16 REFRIGERATION AND AIR CONDITIONING

Cooling of or removal of heat from a system is known as *refrigeration*. A machine which produces cold is known as a *refrigerator*. Thus a refrigerator can either cool or maintain the temperature of a body below that of surroundings.

In heat engine, heat flows from higher temperature to lower temperature and produces work and in refrigeration, the heat flows from low temperature to higher temperature by doing the external work as shown in fig. 16.1.

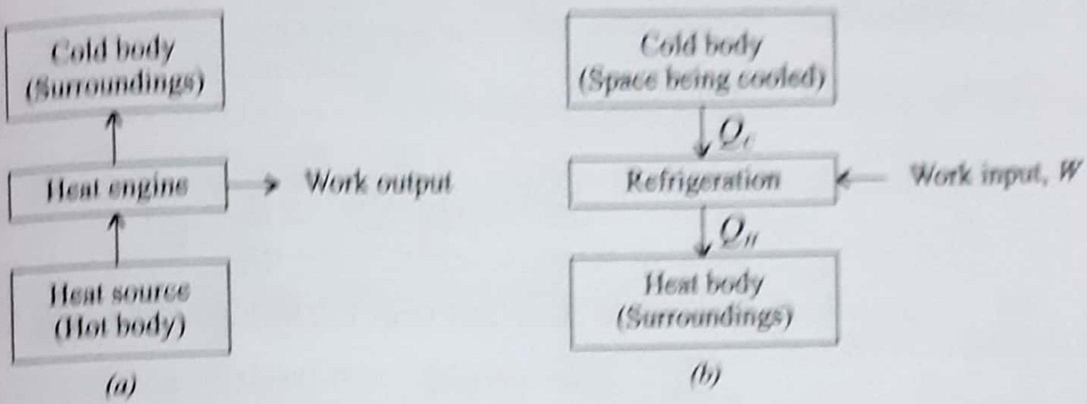

Fig. 16.1 (a) Heat engine, (b) Refrigeration

Applications of refrigeration

The refrigerator is applied for the following purposes

1. Manufacture of ice
2. Processing the food products and beverages
3. To preserve the food, medical and surgical aids
4. Industrial air-conditioning
5. Comfort air-conditioning of hospitals, hotels, theatres, residence, etc.
6. Manufacture of synthetic rubber and photo films
7. Chemical and related industries
8. Liquefication of gases such as nitrogen, oxygen, natural gas, etc.
9. Manufacturing and treatment of metals

Unit of refrigeration

The unit of refrigeration is expressed in kilowatts (kilojoules per second). It is the amount of heat which must be removed per unit time.

Tonne of refrigeration: A tonne of refrigeration is the amount of heat to be removed in order to form one tonne of ice at 0°C in 24 hours when the temperature of water supplied is 0°C. (one tonne = 3.5 kW = 3.5 kJ/s = 210 kJ/min = 3000 Kcal/hr). A tonne of refrigeration is not a unit of mass but a measure of cooling rate.

Coefficient of performance (C.O.P.)

The performance of a refrigeration system is expressed by a term known as *coefficient of performance.* It is defined as the ratio of heat extracted from the refrigerator to the work done.

Let Q = Amount of heat to be removed from cold reservoir

Q_H = Amount of heat supplied to the hot reservoir

W = Input work

$$\therefore \quad \text{Coefficient of performance} \quad \text{COP} = \frac{\text{desired output}}{\text{required input}} = \frac{Q_C}{W} \qquad \text{..... (1)}$$

By first law of thermodynamics, $Q_H = Q_C + W$

$$\therefore \quad \text{Equation (1), becomes} \qquad \text{COP} = \frac{Q_C}{Q_H - Q_C} = \frac{1}{\frac{Q_H}{Q_C} - 1}$$

The first law allows the COP to be greater than 1. The higher the COP, the higher the cooling efficiency of the equipment.

$$\text{Relative} \quad \text{COP} = \frac{\text{actual COP}}{\text{theoretical COP}}$$

The theoretical COP is calculated using laws of thermodynamics.

