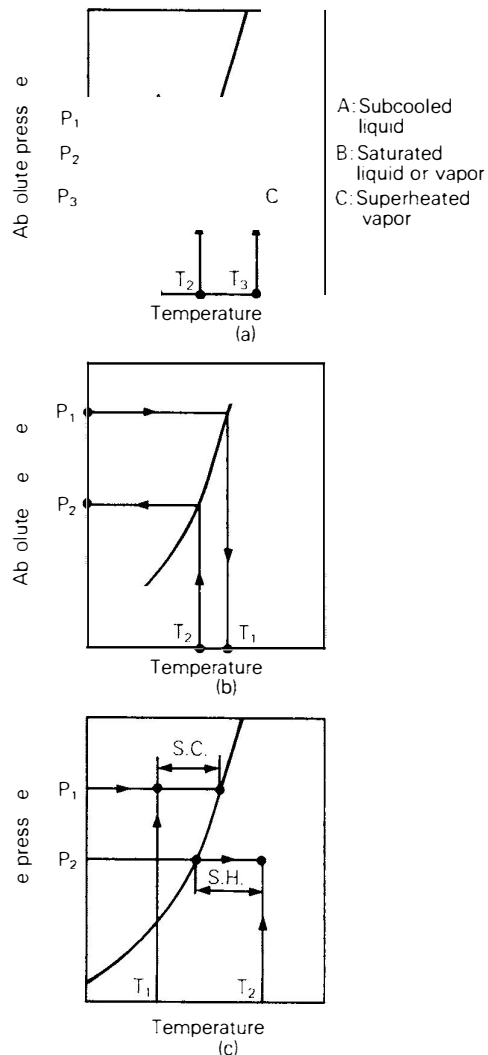
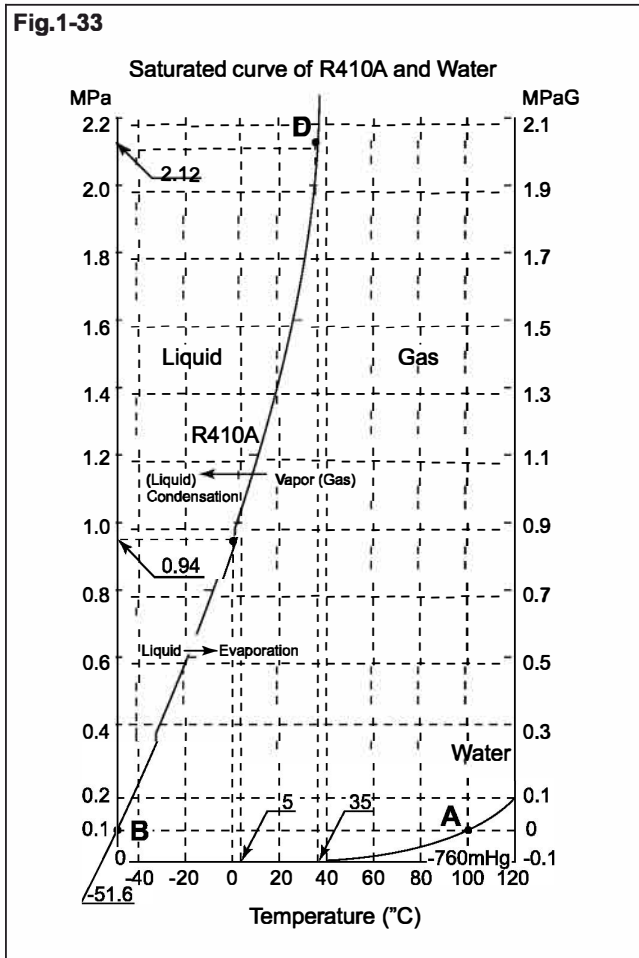


Fig.1-32



At Point B, the R410A refrigerant of 0.1MPa boils at a temperature of -51.6°C .
 Therefore, at **Point D**, if the R410A refrigerant having a temperature of 35°C is in a state of saturated vapor at the pressure of 2.12MPa, it becomes refrigerant saturated liquid of 35°C by removing the condensation latent heat from the said saturated vapor.
 By contrast, at Point C, that means it is required to reduce the pressure down to 0.94MPa in order to boil the R410A refrigerant at 5°C .

