UNIT-I

PRODUCTION OF LOW TEMPERATURE

INTRODUCTION

Low-temperature physics, science concerned with the production and maintenance of temperatures much below normal, down to almost absolute zero, and with various phenomena that occur only at such temperatures. The temperature scale used in low-temperature physics is the Kelvin temperature scale, or absolute temperature scale. Low-temperature physics is also known as cryogenics, from the Greek meaning "producing cold."

Low temperatures are achieved by removing energy from a substance. This may be done in various ways. The simplest way to cool a substance is to bring it into contact with another substance that is already at a low temperature. Ordinary ice, dry ice (solid carbon dioxide), and liquid air may be used successively to cool a substance down to about 80°K (about -190°C). The heat is removed by conduction, passing from the substance to be cooled to the colder substance in contact with it. If the colder substance is a liquefied gas, considerable heat can be removed as the liquid reverts to its gaseous state, since it will absorb its latent heat of vaporization during the transition.

Various liquefied gases can be used in this manner to cool a substance to as low as 4.2°K, the boiling point of liquid helium. If the vapor over the liquid helium is continually pumped away, even lower temperatures, down to less than 1°K, can be achieved because more helium must evaporate to maintain the proper vapor pressure of the liquid helium. The method of adiabatic demagnetization can lower the temperature to only about a millionth of a degree above absolute zero.

Moreover, according to the third law of thermodynamics, it is theoretically impossible to reduce a substance to absolute zero by any finite number of processes. Superconductivity and super fluidity have traditionally been thought of as phenomena that occur only at temperatures near absolute zero, but by the late 1980s several materials that exhibit superconductivity at temperatures exceeding 100°K had been found.

Superconductivity is the vanishing of all electrical resistance in certain substances when they reach a transition temperature that varies from one substance to another; this effect can be used to produce powerful superconducting magnets. Super fluidity occurs in liquid helium and leads to the tendency of liquid helium to flow over the sides of any container it is placed in without being stopped by friction or gravity.

Freezing mixtures

A freezing mixture is a mixture of substances (such as salt and ice) to obtain a temperature below the freezing point of the solvent (such as water).

A freezing mixture is a composite of two or more elements. It is utilized to obtain a temperature below the freezing point of a solvent. The principle behind it is the depression in freezing point.

A freezing Mixture is a mix of salt and ice. It is used to lower the temperature. A compound of dry ice and alcohol can also be utilized for this. A freezing mixture will not receive heat from the external.

The freezing point is that temperature at which liquid transforms into a solid state. For example, NaCl is a non-volatile substance, and it is called salt. When we combine salt with ice, it will first diffuse in the liquid. So, it will decrease the freezing point of water beneath the temperature of ice. So, ice will soften when we combine salt and ice, and extra water will be formed. So, this will assist in dissolving more salt. Freezing mixtures are utilized in labs for Cooling. The freezing compound can be solid, liquid, or both. For example, a compound of dry ice with alcohol can also be utilized as a freezing mixture. They can reduce the temperature up to −80∘C

a combination of substances that when mixed lower the temperature of the mixture by absorbing the melting heat or the heat of solution of the system’s components, which can be liquid, solid, or both. To attain the lowest possible temperature, the components of a freezing mixture are used in quantities that will form a cryohydrate. Water, ice, snow, and various salts and acids will form freezing mixtures that attain a temperature of — 50°C. Salts in dilute acid solutions lower temperatures more than salts in a water solution. Substitution of crushed ice for water makes it possible to attain lower temperatures because, in addition to absorbing the heat of solution of the salt, the mixture absorbs the melting heat of the ice.

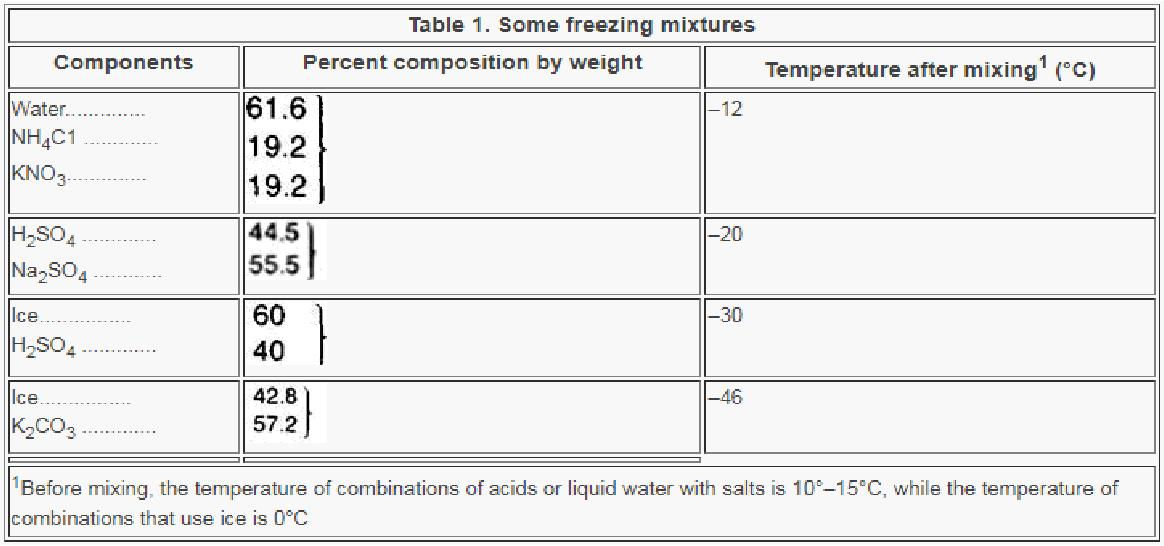
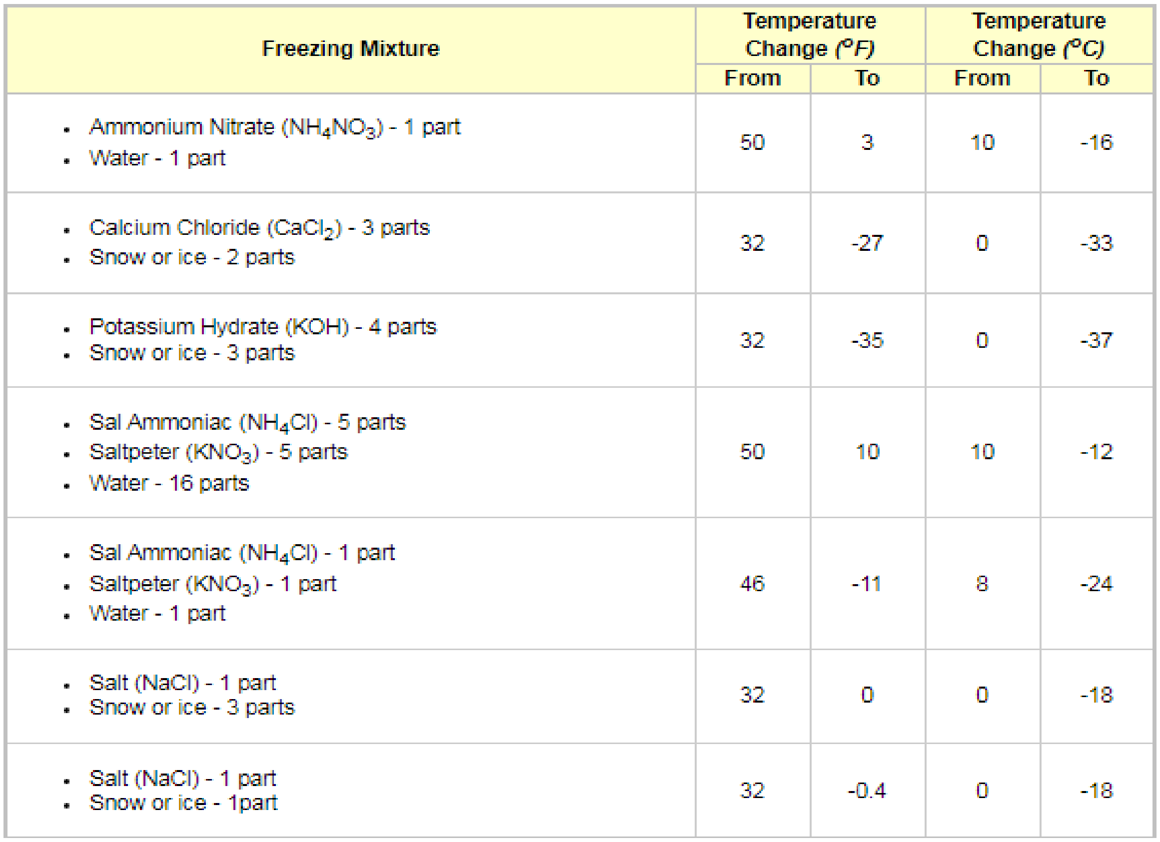


Table 1. Some freezing mixtures

Components	Percent composition by weight	Temperature after mixing[1] (°C)
Water............. NH_4C1 .... KNO_3.............	61.6 19.2 19.2	–12
H_2SO_4 .... Na_2SO_4	44.5 55.5	–20
Ice............... H_2SO_4	60 40	–30
Ice............... K_2CO_3	42.8 57.2	–46

[1] Before mixing, the temperature of combinations of acids or liquid water with salts is 10°–15°C, while the temperature of combinations that use ice is 0°C



Freezing Mixture	Temperature Change (°F)		Temperature Change (°C)	
	From	To	From	To
- Ammonium Nitrate (NH_4NO_3) - 1 part - Water - 1 part	50	3	10	-16
- Calcium Chloride ($CaCl_2$) - 3 parts - Snow or ice - 2 parts	32	-27	0	-33
- Potassium Hydrate (KOH) - 4 parts - Snow or ice - 3 parts	32	-35	0	-37
- Sal Ammoniac (NH_4Cl) - 5 parts - Saltpeter (KNO_3) - 5 parts - Water - 16 parts	50	10	10	-12
- Sal Ammoniac (NH_4Cl) - 1 part - Saltpeter (KNO_3) - 1 part - Water - 1 part	46	-11	8	-24
- Salt (NaCl) - 1 part - Snow or ice - 3 parts	32	0	0	-18
- Salt (NaCl) - 1 part - Snow or ice - 1part	32	-0.4	0	-18

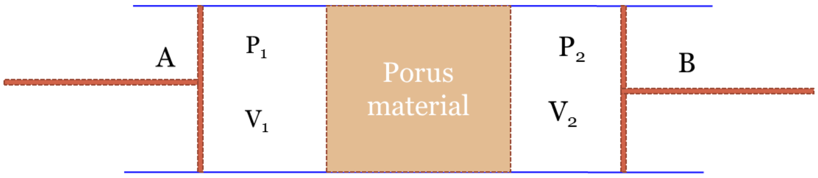
Joule Thomson Effect or Joule Kelvin Effect

When the real gas is forced through a porous plug from high pressure region into low pressure region, the temperature of the gas changes. This is called Joule–Thomson effect or Joule–Kelvin effect.