Types of refrigeration systems

The various important mechanical refrigeration systems are :

1. Vapour compression refrigeration
2. Vapour absorption refrigeration
3. Air refrigeration

The vapour compression refrigeration and vapour absorption refrigeration systems are discussed below.

Parts of a refrigerator

The essential elements required to accomplish the refrigerating process and make up the refrigerating system are :

1. Evaporator, 2. Compressor, 3. Condenser, and 4. Expansion valve.

Evaporator: It is also called as the *cooling unit, chilling unit* or *freezing unit.* The cooling effect is produced in the evaporator. It consists of a coil form of metal tube kept in the medium which is desired to cool. The purpose of this coil is to provide more surface area over which the medium can come in contact, and at the same time, a passage through which refrigerant can flow. The refrigerant in the form of liquid enters the evaporator, absorbs heat from the medium and will gradually change from a liquid to a mixture of liquid and vapour, and finally to a vapour.

Compressor: Compressor is used to establish a pressure difference and thus cause the refrigerant to flow from one part of the system to other. Refrigeration compressors are usually either rotary or reciprocating type and is driven by an electric motor. The main functions of the compressor are:

1. It draws the vapour refrigerant from the evaporator and forces it into the condenser.
2. It increases the pressure and thereby the temperature of the refrigerant.

Condenser: It is made of either finned tubing or tubing interlaced with wire, to increase the heat transfer area. The two important functions of condenser are:

1. It transfers the latent heat which was absorbed by the refrigerant in the evaporator to the surrounding air.
2. It condenses the refrigerant vapour to a refrigerant liquid so that it can be reused in the refrigeration cycle.

Expansion valve: The functions of the expansion valve are:

1. To control the rate at which the refrigerant is admitted to an evaporator.
2. To reduce the pressure and cool the refrigerant.

Vapour compression refrigeration

refrigerant

Most of the modern refrigerators work on vapour compression cycle. In this method, the vapour alternately undergoes a change of phase from vapour to liquid and liquid to vapour during the completion of a cycle. The latent heat of vapourisation is used for absorbing the heat from the refrigerated space and the same is rejected during condensation. In a simple vapour compression system four fundamental processes are completed in one cycle. They are, compression, condensation, expansion and vapourisation.

The flow diagram of vapour compression refrigerator is shown in fig. 16.2. The refrigerant in the form of vapour at low pressure and temperature enters the compressor. In the compressor, it is compressed isentropically and subsequently its pressure and temperature increases. This compressed vapour then enters the condenser. In the condenser, heat is transferred from the hot compressed refrigerant vapour to a cooling medium, usually air or water. The refrigerant is condensed into liquid and is collected in a receiver. From the receiver, it passes through the expansion valve. The expansion valve reduces the pressure of the refrigerant liquid and thereby it reduces the temperature. It finally passes on to the evaporator where it absorbs heat from the surrounding or circulating fluid being refrigerated and vapourises to low pressure vapour, and the cycle is repeated.