Fig.1-33



1.3.5 Sensible heat and latent heat

Fig. 1-34 shows the "temperature-heat content diagram" for 1kg of water heated from -50°C to 150°C vapor under the atmospheric pressure.

- (1) From A to B, 105.4kJ(25.2kcal) of heat were added to increase ice temperature from -50°C to 0°C .
- (2) From B to C, 333.2kJ(79.6kcal) were added to melt ice without changing its temperature.
- (3) From C to D, 418.6kJ(100kcal) were added to heat water to boiling point. (from 0°C to 100°C)
- (4) From D to E, 2256kJ(539kcal) were added to change water to vapor without changing its temperature.
- (5) From E to F, 92.5kJ(22.1kcal) were added to increase vapor temperature from 100°C to 150°C .

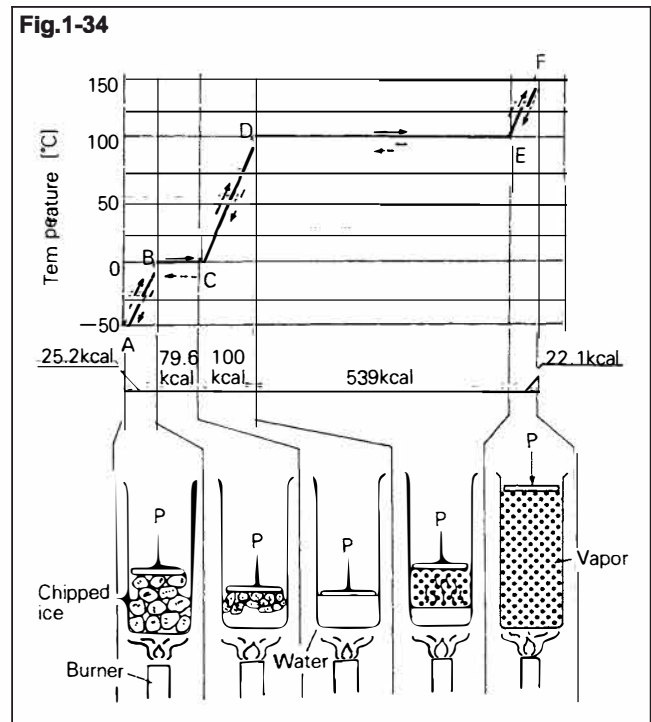
In this example,

- The heat which was required to increase the ice temperature is called "sensible heat". (A to B)
- The heat which was required to change the ice to water is called "latent heat of melting". (B to C)
- The heat which was required to increase the water temperature is also called "sensible heat". (C to D)
- The heat which was required to change the water to steam is called "latent heat of vaporization". (D to E)

If the process is reversed,

- The heat which must be rejected to change the steam to water is called "latent heat of condensation". (E to D)
- The heat which must be rejected to decrease the water temperature is called "sensible heat". (D to C)
- The heat which must be rejected to change the water to ice is called "latent heat of solidification". (C to B)
- The heat which must be rejected to decrease the ice temperature is called "sensible heat". (B to A)