As shown in the figure Porus material is separated the thermally insulated cylinder in to two parts by using two pistons A and B. P_1 and V_1 are pressure and volume in part 1 and, P_2 and V_2 are Pressure and volume in part 2 of the gas. If piston is pushed towards porus plug , the gas pushed the second piston B due to expansion of gas. So the temperature of the gas changes. This is called Joule–Thomson effect or Joule–Kelvin effect.

Results observed in the experiment are:

1. All gasses shows change in temperature when passing from high pressure region into low pressure region through porus plug.
2. At room temperature, all gases except hydrogen, helium, and neon shows cooling effect. But, hydrogen, helium, and neon shows heating effect.
3. The change in temperature is proportional to difference between two pressures at constant initial temperature.
4. When initial temperature increases , at a certain temperature the cooling effect change into heating effect. This initial temperature is called inversion temperature.
5. The inversion temperature of Hydrogen is -80^{o}C and Helium is -240^{o}C.



In Joule kelvin effect or Joule Thomson effect the external work is done on the gas and also by the gas in addition to internal work.

Let us consider thermally insulated cylinder divided into two parts by using porous plug and fitted with two non-conducting Pistons A and B. If one gram mole of gas passes through porous plug by the force exerted by piston at constant pressure P_1 into second part situated at constant pressure P_2. Let us assume V_1 and V_2 are Volumes of the gas before and after passing through the porous plug.

So that external work done by the gas by the piston= $P_1 V_1$

External work done by the gas and the piston= $P_2 V_2$

An amount of internal work is done by the gas to pull the molecules further apart against their mutual attractive forces. If we assume the gas obey Van Der waal gas equation then the attractive force between molecules is equal to a/ V^2.

In which a is a constant and V is the volume occupied by the gas.

So that the internal work done against these forces to expand one gram mole of gas from volume V_1 to V_2 is

$$\int_{V_1}^{V_2} \frac{a}{V^2} dV = \frac{a}{V_1} - \frac{a}{V_2}$$

The total work done by the gas is given by

$$W = P_2V_2 - P_1V_1 + \frac{a}{V_1} - \frac{a}{V_2} \quad \text{-----1}$$

According to the equation of Van der Waal gas equation

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

$$PV + \frac{a}{V} - Pb - \frac{ab}{V^2} = RT$$

In which a and b are small quantities and hence ab/ V^2 term can be neglected from the above equation

$$PV + \frac{a}{V} - Pb = RT$$

$$PV = RT - \frac{a}{V} + Pb$$

Now for two compartments of porus plug, we may write

$$P_1V_1 = RT - \frac{a}{V_1} + P_1b$$

And

$$P_2V_2 = RT - \frac{a}{V_2} + P_2b$$

From above two equations

$$P_2V_2 - P_1V_1 = RT - \frac{a}{V_2} + P_2b - RT + \frac{a}{V_1} - P_1b$$

$$P_2V_2 - P_1V_1 = a\left(\frac{1}{V_1} - \frac{1}{V_2}\right) - b(P_1 - P_2)$$

Substitute this value in to equation1, $W = P_2V_2 - P_1V_1 + \frac{a}{V_1} - \frac{a}{V_2}$

$$The\ total\ work\ done\ W = a\left(\frac{1}{V_1} - \frac{1}{V_2}\right) - b(P_1 - P_2) + \frac{a}{V_1} - \frac{a}{V_2}$$

$$The\ total\ work\ done\ W = 2a\left(\frac{1}{V_1} - \frac{1}{V_2}\right) - b(P_1 - P_2)$$

$\frac{a}{V_1}$ *and* $\frac{a}{V_2}$ are very small quantities and hence for approximation, we may use ideal gas equation

PV=RT

From this $\frac{1}{V_1} = \frac{P_1}{RT}$ *and* $\frac{1}{V_2} = \frac{P_2}{RT}$

$$The\ total\ work\ done\ W = 2a\left(\frac{P_1}{RT} - \frac{P_2}{RT}\right) - b(P_1 - P_2)$$

$The\ total\ work\ done\ W = (P_1 - P_2)\left(\frac{2a}{RT} - b\right)$ -----2

We know the system is thermally insulated so that the work is drawn from the internal energy. So that gas cools and if -dT is the fall in temperature and C_P is the specific heat at constant pressure, then an amount of heat supply to restore the original temperature is $-C_P$ dT in calories.

Value of an amount of heat in SI System of units is $-C_P$ dTJ. -------3

Equations 2 and 3 are equal.

Hence

$$-\mathrm{C_p\ dTJ} = (P_1 - P_2)\left(\frac{2a}{RT} - b\right)$$

$$\mathrm{dT} = \frac{(P_1 - P_2)}{\mathrm{C_p\ J}}\left(\frac{2a}{RT} - b\right)$$

This is the expression for cooling of gas using joule Kelvin effect.

1. According to this equation at any temperature the cooling is directly proportional to the difference of pressure across the porous plug (P_1- P_2)

2. For a given pressure difference (P_1- P_2) across the porous plug cooling is Greater for lower initial temperature T.

$$\frac{2a}{\mathrm{RT}} = b\ , then\ \left(\frac{\mathrm{dT}}{\mathrm{dP}}\right)_{\mathrm{H}} = 0, \text{it means neither cooling nor heating.}$$

So that the temperature T= 2a/Rb is called Inversion temperature.

$$Inversion\ temperature\ \ T_i = \frac{2a}{\mathrm{Rb}}$$

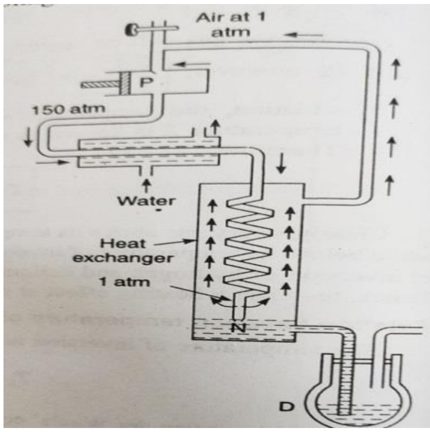
Principle of regenerative cooling

The gas below its inversion temperature suffers joule Thomson expansion and gets cooled. The principal behind the liquefaction of gases depends on joule Thomson expansion and regenerative cooling.

When the gas passes through porous plug from high pressure region into low pressure region below its inversion temperature shows cooling effect. This is called Joule -Thomson effect.

But the cooling is very small and this temperature is not sufficient to get the liquefaction of gases.

For this purpose principle of regenerative cooling is used to get more cooling of gases.



We know, if the initial temperature of the gas is a small then the cooling effect is more.

In regenerative cooling the cooled gases due to joule Thomson expansion sent back to the compressor. The the gas send in to the compressor and again sent thorough the nozzle and gets more cooled.

This method repeated again and again finally the temperature of the gas reaches its critical temperature and hence liquefied.

This is called principle of regenerative cooling.

Different Methods of Liquefaction of gases

In general, gases can be liquefied by one of three general methods: (1) by compressing the gas at temperatures less than its critical temperature; (2) by making the gas do some kind of work against an external force, causing the gas to lose energy and change to the liquid state; and (3) by making gas do work against its own internal forces, also causing it to drop energy and turn to liquid.

In the first approach, the application of pressure alone is sufficient to cause a gas to change to a liquid. For example, ammonia has a critical temperature of 406K (271.4°F [133°C]). This temperature is well above room temperature, so it is relatively simple to convert ammonia gas to the liquid state simply by applying sufficient pressure. At its critical temperature, that pressure is 112.5 atmosphere, although the cooler the gas is to begin with, the less pressure is needed to make it condense.

For example, the critical temperature of carbon dioxide is 30.98^{o}C. This implies that carbon dioxide cannot be liquefied above 30.98^{o}C, howsoever high may be the pressure applied on it.

The critical temperature is represented by Tc. It is given by-

$$T_c=8a/27bR$$

Critical pressure and critical volume:

The minimum pressure required to liquefy a gas at the critical temperature is called the critical pressure of the gas. It is represented by Pc and is given by-

$$P_c=a/27b^2$$

Where a and b are Van der Waal’s constant.

The volume occupied by one mole of a gas at critical conditions is known as the critical volume of the gas. It is represented by V_c and is given by-

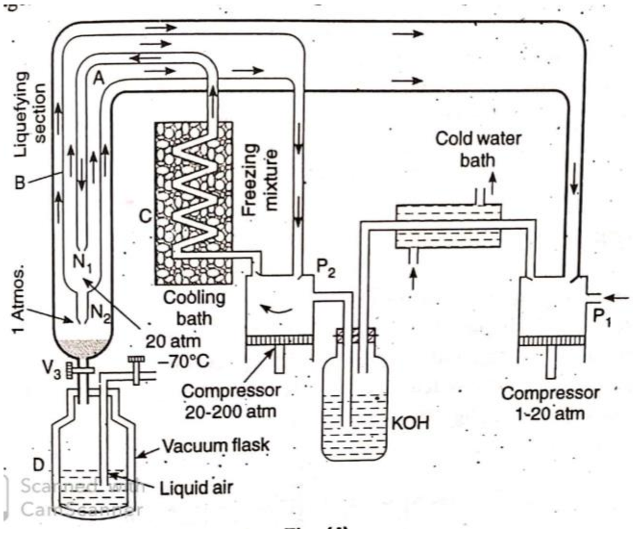
$$V_c=3b$$

where b represents the effective volume of the molecules per mole of the gas.