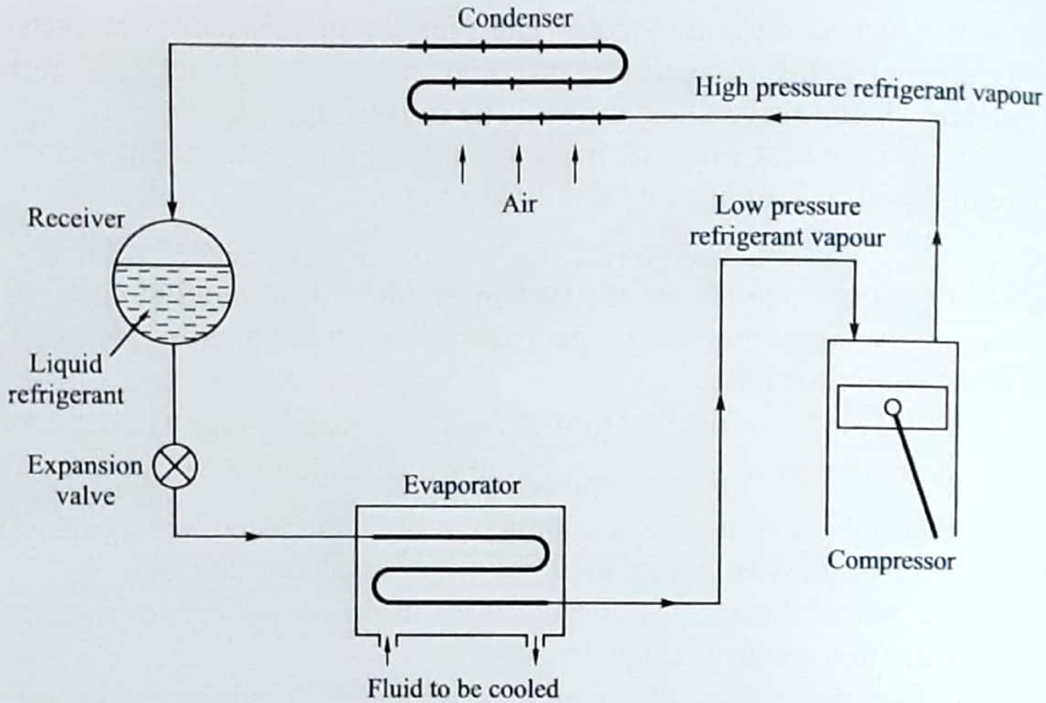

Fig. 16.2 Vapour compression refrigerator

Vapour absorption refrigerator

A vapour absorption refrigerator uses some vapour which is highly soluble at low temperature water and can be easily separated by the application of heat. The vapour generally used for the above purpose is the ammonia vapour.