Fig.1-34



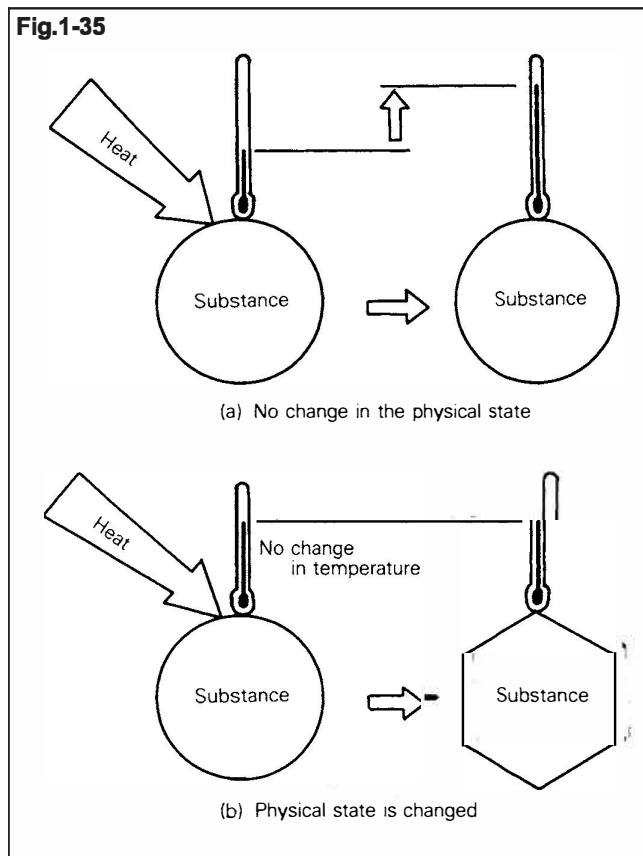


Sensible heat...If a substance is heated and the temperature rises as the heat is added, the increase in heat is called sensible heat. Likewise, heat may be removed from a substance. If the temperature falls, the heat removed is also called sensible heat. [See Fig. 1-35(a).]

Heat which causes a change in temperature in a substance is called sensible heat.

Latent heat...It has already been established that all pure substances are able to change their state. Solids become liquids, liquids become gases, etc. It takes the addition of heat or the removal of heat to produce these changes. Heat causes these changes are called latent heat. [See Fig. 1-35(b).]

Heat which brings about a change of state with no change in temperature is called latent heat.



1.3.6 Calculating heat amount

Specific heat...The specific heat of a substance is the amount of heat that must be added or released to change the temperature of one kilogram of the substance one degree Celsius.

Note that by the definition of kcal the specific heat of water is 1 kcal per kilogram per degree Celsius.

The heat required to cause a temperature change in substances varies with kinds and amounts of substances. Table 1-7 lists the specific heat of several common substances.

Table 1-7

Substance	Specific heat	
	Conventional metric and Yard-pound system	S.I metric system
	kcal/kg °C, Btu/lb °F	kJ/kg ·K
Water	1.0	4.187
Ice	0.504	2.110
Wood	0.327	1.369
Iron	0.129	0.540
Mercury	0.0333	0.139
Alcohol	0.615	2.575
Copper	0.095	0.398

Note: The above values may be used for calculations which involve no change of state.

* The specific heat of any material also varies somewhat throughout the temperature scale. The variation is so slight that it can be considered that the specific heat is a constant amount for most calculations.

The amount of heat which must be added to or removed from any given mass of material in order to bring about a specified change in its temperature can be computed by using the following equation:

$$Q_s = M \cdot C (t_2 - t_1)$$

Where Q_s = Amount of heat either absorbed or rejected by the substance

M = Mass of the substance

C = Specific heat of the substance

t_2 = Final temperature

t_1 = Initial temperature

Example : Find the amount of heat, in kcal, which must be added to heat 20kg of copper block from 30°C to 250°C

Solution : The specific heat of copper
 = 0.095 kcal/kg °C
 $Q_s = 20\text{kg} \times 0.095 \text{ kcal/kg}^\circ\text{C} \times (250 - 30)^\circ\text{C}$
 = 418kcal

Solution **<SI Metric>**

The specific heat of copper
 = 0.398 kJ/kg ·K
 $Q_s = 20\text{kg} \times 0.398\text{kJ/kg} \cdot\text{K} \times (250 - 30)^\circ\text{C}$
 = 1751.2 kJ