T_c,P_c, and V_c are collectively referred to as critical constants of a gas.

Linde’s air liquefier:

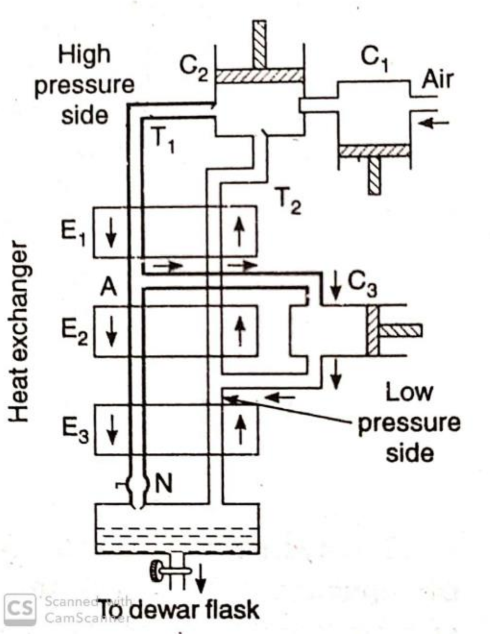
The Linde air liquefier is shown in fig. It consists of two compressors P_1 and P_2. The first compressor compresses the incoming air from 1 to 20 atmospheres. The compressed air is passed through cold water bath to remove the heat of compression and then allowed to pass through caustic potash, calcium chloride and phosphorous pentaoxide to remove carbon di-oxide and water.



This is done because carbon di-oxide and water vapours will solidify before the air is liquefied and choke the whole system. Air free from carbon di-oxide and water vapour now enters the second compressor where it is compressed to 200 atmospheric pressure. The compressed air then passes through the spiral tube kept in freezing mixture. The temperature of air here falls to -20 ^{o}C. The air thus, cooled at high pressure enters the liquefying section and suffers Joule-Thomson expansion at nozzle N_1. As the gas, at this stage is allowed to expand to 20 atmospheric pressure its temperature falls to about - 70 ^{o}C. The nozzle N_2 is closed at this stage. So the cooled air flows through the wider tube B back to the compressor P_2. Where it is again compressed to 200 atmospheric pressure. In its way to compressor P_2, it cools the incoming gas in tube A. The principle of regenerative cooling takes place and after few cycles, the air is cooled to sufficiently low temperature (-183 ^{o}C). Now the second nozzle N_2 is opened. The air expands to one atmospheric pressure and is liquefied. The liquid air is collected in Dewar flask D.

Claude's air liquefier:

The efficiency of Hampson and Linde liquefier is very low. To increase the efficiency, Claude adopted the adiabatic expansion method, i.e., allowing the compressed gas to expand adiabatically in a cylinder. In adiabatic expansion at low temperature, the main difficulty is of a suitable lubricant for the moving part of expansion cylinder. The reason being that ordinary lubricant's become solidified . Claude removed this difficulty by using petroleium ether because this lubricant remains viscous upto even 113K.

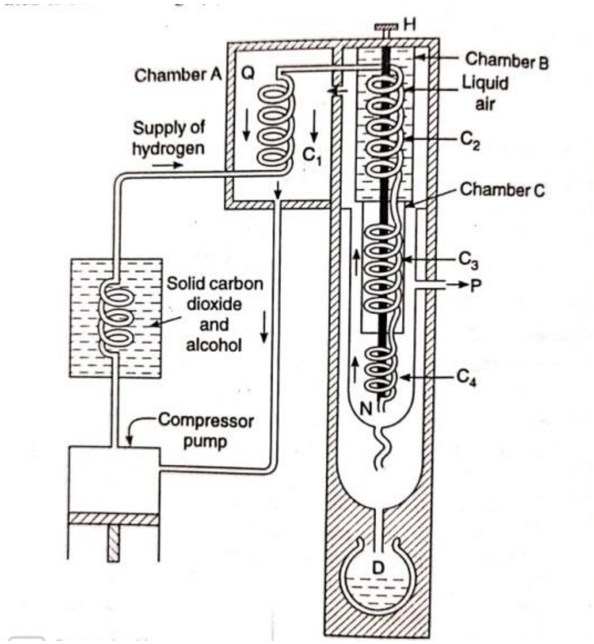


Claude's air liquefier is shown in figure.

Air free from carbon di-oxide and water vapour is compressed to 40 atmospheres with the help of compressors C1 and C2 . The compressed air then flows through tube T1. The tube T1 in turn passes through the three heat exchanges E1,E2 and E3. The cooled air from heat exchanger E1 is divided into two parts at A. One part continues to flow through tube T1 and passes through the heat exchangers E2 and E3. The second part flows into the compressor C3 where the air expands adiabatically. The air pushes the piston outward and performs external work. Due to the expansion the air is cooled. The cooled air then enters tube T2 and meets the incoming air in heat exchanger E2. The temperature of incoming air is further decreased. The incoming gas then suffers Joule-Thomson expansion at nozzle N. The process of regenerative cooling is continued till air reaches its liquefaction temperature. The liquefied air is collected in Dewar flask. Due to some technical difficulties , this method is not more efficient than Linde’s method.

Production of hydrogen

Although the hydrogen atom is the most abundant atom in the universe, molecular hydrogen gas itself is not an earth abundant resource. Hydrogen gas has to be produced from other products. It is not an energy source like fossil fuels, but it functions more as an energy vector. There exist several methods for the production of hydrogen, but not all production methods for hydrogen can be considered green. Currently, about 96% of all hydrogen produced, is produced via reforming processes of fossil fuels, either natural gas, heavy oil and naphtha or from coal, water, and biomass.



Olszewski successfully produced liquid hydrogen in 1895 at a temperature of -211^{o}Cand 190 atmosphere of pressure. In 1989 Dewar successfully liquefied the hydrogen by Joule Thomson process. The apparatus for the production of liquid hydrogen is as shown in figure.

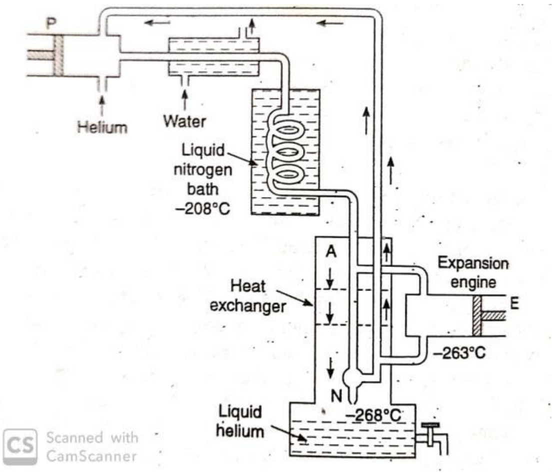
As shown in figure the pure hydrogen is compressed to 200 atmospheres by using compressed pump. Then the gas passes through a coil immersed in solid carbon dioxide and alcohol. Now the gas is passed through coil C_1 in the chamber A already cooled by the outgoing cold hydrogen. The hydrogen gas passes through a generative coil C_2 immersed in liquid air placed in the chamber B. Now the hydrogen gas attained the temperature of -170^{o}C. Here the hydrogen gas passed through another coil C_3 placed in the chamber C, were the liquid air boils under reduced pressure.

The hydrogen in the coil C3 is cooled to the temperature of -200^{o}C. The hydrogen at this temperature -200oC is passed through the regenerative coil C4 and made to suffer Joule – Thomson expansion at the nozzle N. Now hydrogen further called due to Joule – Thomson expansion and allowed to circulate back to the compressor pump. After performing different rotations , the temperature of the hydrogen reached -250oC at the nozzle. After Joule- Thomson expansion hydrogen gas is liquefied and collected in Dewar flask D.

Liquefaction of helium- Kapitza method

The critical temperature of helium is -268^{o}C, it is very low and hence it is the last gas to be liquefied. Hence the critical temperature of helium is-268^{o}C, it is necessary to cool helium below -268^{o}C before it could be liquefied. The temperature of inversion for helium is -240 ^{o}C and it is possible to cool it below this temperature only. Kapitza was made in expansion engine has made an important modification where no lubricant is used.

The experimental setup to liquefy helium gas by Kapitza was as shown in figure. Actually all the lubricant becomes solidified at such low temperatures. Kapitza used the compressor where the piston is loosely fitted with the cylinder with a very small clearance. When expansion takes place a little gas escapes through the clearance. Here the expansion is so rapid that the escape part is little.

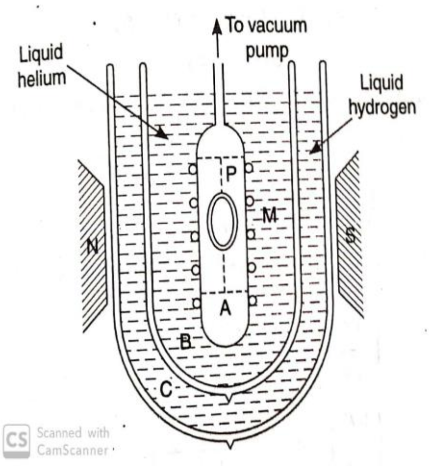


In this liquefier a pure and dry helium is compressed to 30 atmospheres by compressor P. Heat of compression is removed by flowing water in a jacket surrounding a portion of the tube. The gas is then pre cooled by passing it through a bath of liquid nitrogen boiling under reduced pressure. The pre cooled gas is divided into two parts at point A in the heat exchanger. The first part passes to the expansion engine E. Due to adiabatic expansion of the helium it cools to -263^{O}C. This cold gas rises up in the heat exchanger and cools. The second part coming towards the nozzle N. The second part is now so cold that after the expansion at nozzle and it is liquefied. The liquefied portion of helium is collected in Dewar flask and the remaining part goes back to the compressor through heat exchanger.