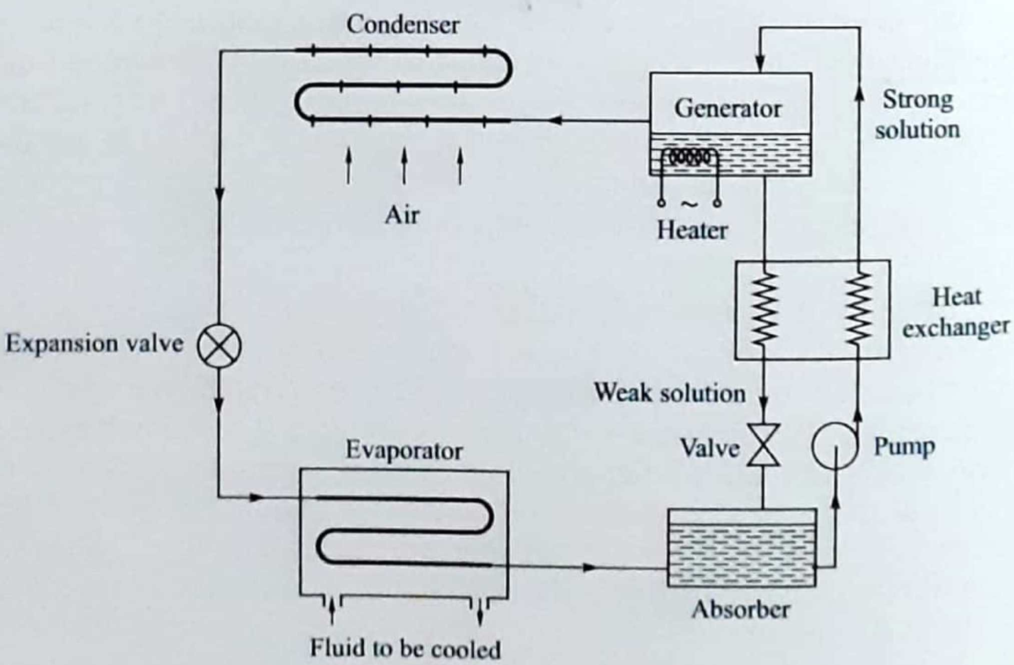

Fig. 16.3 Vapour absorption refrigerator

A simple absorption system is shown in fig. 16.3. The low pressure ammonia vapour leaving the evaporator is readily absorbed in the low temperature water in the absorber. This process is accompanied by the rejection of heat. The strong ammonia solution is pumped to the generator where it gets heated with the help of an external source. Due to reduced solubility of ammonia in water at the higher pressure and temperature, the vapour is removed from the solution. The vapour then passes to the condenser, where it gets condensed. The high pressure liquid ammonia is now expanded in the expansion valve. The low pressure liquid ammonia at low temperature passes on to evaporator, where it extracts heat from the surrounding or circulating fluid being refrigerated and vapourised to low pressure vapour and the cycle is repeated.

The weak hot ammonia solution from the generator is passed through a heat exchanger where it gives its sensible heat to the incoming strong ammonia solution and thereby increases the overall performance of the system. The weak ammonia solution from the heat exchanger enters the absorber through a pressure reduction valve.

Comparison between vapour compression system and vapour absorption system

Description	***Vapour compression system***	***Vapour absorption system***
Type of energy supplied	Mechanical energy	Heat energy
Maintenance	More	Less
Operation	Noisy due to the reciprocating compressor	Quiet in operation as there is no compressor
Performance (COP) at part loads	Poor	System is not affected by variations in load
Charging of refrigerant	Simple	Difficult
Leakage of refrigerant	Chances are more	No leakage
Refrigerant	Feon-12	Ammonia
Size	Bulky	Compact
Cost	High	Low

Refrigerants

A *refrigerant* is a medium of heat transfer which absorbs heat by evaporating at a low temperature and gives up heat by condensing at high temperature and pressure.

Properties of a refrigerant

An ideal refrigerant should possess the following properties:

1. Thermodynamic properties:

(i) Low boiling point, (ii) Low freezing point,

(iii) High critical temperature, (iv) High latent heat of vapourisation.

2. *Physical properties:*
   (i) Low specific heat, (ii) Low specific volume of vapour,
   (iii) High thermal conductivity, (iv) Low viscosity, and
   (v) High electrical insulation.
3. *Safe working properties:*
   (i) Non-toxic, (ii) Non-flammable and non-explosive, and
   (iii) Non-corrosive
4. *Other properties:*
   (i) High coefficient of performance, (ii) Availability and low cost,
   (iii) Ease of locating leakage, (iv) Ease of handling.
   (v) Low toxicity and flammabilits, and (vi) Non corrosive to metals.

Types of refrigerants

The commonly used refrigerants and its specific applications are given below:

Ammonia (NH_3) - Ice plants

Carbon dioxide (CO_2) - Marine refrigerators

Methyl chloride (CH_3Cl) - Domestic and industrial refrigerators.

Freon-12 (F_{12}) - Domestic refrigerators, water coolers, etc

Freon-22(F_{22}) - Air-conditioning plants, cold storage, food freezing and storage, etc.

AIR - CONDITIONING

Air-conditioning is defined as a process which heats, cools, cleans and circulates air and controls the moisture content. Air-conditioning thus makes it possible to change the condition of air in an enclosed area. Generally, air-conditioning is divided into comfort and industrial air-conditioning. The controlled atmosphere which gives maximum comfort to the human being is known as *comfort air-conditioning*. It is used in houses, offices, shops, restaurants, theaters, hospitals, etc. The conditioned atmosphere which is required in the processing or manufacturing plant is known as *industrial air-conditioning* and is used in food processing, photographic, textile, paper and machine tool industries. The comfort air-conditioning is further divided into summer and winter air-conditioning.