Adiabatic demagnetization

Debye and Giauque in 1926 independently developed to obtain low temperature by using adiabatic demagnetization of paramagnetic materials.

The principle of adiabatic demagnetization of paramagnetic materials is in which a paramagnetic material contains molecules which are lying in disorderly manner. So that, the resultant magnetic moment is zero. When the substance is kept in a magnetic field gets magnetized and the molecules are set in the direction of magnetic field.



In which certain amount of external work is done in this process which is added to the internal energy of the substance. So the temperature of the substance slightly increases.

When a paramagnetic substance already magnetized is suddenly demagnetized the molecules again gets disorderly manner. So that, the temperature of the substance decreases. If the substance is already at sufficiently low temperature the fall in temperature is remarkable.

The experimental setup adiabatic demagnetization is as shown in figure. In which the paramagnetic material Gadolinium Sulphate is suspended in a vessel A connected to a vacuum pump. This vessel is surrounded by liquid helium at a temperature 1K by using Dewar flask B. This flask is again surrounded by another Dewar flask C containing liquid hydrogen. A strong magnetic field is applied to magnetize the magnetic material using magnets NS. The coils M around A are used to measure the temperature by susceptibility measurements.

Initially a vessel A is filled with helium gas so that paramagnetic substance P comes in thermal contact of liquid helium and cool to 1 K. The magnetic field is on, the paramagnetic salt becomes warmed, but heat flows through to helium gas into the liquid helium. Paramagnetic material regains its temperature to 1K. At this moment helium gas is pumped out from the vessel A, and hence the paramagnetic substance becomes thermally insulated. Now when the magnetic field is switch off, then due to adiabatic demagnetization the temperature of the substance decreases. The decrease in temperature is detected by susceptibility measuring coils.

In this procedure Gianque and Mc Dougall obtained a temperature of 0.25K. White and Hass by using double sulphate of potassium and Aluminium obtained temperature of 0.002K. 0.0014K was obtained by Steenland and Gorter using crystals of chromium aluminium alum.

If paramagnetic substance is magnetized by placing it in a magnetic flux density of B, its molecules are try to align in the direction of magnetic field and work done.

Let us consider the intensity of magnetization is I and change in intensity of magnetization is dI by placing in a magnetic field, then an amount of work done by the field on the substance is BdI.

When the substance is demagnetized, then the same work is done by the substance is equal to - BdI

From first law of thermodynamics, we know

dQ=dU+dW

Where Work dW= PdV-BdI

dQ=dU+PdV-BdI

But adiabatic demagnetization, volume does not change and hence, dV=0

dQ=dU-BdI

But we know from entropy definition, dQ=TdS

TdS=dU-BdI

When compare this equation with TdS=dU+PdV, then P=-B and V=I.

But from the third Maxwell thermodynamic relation

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

From the above two equations we can replace -B for P and I for V, then

$$\left(\frac{\partial T}{\partial B}\right)_S = -\left(\frac{\partial I}{\partial S}\right)_B$$

If it is multiplied and divided by dT, then

$$\left(\frac{\partial T}{\partial B}\right)_S = -\left(\frac{(\partial I/\partial T)}{(\partial S/\partial T)}\right)_B$$

If it is multiplied and divided by T, then

$$\left(\frac{\partial T}{\partial B}\right)_S = -\frac{T(\partial I/\partial T)_B}{T(\partial S/\partial T)_B}$$

If m is the mass of the substance and CB is the specific heat constant filed B , then

$$C_B = \frac{1}{m}\left(\frac{\partial Q}{\partial T}\right)_B = \frac{T}{m}\left(\frac{\partial S}{\partial T}\right)_B$$

Where dQ=TdS

$$T\left(\frac{\partial S}{\partial T}\right)_B = mC_B$$

$$\left(\frac{\partial T}{\partial B}\right)_S = -\frac{T(\partial I/\partial T)_B}{mC_B}$$

$$\left(\frac{\partial T}{\partial B}\right)_S = -\frac{T}{mC_B}\left(\frac{\partial I}{\partial T}\right)_B$$

$$\partial T = -\frac{T}{mC_B}\left(\frac{\partial I}{\partial T}\right)_B \partial B \qquad \text{--------1}$$

This gives the decrease in temperature of the substance due to adiabatic demagnetization.

The susceptibility (χ)of the substance can be defined as

$$\chi = \frac{\text{Intensity of Magnetization}}{\text{Intensity of Magnetic Field}} = \frac{\mathrm{I}}{\mathrm{B}} \qquad \text{----------2}$$

According to Curie’s law the succeptibility is inversely proportional to its absolute temperature.

$$\chi \alpha \frac{1}{\mathrm{T}} \quad \text{and} \quad \chi = \frac{\mathrm{C}}{\mathrm{T}}$$

Where C is constant.

From equation 1 and 2

$$\chi = \frac{\mathrm{I}}{\mathrm{B}} = \frac{\mathrm{C}}{\mathrm{T}}$$

$$\mathrm{I} = \frac{\mathrm{CB}}{\mathrm{T}}$$

Substitute the value of I into equation1,then

$$\partial T = -\frac{T}{mC_B}\left(\frac{\partial\left(\frac{\mathrm{CB}}{\mathrm{T}}\right)}{\partial T}\right)_B \partial B$$

If this equation s integrated by taking limits having temperatures Ti and Tf, and magnetic fields having limits Bi to Bf, then

$$T_f - T_i = -\frac{T}{mC_B}\int_{B_i}^{B_f}\frac{\partial\left(\frac{\mathrm{CB}}{\mathrm{T}}\right)}{\partial T}\,\partial B$$

$$T_f - T_i = -\frac{T}{mC_B}\int_{B_i}^{B_f} -\frac{\mathrm{CB}}{\mathrm{T}^2}\,\partial B$$

$$T_f - T_i = \frac{C}{mC_B T}\int_{B_i}^{B_f} B\,\partial B$$

$$T_f - T_i = \frac{C}{mC_B T}\left(\frac{B^2}{2}\right)_{B_i}^{B_f}$$

$$T_f - T_i = \frac{C}{2mC_B T}\left({B_f}^2 - {B_i}^2\right)$$

When field is switched off, B_f=0, hence

$$T_f - T_i = -\frac{C{B_i}^2}{2mC_B T}$$

$$T_f - T_i = -\frac{k{B_i}^2}{2C_B T}$$

Where k=C/m is called Curie constant per unit mass.

Where negative sign shows the decrease in temperature in an adiabatic demagnetization.

Properties of substances at low temperature

Matter exhibits some Peculiar properties at low temperatures as compared to the properties at ordinary temperature. So at low temperatures they have number of applications

1. At temperatures below 90 K most of the chemical reactions cease to take place. At these temperatures animal and vegetable matter can be preserved without purification.

2. Certain materials like a cotton and wool exhibit the property of fluorescence when exposed to temperature of liquid for some time.

3. Below 83 K of temperature LED loses elasticity and attains plastic state. These substances like a rubber and glass become extremely brittle at this low temperature. Rubber cooled to such a low temperature breaks into pieces just like a cork when hammered.

4. In all substances the atomic heat tends to become zero at the absolute zero of temperature.

5. Elements like oxygen are not paramagnetic in nature in their gaseous state. But when they are converted into liquids at low temperatures they become paramagnetic.

6. The magnetic susceptibility of certain paramagnetic materials like copper sulphate varies inversely as the Absolute Temperature in the region of low temperatures.

7. Cryogenics is the production and behavior of materials at very low temperatures.

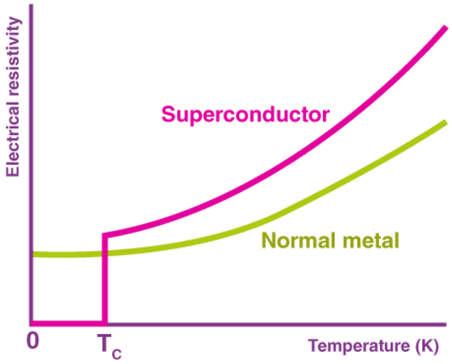
8. Superconductivity and super fluidity have traditionally been thought of as phenomena that occur only at very low temperatures.

Superconductivity is the vanishing of all electrical resistance in certain substances when they reach a transition temperature that varies from one substance to another; this effect can be used to produce powerful superconducting magnets. Super fluidity occurs in liquid helium and leads to the tendency of liquid helium to flow over the sides of any container it is placed in without being stopped by friction or gravity.

Superconductivity

Superconductivity was discovered in 1911 by the Dutch physicist Heike Kamerlingh Onnes; he was awarded the Nobel Prize for Physics in 1913 for his low-temperature research. Kamerlingh Onnes found that the electrical resistivity of a mercury wire disappears suddenly when it is cooled below a temperature of about 4 K (−269 °C).

The property of the material in which completely disappeared of electrical resistance in various solids when they are cooled below a characteristic temperature is called superconductivity. This temperature, called the transition temperature.



The majority of chemical elements become superconducting at sufficiently low temperature.

Properties of Superconductors

1. Critical temperature/Transition temperature

The temperature below which the material changes from conductors to superconductors is called critical temperature or transition temperature. The transition from conductors to superconductors is sudden and complete.

2. Zero Electric Resistance/Infinite Conductivity

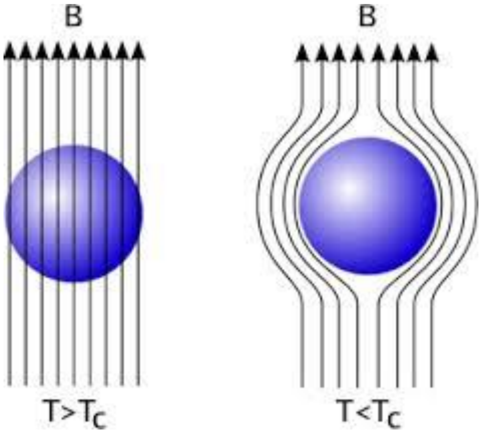
In the superconducting state, the material has zero resistance. When the temperature of the material is reduced below the critical temperature, its resistance suddenly reduces to zero. Mercury is an example of a superconductor that shows zero resistance below 4 kelvin.

Tc increases with a high power of the atomic volume and inversely as the atomic mass and is known as isotope effect.

Superconductivity occurs in materials having high normal resistivities. Good conductors at room temperature are not superconductors and superconducting metals are not good conductors at room temperature as the normal metals.

3. Expulsion of Magnetic Field

Below the critical temperature, superconductors do not allow the magnetic field to penetrate inside it. This phenomenon is called Meisser Effect. Superconductors are diamagnetic in nature. As magnetic susceptibility of Superconductors is —1.



4. : Critical Magnetic Field

The certain value of the magnetic field beyond which the superconductors return to conducting state is called the critical magnetic field. The value of the critical magnetic field is inversely proportional to the temperature. As the temperature increases, the value of the critical magnetic field decreases.

5. Persistent Current

If a ring made of a superconductor is placed in a magnetic field above its critical temperature, now cool the ring of superconductor below its critical temperature and now if we remove the magnetic field a current is induced in ring due to its self-inductance. By Lenz law the direction of this induced current is such that it opposes the change in flux passing through the ring. As the ring is in superconducting state (zero resistance), the current induced is ring will be continue to flow this current is called the persistent current.

6. Critical Current

When a current is passed through a conductor under superconducting state, a magnetic field is developed. If the current increase beyond certain value the magnetic field increased up to critical value at which conductor returns to its normal state. This value of current is called critical current.

7. Types of Superconductors

There are two types of superconductors commonly known as Type I and Type II superconductors.

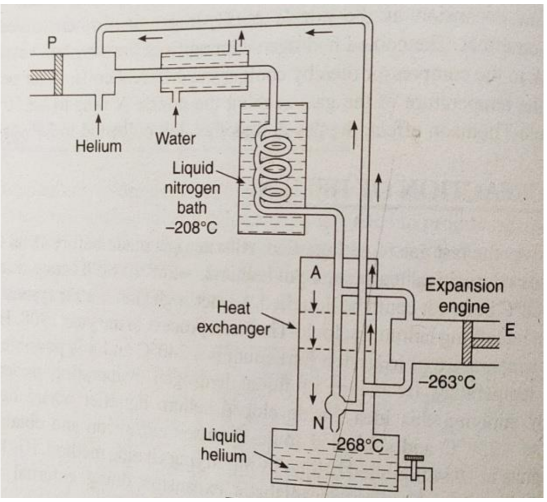
Type I superconductors are soft superconductors. They are usually pure specimens of some elements i.e. metals. They have very little use in technical applications.

Type II superconductors are hard superconductors. They are usually alloys of metals with high value of resistivity in normal state. These are very useful as compared to Type I materials.

Liquefaction of helium- Kapitza method

The critical temperature of helium is -268^{o}C, it is very low and hence it is the last gas to be liquefied. Hence the critical temperature of helium is-268^{o}C, it is necessary to cool helium below -268^{o}C before it could be liquefied. The temperature of inversion for helium is -240 ^{o}C and it is possible to cool it below this temperature only. Kapitza was made in expansion engine has made an important modification where no lubricant is used.

The experimental setup to liquefy helium gas by Kapitza was as shown in figure. Actually all the lubricant becomes solidified at such low temperatures. Kapitza used the compressor where the piston is loosely fitted with the cylinder with a very small clearance. When expansion takes place a little gas escapes through the clearance. Here the expansion is so rapid that the escape part is little.



In this liquefier a pure and dry helium is compressed to 30 atmospheres by compressor P. Heat of compression is removed by flowing water in a jacket surrounding a portion of the tube. The gas is then pre cooled by passing it through a bath of liquid nitrogen boiling under reduced pressure. The pre cooled gas is divided into two parts at point A in the heat exchanger. The first part passes to the expansion engine E. Due to adiabatic expansion of the helium it cools to -263^{O}C. This cold gas rises up in the heat exchanger and cools. The second part coming towards the nozzle N. The second part is now so cold that after the expansion at nozzle and it is liquefied. The liquefied portion of helium is collected in Dewar flask and the remaining part goes back to the compressor through heat exchanger.

LOW TEMPERATURE PHYSICS

Distinction between expansion, adiabatic expansion and joule Kelvin expansion

1. Joules expansion

Free expansion is an example of joules expansion, in which the gas expands into vacuum and hence no external work done by the gas. In joule's expansion the gas was the done and internal work against the intermolecular attraction. The contribution of resultant external work due to may be cooling effect or heating effect depending on the initial temperature of the gas. In general, joule effect is not observed due to the large heat capacity of apparatus.

2. Adiabatic expansion

In adiabatic expansion the compressed gas is suddenly exposed to atmosphere. So that gas performs an external work against the pressure of the atmosphere. In adiabatic expansion, the process is so fast and hence no appreciable heat transfer into the gas from surroundings. So that the external work is drawn from the internal energy of the gas. So the temperature of the gas decreases. It means adiabatic expansion is given cooling effect due to its external work.

3. Joule Kelvin expansion

In joule-Kelvin expansion the gas passes from high pressure region into low pressure region through porous plug. In which external work is done on the gas and also by the gas in addition to internal work. In this expansion maybe cooling effect or heating effect is depending on the initial temperature of the gas. Except hydrogen and helium remaining all gases shows cooling effect.

Expression for John Thomson cooling

Let us consider thermally insulated cylinder divided into two parts by using porous plug and fitted with two non-conducting Pistons A and B. If one gram mole of gas passes through porous plug by the force exerted by piston at constant pressure P_1 into second part situated at constant pressure P_2. Let us assume V_1 and V_2 are Volumes of the gas before and after passing through the porous plug.

So that external work done by the gas by the piston= $P_1 V_1$

External work done by the gas and the piston= $P_2 V_2$

An amount of internal work is done by the gas to pull the molecules further apart against their mutual attractive forces. If we assume the gas obey Van Der waal gas equation then the attractive force between molecules is equal to a/ V^2.

In which a is a constant and V is the volume occupied by the gas.

So that the internal work done against these forces to expand one gram mole of gas from volume V_1 to V_2 is

$$\int_{V_1}^{V_2} \frac{a}{V^2} dV = \frac{a}{V_1} - \frac{a}{V_2}$$

The total work done by the gas is given by

$$W = P_2V_2 - P_1V_1 + \frac{a}{V_1} - \frac{a}{V_2} \text{ -----1}$$

According to the equation of Van der Waal gas equation

$$\left(P+\frac{a}{V^2}\right)(V-b)=RT$$

$$PV+\frac{a}{V}-Pb-\frac{ab}{V^2}=RT$$

In which a and b are small quantities and hence ab/ V^2 term can be neglected from the above equation

$$PV+\frac{a}{V}-Pb=RT$$

$$PV=RT-\frac{a}{V}+Pb$$

Now for two compartments of porus plug, we may write

$$P_1V_1=RT-\frac{a}{V_1}+P_1b$$

And

$$P_2V_2=RT-\frac{a}{V_2}+P_2b$$

From above two equations

$$P_2V_2-P_1V_1=RT-\frac{a}{V_2}+P_2b-RT+\frac{a}{V_1}-P_1b$$

$$P_2V_2-P_1V_1=a\left(\frac{1}{V_1}-\frac{1}{V_2}\right)-b(P_1-P_2)$$

Substitute this value in to equation1, $W=P_2V_2-P_1V_1+\frac{a}{V_1}-\frac{a}{V_2}$

$$The\ total\ work\ done\ W = a\left(\frac{1}{V_1} - \frac{1}{V_2}\right) - b(P_1 - P_2) + \frac{a}{V_1} - \frac{a}{V_2}$$

$$The\ total\ work\ done\ W = 2a\left(\frac{1}{V_1} - \frac{1}{V_2}\right) - b(P_1 - P_2)$$

$\frac{a}{V_1}\ and\ \frac{a}{V_2}$ are very small quantities and hence for approximation, we may use ideal gas equation

PV=RT

From this $\frac{1}{V_1} = \frac{P_1}{RT}\quad and\ \frac{1}{V_2} = \frac{P_2}{RT}$

$$The\ total\ work\ done\ W = 2a\left(\frac{P_1}{RT} - \frac{P_2}{RT}\right) - b(P_1 - P_2)$$

$The\ total\ work\ done\ W = (P_1 - P_2)\left(\frac{2a}{RT} - b\right)$ -----2

We know the system is thermally insulated so that the work is drawn from the internal energy. So that gas cools and if -dT is the fall in temperature and C_P is the specific heat at constant pressure, then an amount of heat supply to restore the original temperature is -C_P dT in calories.

Value of an amount of heat in SI System of units is -C_P dTJ. -------3

Equations 2 and 3 are equal.

Hence

$$-C_p\ \mathrm{dTJ} = (P_1 - P_2)\left(\frac{2a}{RT} - b\right)$$

$$\mathrm{dT} = \frac{(P_1 - P_2)}{C_p\ J}\left(\frac{2a}{RT} - b\right)$$

This is the expression for cooling of gas using joule Kelvin effect.