Psychrometry

Psychrometry is the study of the properties of air and water vapour mixture.

Psychrometric terms

Dry air has no moisture content.

Moist air is the mixture of dry air and water vapour.

Moisture is the presence of water vapour in the air.

Dry bulb temperature is the temperature of air measured by an ordinary thermometer.

Wet bulb temperature is the temperature of air as measured by an ordinary thermometer whose bulb is covered with wet cloth.

Wet bulb depression is the difference between dry bulb and wet bulb temperatures.

Dew point temperature is the temperature at which the moisture present in the air begins to condense when the air is cooled.

Dew point depression is the difference between the dry bulb and the dew point temperatures.

Specific humidity is the mass of water vapour present in unit mass of dry air.

Relative humidity is the ratio of the actual amount of moisture in the air to maximum possible amount of moisture the air can hold at the prevailing temperature. The saturated air will have a relative humidity of 100 percent.

Sensible heat of air is the quantity of heat which can be measured by measuring the dry bulb temperature of air.

Total heat of air is the sum of sensible heat of dry air and sensible plus the latent heat of water vapour associated with dry air.

Psychrometric process involves heating or cooling of air and adding moisture (humidification) or removing moisture (dehumidification).

Window type air conditioner

The most common air conditioning system use a vapour compression cycle similar to the one used by a refrigerator. The air conditioner take heat from inside the house and release it to the outside environment. This unit is usually packaged in a decorative cabinet and is mounted through the wall. Inside the cabinet is a compressor, condensing coil, evaporator coil, blower, fan, temperature control and small duct work. A damper will allow the unit to draw fresh air in or re-circulate 100 % of the room air. The indoor side (room side) and outdoor side of the unit is separated by an insulated partition wall. The shaft extended from one side of a motor drives a fan and the shaft extended from other side of the motor drives a blower as shown in fig. 16.4.

When warm, moist 'inside' air is blown across the surface of the evaporator coil, the air temperature drops and the water vapour in it condenses making the air cooler and drier and therefore more comfortable. The liquid refrigerant evaporates in the evaporator coil by absorbing the heat from the surrounding air. By means of a compressor, the hot refrigerant gas is pumped into the condenser, where it reverts back to liquid giving up its heat to the outside air flowing over the condenser's coil. The liquid refrigerant again enter the evaporator and the cycle repeats. Nearly all air conditioning systems now employ halogenated-chlorofluoro carbons as refrigerant.