1. According to this equation at any temperature the cooling is directly proportional to the difference of pressure across the porous plug (P_1- P_2)

2. For a given pressure difference (P_1- P_2) across the porous plug cooling is Greater for lower initial temperature T.

$$\frac{2a}{\mathrm{RT}} = b \,, then \left(\frac{\mathrm{dT}}{\mathrm{dP}}\right)_{\mathrm{H}} = 0, \text{it means neither cooling nor heating.}$$

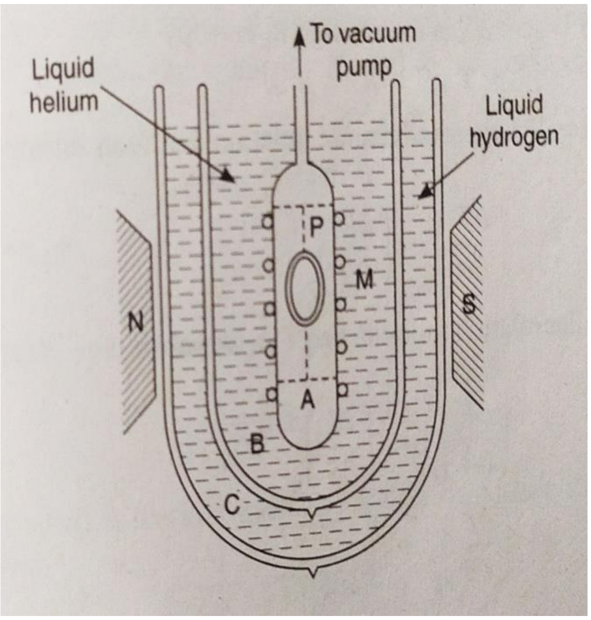
So that the temperature T= 2a/Rb is called Inversion temperature.

$$Inversion\ temperature\ \ T_i = \frac{2a}{\mathrm{Rb}}$$

Adiabatic demagnetization

Debye and Giauque in 1926 independently developed to obtain low temperature by using adiabatic demagnetization of paramagnetic materials.

The principle of adiabatic demagnetization of paramagnetic materials is in which a paramagnetic material contains molecules which are lying in disorderly manner. So that, the resultant magnetic moment is zero. When the substance is kept in a magnetic field gets magnetized and the molecules are set in the direction of magnetic field. In which certain amount of external work is done in this process which is added to the internal energy of the substance. So the temperature of the substance slightly increases.



When a paramagnetic substance already magnetized is suddenly demagnetized the molecules again gets disorderly manner. So that, the temperature of the substance decreases. If the substance is already at sufficiently low temperature the fall in temperature is remarkable.

The experimental setup adiabatic demagnetization is as shown in figure. In which the paramagnetic material Gadolinium Sulphate is suspended in a vessel A connected to a vacuum pump. This vessel is surrounded by liquid helium at a temperature 1K by using Dewar flask B. This flask is again surrounded by another Dewar flask C containing liquid hydrogen. A strong magnetic field is applied to magnetize the magnetic material using magnets NS. The coils M around A are used to measure the temperature by susceptibility measurements.

Initially a vessel A is filled with helium gas so that paramagnetic substance P comes in thermal contact of liquid helium and cool to 1 K. The magnetic field is on, the paramagnetic salt becomes warmed, but heat flows through to helium gas into the liquid helium. Paramagnetic material regains its temperature to 1K. At this moment helium gas is pumped out from the vessel A, and hence the paramagnetic substance becomes thermally insulated. Now when the magnetic field is switch off, then due to adiabatic demagnetization the temperature of the substance decreases. The decrease in temperature is detected by susceptibility measuring coils.

In this procedure Gianque and Mc Dougall obtained a temperature of 0.25K. White and Hass by using double sulphate of potassium and Aluminium obtained temperature of 0.002K. 0.0014K was obtained by Steenland and Gorter using crystals of chromium aluminium alum.

If paramagnetic substance is magnetized by placing it in a magnetic flux density of B, its molecules are try to align in the direction of magnetic field and work done.

Let us consider the intensity of magnetization is I and change in intensity of magnetization is dI by placing in a magnetic field, then an amount of work done by the field on the substance is BdI.

When the substance is demagnetized, then the same work is done by the substance is equal to -BdI

From first law of thermodynamics, we know

$$dQ=dU+dW$$

Where Work dW= PdV-BdI

dQ=dU+PdV-BdI

But adiabatic demagnetization, volume does not change and hence, dV=0

dQ=dU-BdI

But we know from entropy definition, dQ=TdS

TdS=dU-BdI

When compare this equation with TdS=dU+PdV, then P=-B and V=I.

But from the third Maxwell thermodynamic relation

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

From the above two equations we can replace -B for P and I for V, then

$$\left(\frac{\partial T}{\partial B}\right)_S = -\left(\frac{\partial I}{\partial S}\right)_B$$

If it is multiplied and divided by dT, then

$$\left(\frac{\partial T}{\partial B}\right)_S = -\left(\frac{(\partial I/\partial T)}{(\partial S/\partial T)}\right)_B$$

If it is multiplied and divided by T, then

$$\left(\frac{\partial T}{\partial B}\right)_S = -\frac{T(\partial I/\partial T)_B}{T(\partial S/\partial T)_B}$$

If m is the mass of the substance and CB is the specific heat constant filed B , then

$$C_B = \frac{1}{m}\left(\frac{\partial Q}{\partial T}\right)_B = \frac{T}{m}\left(\frac{\partial S}{\partial T}\right)_B$$

Where dQ=TdS

$$T\left(\frac{\partial S}{\partial T}\right)_B = mC_B$$

$$\left(\frac{\partial T}{\partial B}\right)_S = -\frac{T(\partial I/\partial T)_B}{mC_B}$$

$$\left(\frac{\partial T}{\partial B}\right)_S = -\frac{T}{mC_B}\left(\frac{\partial I}{\partial T}\right)_B$$

$$\partial T = -\frac{T}{mC_B}\left(\frac{\partial I}{\partial T}\right)_B \partial B \qquad \text{--------1}$$

This gives the decrease in temperature of the substance due to adiabatic demagnetization.

The susceptibility (χ)of the substance can be defined as

$$\chi = \frac{\text{Intensity of Magnetization}}{\text{Intensity of Magnetic Field}} = \frac{\mathrm{I}}{\mathrm{B}} \qquad \text{----------2}$$

According to Curie's law the succeptibility is inversely proportional to its absolute temperature.

$$\chi\alpha\ \frac{1}{\mathrm{T}} \quad \text{and} \quad \chi = \frac{\mathrm{C}}{\mathrm{T}}$$

Where C is constant.

From equation 1 and 2

$$\chi = \frac{\mathrm{I}}{\mathrm{B}} = \frac{\mathrm{C}}{\mathrm{T}}$$

$$\mathrm{I} = \frac{\mathrm{CB}}{\mathrm{T}}$$

Substitute the value of I into equation1,then

$$\partial T = -\frac{T}{mC_B}\left(\frac{\partial\left(\frac{\mathrm{CB}}{\mathrm{T}}\right)}{\partial T}\right)_B \ \partial B$$

If this equation s integrated by taking limits having temperatures Ti and Tf, and magnetic fields having limits Bi to Bf, then

$$T_f - T_i = -\frac{T}{mC_B}\int_{B_i}^{B_f}\frac{\partial\left(\frac{\mathrm{CB}}{\mathrm{T}}\right)}{\partial T}\ \partial B$$

$$T_f - T_i = -\frac{T}{mC_B}\int_{B_i}^{B_f} -\frac{\mathrm{CB}}{\mathrm{T}^2}\ \partial B$$

$$T_f - T_i = \frac{C}{mC_B T}\int_{B_i}^{B_f} B\ \partial B$$

$$T_f - T_i = \frac{C}{mC_B T}\left(\frac{B^2}{2}\right)_{B_i}^{B_f}$$

$$T_f - T_i = \frac{C}{2mC_B T}\left({B_f}^2 - {B_i}^2\right)$$

When field is switched off, $B_f=0$, hence

$$T_f - T_i = -\frac{C{B_i}^2}{2mC_B T}$$

$$T_f - T_i = -\frac{k{B_i}^2}{2C_B T}$$

Where k=C/m is called Curie constant per unit mass.

Where negative sign shows the decrease in temperature in an adiabatic demagnetization.

Applications and properties of substances at low temperature

Matter exhibits some Peculiar properties at low temperatures as compared to the properties at ordinary temperature. So at low temperatures they have number of applications

1. At temperatures below 90 K most of the chemical reactions cease to take place. At these temperatures animal and vegetable matter can be preserved without purification.
2. Certain materials like a cotton and wool exhibit the property of fluorescence when exposed to temperature of liquid for some time.
3. Below 83 K of temperature LED loses elasticity and attains plastic state. These substances like a rubber and glass become extremely brittle at this low temperature. Rubber cooled to such a low temperature breaks into pieces just like a cork when hammered.
4. In all substances the atomic heat tends to become zero at the absolute zero of temperature.
5. Elements like oxygen are not paramagnetic in nature in their gaseous state. But when they are converted into liquids at low temperatures they become paramagnetic.
6. The magnetic susceptibility of certain paramagnetic materials like copper sulphate varies inversely as the Absolute Temperature in the region of low temperatures.
7. Cryogenics is the production and behavior of materials at very low temperatures.
8. Superconductivity and super fluidity have traditionally been thought of as phenomena that occur only at very low temperatures.

Superconductivity is the vanishing of all electrical resistance in certain substances when they reach a transition temperature that varies from one substance to another; this effect can be used to produce powerful superconducting magnets. Super fluidity occurs in liquid helium and leads to the tendency of liquid helium to flow over the sides of any container it is placed in without being stopped by friction or gravity.

Principle of regenerative cooling

The gas below its inversion temperature suffers joule Thomson expansion and gets cooled. The principal behind the liquefaction of gases depends on joule Thomson expansion and regenerative cooling.

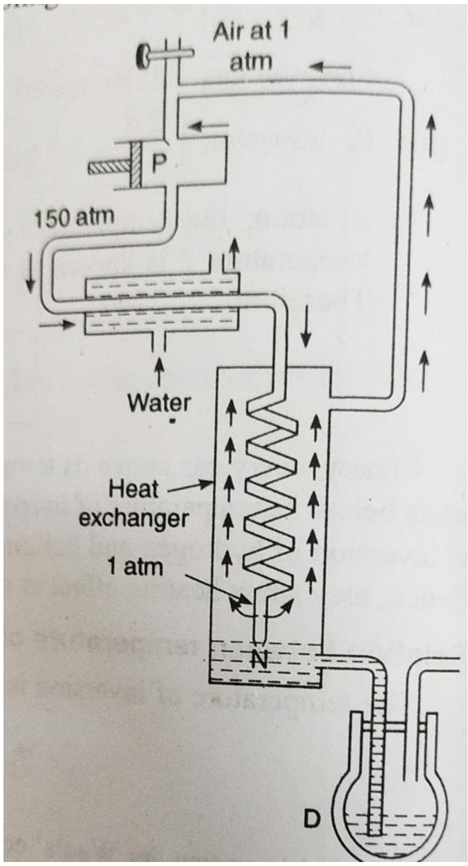
When the gas passes through porous plug from high pressure region into low pressure region below its inversion temperature shows cooling effect. This is called Joule -Thomson effect.

But the cooling is very very small and this temperature is not sufficient to get the liquefaction of gases.

For this purpose principle of regenerative cooling is used to get more cooling of gases.

We know, if the initial temperature of the gas is a small then the cooling effect is more.

In regenerative cooling the cooled gases due to joule Thomson expansion sent back to the compressor. The the gas send in to the compressor and again sent thorough the nozzle and gets more cooled.



This method repeated again and again finally the temperature of the gas reaches its critical temperature and hence liquefied.

This is called principle of regenerative cooling.

Refrigeration

The refrigerator is a machine used for producing low temperatures below the surrounding temperature and maintenance in enclosure at low temperature.

Refrigerator can also be defined as a machine which moves the heat energy from the cold region to the hot region.

It is a Carnot's engine working in backward direction. Refrigerator are two types

1. Vapour compression machine and

2. Vapour absorption machine.

In which some amount of work has to be done to transfer heat from the chamber to the environment.

UNIT II

MEASUREMENT OF LOW TEMPERATURES

Gas Thermometer Definition

The gas thermometer is a device that measures the temperature by taking the count of variation in volume or pressure of a gas enclosed in a constant volume tube.

Charles law states that the volume of an ideal gas is directly proportional to the absolute temperature at constant pressure.

$$V \propto T$$

$$V_2/V_1 = T2/T1$$

$$V_T = V_0 \ (1 + T/273)$$

Gay-Lussac's law states that the pressure exerted by a gas varies directly with the absolute temperature of the gas of a given mass and kept at a constant volume. In other words, the pressure exerted by a gas is proportional to the temperature of the gas when the mass is fixed and the volume is constant.

This law was formulated by the French chemist Joseph Gay-Lussac in the year 1808. The mathematical expression of Gay-Lussac's law can be written as follows:

$$P \propto T$$

$$P/T = \text{Constant}$$

$$P_1/T_1 = P_2/T_2$$

Where:

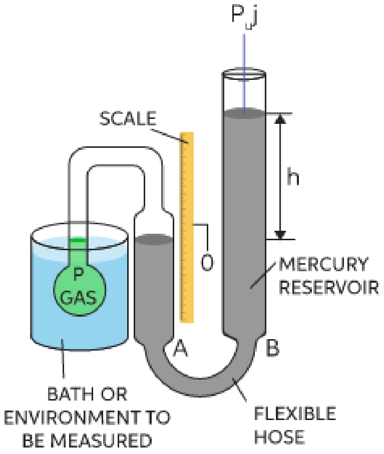
P is the pressure exerted by the gas

T is the absolute temperature of the gas

k is a constant

A constant volume gas thermometer

A constant volume gas thermometer works on the zeroth law of thermodynamics, which states that if two bodies individually are in thermal equilibrium with a third body then, the two bodies will also be in thermal equilibrium with each other. These thermometers are used to calibrate other thermometers, as their temperature scale coincides with the thermodynamic scale. Looking at the construction of a constant volume gas thermometer, it consists of a tube for holding the dilute gas, and a mercury manometer to measure the pressure of the gas.



As shown in the figure above the mercury manometer has two arms to carry mercury, one of which is having a fixed amount of mercury up to a fixed point while for the other part mercury can move up or down. Now, on varying the temperature of the sample, its pressure will vary as well, according to what Gay-Lussac said in the law: for constant volume, the pressure of the given mass of gas varies linearly with its absolute temperature.

This is the working principle of constant volume gas thermometer, i.e. on increasing the temperature of the gas its pressure will increase linearly, and on decreasing the temperature of the gas its pressure will also decrease linearly. But, it should be noted that the pressure and the temperature of the gas should be such that its form remains gaseous.

Coming to the calculation part, to find the temperature at certain pressure T=aP+b equations can be used, where T and P represent temperature and pressure respectively and 'a' and 'b' are the two constants. For determining the values of constant certain known points can be considered, like the freezing point of water, the boiling point of water, or the triple point of water. When a triple point is taken for the purpose of the value of constant 'a' is found to be 273.16 (P/P_{tp})

P_{tp} is the pressure corresponding to the triple point of water at temperature 273.16 Kelvin. Now, the equation can be rewritten as:

$$T=273.16(P/P_{tp})$$

At T=0 and P=0,

$$0=a\times0+b$$

$$b=0$$

At , T=273.16 K

$P= P_{tp}$

$273.16=a\times P_{tp} +0$

$a=273.16/ P_{tp}$

From the above equations Temperature can be rewritten as:

$$T=273.16(P/ P_{tp})$$

Using these temperatures can be determined in a constant volume gas thermometer.

By using different gas thermometers a wide range of temperatures can be measured:

Hydrogen -200 ^{o}C to +500 ^{o}C

Nitrogen +500 ^{o}C to + 1500 ^{o}C

Helium -270 ^{o}C to + 1500 ^{o}C

Calibration: Initially bulb A is immersed in a liquid having ice at O^{o}C or any liquid at very small known temperature of triple point. Note down the mark on a scale. Later bulb A immersed in the boiled water at 100^{o}C or any liquid at boiling temperature. Note the temperature on the scale. Now the scale is divided into several parts.

Constant pressure gas thermometer

In case of a constant pressure gas thermometer, the fact that on keeping pressure constant, volume of the given mass of gas varies linearly with the absolute temperature.

Charles law states that the volume of an ideal gas is directly proportional to the absolute temperature at constant pressure.

$$V \propto T$$

$$V_2/V_1=T2/T1$$

$$V_T = V_0\ (1 + T/273)$$

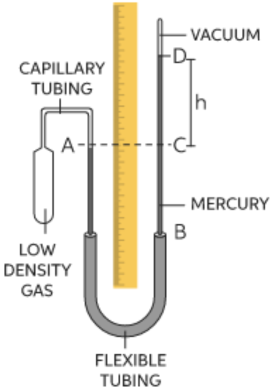
Where:

V is the volume of the gas

T is the absolute temperature of the gas

k is a constant

Such processes involving the constant pressure are said to be isobaric processes. A closed tube with filled air and mercury is used to keep pressure constant, and then on varying temperatures the volume of air varies as well; hence, a calibrated reading can be noted.



Advantages and Drawbacks of Gas Thermometer

Advantages:

1. Sensitivity of gas thermometers is really high due to the volumetric expansion being large enough.
2. The expansion in the dilute gases used is regular.
3. Scale range of gas thermometers is large.
4. The properties of permanent gases almost coincide with that of an ideal gas, hence when used in thermometers gives reading accurately near to thermodynamic scale reading.
5. The property known as thermal capacity is low in case of gases.

Drawbacks:

1. It requires a lot of work to determine temperature using gas thermometers.
2. Being a spacious and large setup it is hard to relocate it easily.
3. Its accuracy or precision comes down when used for measuring varying temperature with a faster rate.

Secondary Thermometers

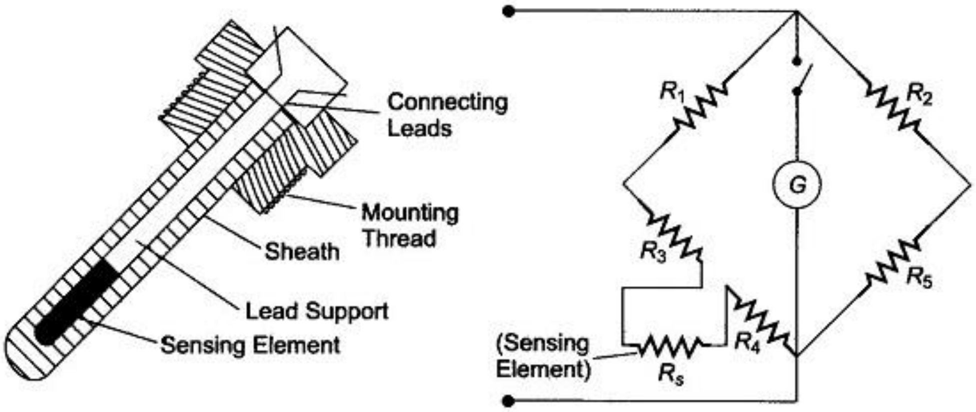
A thermometer is called primary or secondary based on how the raw physical quantity it measures is mapped to a temperature. For primary thermometers the measured property of matter is known so well that temperature can be calculated without any unknown quantities. Examples of these are thermometers based on the equation of state of a gas, on the velocity of sound in a gas, on the thermal noise voltage or current of an electrical resistor, and on the angular anisotropy of gamma ray emission of certain radioactive nuclei in a magnetic field.

Secondary thermometers are most widely used because of their convenience. Also, they are often much more sensitive than primary ones. For secondary thermometers knowledge of the measured property is not sufficient to allow direct calculation of temperature. They have to be calibrated against a primary thermometer at least at one temperature or at a number of fixed temperatures.

The temperature dependent behavior of several new types of carbon resistors and germanium sensors to determine whether any particular type might be suitable as a secondary thermometer in the 0.01–1.0 K temperature interval. Each thermometer was specially constructed to improve the thermal contact to the sensing element. Several commercial germanium and carbon resistance sensors appear promising as thermometers in the very low temperature interval.