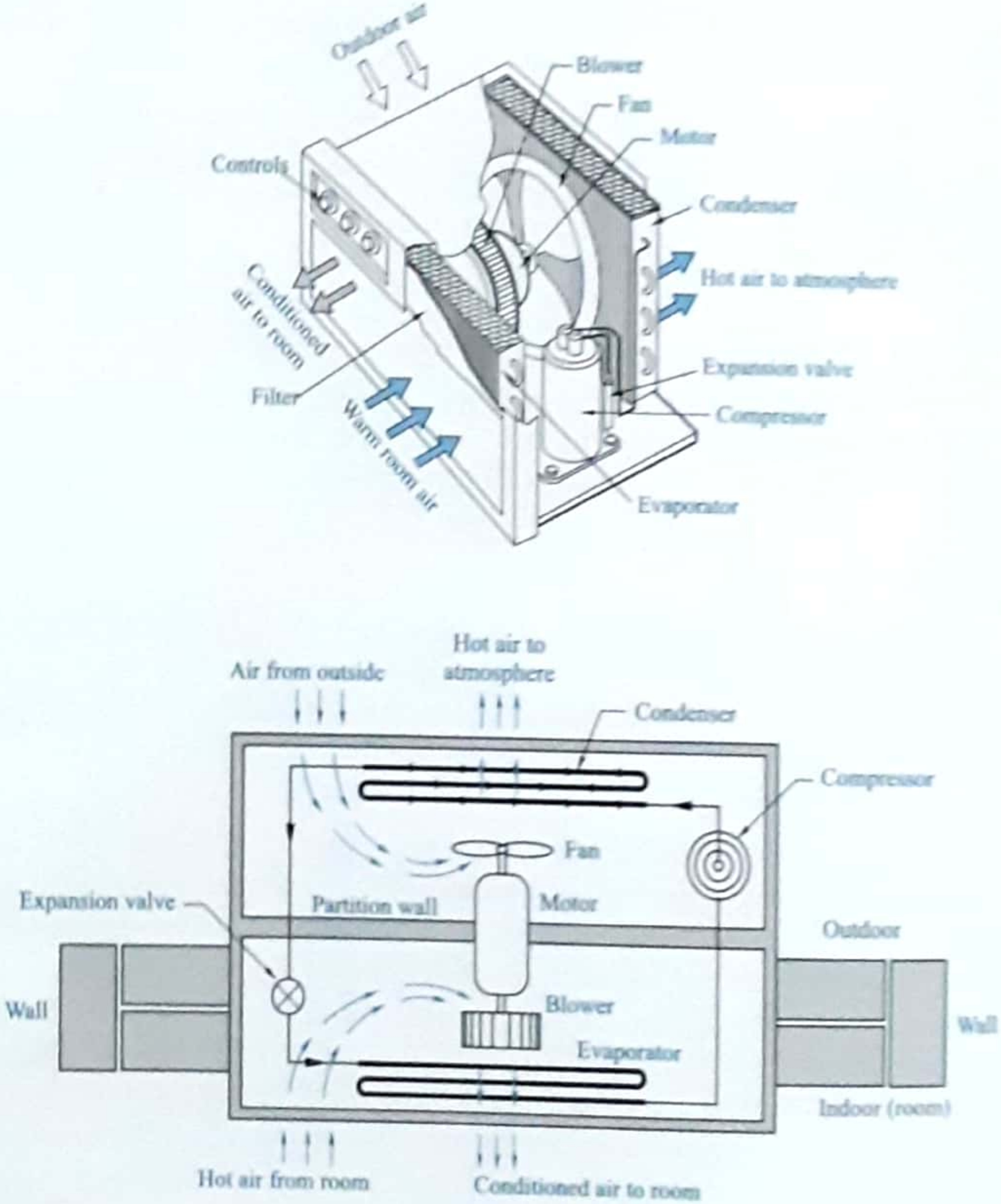

Fig. 16.4 Window type air conditioner

Central air-conditioning system

This type of system is suitable for air-conditioning large spaces such as theaters, restaurants, exhibition halls, public buildings, etc. The central air-conditioning system should accomplish the following.

1. Eliminate the dust, soot and germs from the air entering the intake ducts, 2. Warm the air in winter. 3. Cool the air in summer, 4. Increase the humidity in dry condition,

5. Decrease the relative humidity in wet condition, 6. Circulate the conditioned air evenly and pleasantly throughout the building at all times.

Split air conditioner

The window air conditioner is split into two-package units. The first unit consist of evaporator, and expansion valve and are kept in side the room to be cooled. The second unit consists of compressor and condenser and are kept outside to room to reduce the noise. The split air-conditioner can be mounted on any wall of the room.

Choose the correct answer:

1. In SI units, one tonne of refrigeration is equivalent to
   (a) 1.5 kW (b) 2.5 kW (c) 3.5 kW (d) 4.5 kW
2. COP is always
   (a) Less than unity (b) Equal to unity
   (c) More than unity (d) None of the above
3. In a vapour compression system, the condition of refrigerant before entering the expansion valve is
   (a) High pressure saturated liquid (b) Wet vapour
   (c) Dry vapour (d) High pressure vapour
4. The main parts of a vapour compression refrigeration system in sequence are;
   (a) Compressor, condenser, evaporator and expansion valve
   (b) Compressor, expansion valve, condenser and evaporator
   (c) Compressor, condenser, expansion valve and evaporator
   (d) Compressor, evaporator, condenser and expansion valve
5. Vapour absorption refrigeration system as compared to vapour compression refrigeration system requires
   (a) More input energy (b) Less input energy
   (c) Equal energy (d) None of the above
6. The desirable property of a refrigerant is
   (a) Low boiling point (b) High specific heat
   (c) High viscosity (d) None of the above
7. Air condition means
   (a) Cooling and heating (b) De-humidifying
   (c) Removal of impurities (d) All of the above

8. The chilling or freezing unit of a refrigerator is called as
   (a) Compressor (b) Evaporator (c) Condenser (d) Carburettor
9. Ratio of heat removed from a cold body to the work input is known as
   (a) Ton of refrigeration (b) Coefficient of performance
   (c) Relative coefficient of performance (d) Refrigeration effect
10. The most commonly used refrigerant in vapour absorption refrigeration system is
    (a) Feon (b) CO_2 (c) SO_2 (d) NH_3
11. The heart of the refrigerator is
    (a) Compressor (b) Condenser (c) Expansion valve (d) Evaporator
12. The refrigerant used in vapour compression refrigerator is
    (a) Ammonia (b) Air (c) Freon 22 (d) Nitrogen
13. Refrigerant should have
    (a) Low viscosity (b) Low freezing point (c) Low boiling point (d) All the above
14. Condenser is used in a refrigerator
    (a) To compress the refrigerant (b) To expand the vapour
    (c) To absorb the heat from the refrigerant (d) To transform into vapour
15. The name of the refrigerant, commonly used in domestic refrigerator, is
    (a) Water (b) Freon-12 (c) Carbon (d) Ice

Review questions

1. Define refrigeration and refrigerator. What is the unit of refrigeration? List the areas where refrigeration is used.
2. Define C.O.P. of a refrigerating machine.
3. Name the various parts of a refrigerator and state their functions. (VTU, July 2009)
4. Draw a line diagram of vapour compression refrigeration system and explain its working.
5. Draw a line diagram of vapour absorption refrigeration system and explain its working. (VTU, June 2010)
6. What are the merits and demerits of vapour compression system over vapour absorption system?
7. Define a refrigerant.
8. What are the basic requirements of a good refrigerant? (VTU, June 2010)
9. Name the commonly used refrigerants.
10. Define the term air-conditioning
11. Enumerate the various applications of air-conditioning.

12. Define the following psychrometric terms:
    (i) Dry bulb temperature, (ii) Wet bulb temperature, (iii) Dew point temperature, (iv) Specific humidity, and (v) Relative humidity.
13. What do you mean by psychrometric processes?
14. Write a note on psychrometric chart.
15. Sketch and describe the working of a window air conditioner.
16. Write a short note on central air-conditioning system.
17. Draw a neat sketch of a room air conditioner and explain its working principle. (VTU, Jan 2013)
18. Explain the principle of refrigeration. (VTU, Aug 2001)
19. With a neat sketch, explain the working of vapour compression refrigeration. (VTU, Jan 2013)
20. What are the desirable properties of a good refrigerant? Explain with a neat sketch, the working of vapour absorption refrigeration system. (VTU, Feb 2005)
21. What is air-conditioning ? How is it classified ? What are its applications ? With a suitable diagram, show the flow of refrigerant used in any air-conditioner. (VTU, July 2006)
22. Explain the following terms:
    i) Refrigerant ii) Refrigerating effect iii) Ton of refrigeration iv) Coefficient of performance. (VTU, Jan 2011)
23. Distinguish between the vapour compression and vapour absorption refrigeration. (VTU, July 2013)
24. Explain vapour absorption refrigeration system. (VTU, Dec 2011)
25. What is the principle of refrigeration? Name the essential parts of a refrigerator and briefly explain their functions. (VTU, June 2012)
26. Mention the uses of any four refrigerants. (VTU, July 2013)