Resistance thermometer

Resistance thermometers, also called Resistance Temperature Detectors (RTDs). Resistance thermometers are sensors used to measure temperature. Many RTD elements consist of a length of fine wire wrapped around a heat-resistant ceramic or glass core but other constructions are also used. The RTD wire is a pure material, typically platinum (Pt), nickel (Ni), or copper (Cu). The material has an accurate resistance/temperature relationship which is used to provide an indication of temperature. As RTD elements are fragile, they are often housed in protective probes.



RTDs, which have higher accuracy and repeatability, are slowly replacing thermocouples in industrial applications below 600 °C.

Common RTD sensing elements for biomedical application constructed of platinum (Pt), nickel (Ni), or copper (Cu) have a repeatable resistance versus temperature relationship (R vs T) and operating temperature range. The R vs T relationship is defined as the amount of resistance change of the sensor per degree of temperature change.

Platinum was proposed by Sir William Siemens as an element for a resistance temperature detector at the Bakerian lecture in 1871; it is a noble metal and has the most stable resistance–temperature relationship over the largest temperature range. Nickel elements have a limited temperature range because the amount of change in resistance per degree of change in temperature becomes very non-linear at temperatures over 300 °C (572 °F). Copper has a very linear resistance–temperature relationship; however, copper oxidizes at moderate temperatures and cannot be used over 150 °C (302 °F).

The significant characteristic of metals used as resistive elements is the linear approximation of the resistance versus temperature relationship between 0 and 100 °C. This temperature coefficient of resistance is denoted by α and is usually given in units of Ω/(Ω·°C).

$$\alpha = \frac{R_{100} - R_0}{100R_0}$$

R_o is the resistance of the sensor at 0 °C,

R_{100} is the resistance of the sensor at 100 °C.

Pure platinum has α = 0.003925 Ω/(Ω·°C) in the 0 to 100 °C range and is used in the construction of laboratory-grade RTDs.[citation needed] Conversely, two widely recognized standards for industrial RTDs IEC 60751 and ASTM E-1137 specify α = 0.00385 Ω/(Ω·°C). Before these standards were widely adopted, several different α values were used. It is still possible to find older probes that are made with platinum that have α = 0.003916 Ω/(Ω·°C) and 0.003902 Ω/(Ω·°C).

These different α values for platinum are achieved by doping – carefully introducing impurities, which become embedded in the lattice structure of the platinum and result in a different R vs. T curve and hence α value.

Advantages and limitations

Advantages

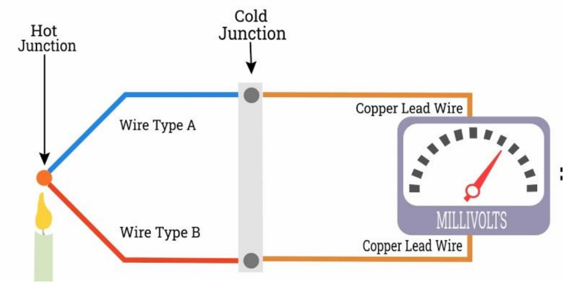
1. High accuracy
2. Low drift
3. Wide operating range
4. Suitability for precision applications.

Limitations:

1. RTDs in industrial applications are rarely used above 660 °C.
2. At temperatures above 660 °C it becomes increasingly difficult to prevent the platinum from becoming contaminated by impurities from the metal sheath of the thermometer.
3. At very low temperatures, say below −270 °C (3 K), because there are very few phonons, the resistance of an RTD is mainly determined by impurities and boundary scattering and thus basically independent of temperature. As a result, the sensitivity of the RTD is essentially zero and therefore not useful.

Thermocouples

A thermocouple, also known as a "thermo electrical thermometer", is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage as a result of the Seebeck effect, and this voltage can be interpreted to measure temperature. Thermocouples are widely used as temperature sensors.



When two dissimilar metal (eg: copper and bismuth) wires are joined at two ends to form a loop, a voltage is developed in the circuit if the two junctions are kept at different temperatures. The pair of metals forming the circuit is called a thermocouple. The effect is due to conversion of thermal energy to electrical energy.

This phenomenon is called thermo electric effect. This was discovered by German scientist Seebeck.

A thermocouple is a device for measuring temperature. It comprises two dissimilar metallic wires joined together to form a junction. When the junction is heated or cooled, a small voltage is generated in the electrical circuit of the thermocouple which can be measured, and this corresponds to temperature.

A thermocouple is simply a sensor that is used for measuring temperature. This design of sensor consists of two dissimilar metal wires which are joined together at one end, connected to an instrument that is capable of accepting a thermocouple input and measure the reading. Thermocouples can provide temperature measurements over a wide spectrum of temperatures dependent on which thermocouple type you use.

According to different types of combinations of alloys, the thermocouples are available in different types.

K type Thermocouple

The K-type thermocouple is the most common type of thermocouple, and it has the widest temperature measuring range.

The positive lead of Type K thermocouple is composed of approximately 90% nickel and 10% chromium. The negative lead is composed of approximately 95% nickel, 2% aluminum, 2% manganese, and 1% silicon.

The temperature range of type K thermocouple is -200˚C to +1260˚C (-328 F to +2300 F).

T type Thermocouple

This type of thermocouple is suitable to measure low temperature. The positive lead is composed of copper and the negative lead is composed of constantan (45% nickel and 55% copper).

The sensitivity of the type T thermocouple is 43 µV/°C. This thermocouple is suitable to works in an oxidizing atmosphere. The temperature range of this thermocouple is between -200°C to 350°C.

J type Thermocouple

This type of thermocouple is a low-cost and most used thermocouple. The positive lead is made of iron and a negative lead is made of constantan (45% nickel and 55% copper).

The positive lead is colored white and the negative terminal is colored red. And the overall jacket is colored black. The temperature range of type J thermocouple is between -210˚C to 750˚C (-346F to 1400F).

B-Type Thermocouple

The alloy combination is of Platinum (6% Rhodium) and Platinum (30% Rhodium). This thermocouple exhibits a temperature range between 1370 to 1700 °C. It is mainly used in applications executed at extremely high temperatures, such as glass production.

E-Type Thermocouple

Chromel and Constantan are the alloys that form an E-type thermocouple.

The temperature range is between 0 to 870 °C. This thermocouple does not focus on the oxidation in the atmosphere and can be used in an inert environment.

N-Type Thermocouple

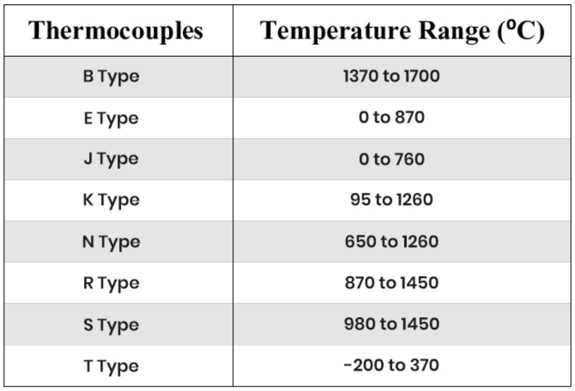
This thermocouple is a combination of alloys Nicrosil and Nisil. The temperature range is between 650 to 1260 °C. Unlike K-type thermocouples, the N-type thermocouple offers very high resistance for degradation due to green rot and hysteresis. They are most commonly used in refineries and petrochemical industries.

R-Type Thermocouple

A combination of Platinum +13% Rhodium and Platinum forms R type thermocouple. The temperature range is between 870 to 1450 °C. It is costlier than S type thermocouple as it contains a higher percentage of Rhodium. Its high accuracy and stability make it an ideal thermocouple to used in Sulfur recovery units.

S-Type Thermocouple

It is a combination of Platinum +10% Rhodium and Platinum. The temperature range is between 980 to 1450 °C. S type thermocouple is used in applications involving very high temperatures. This type is widely used across various l industries.



Thermocouples	Temperature Range (°C)
B Type	1370 to 1700
E Type	0 to 870
J Type	0 to 760
K Type	95 to 1260
N Type	650 to 1260
R Type	870 to 1450
S Type	980 to 1450
T Type	-200 to 370

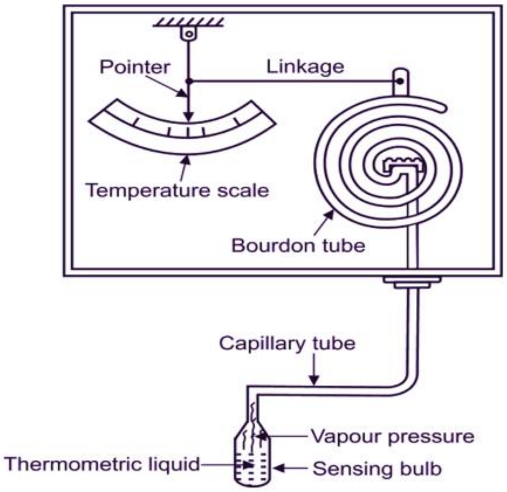
Vapour pressure thermometers

In vapour pressure thermometers a highly volatile liquid is used, but only partially occupies the thermometer volume. The liquid begins to vaporize and fills the rest of the volume with steam. As a result, the pressure rises until equilibrium between the liquid phase and the gas phase is reached.

The relation between pressure P and absolute temperature T is

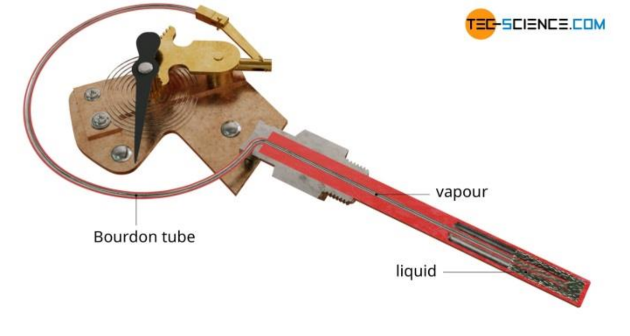
$$\log P - a + bT + \frac{c}{T}$$

Where a, b and c are constants. Vapour pressure thermometers are used to measure temperature in the range from 0.7 K to 120K.

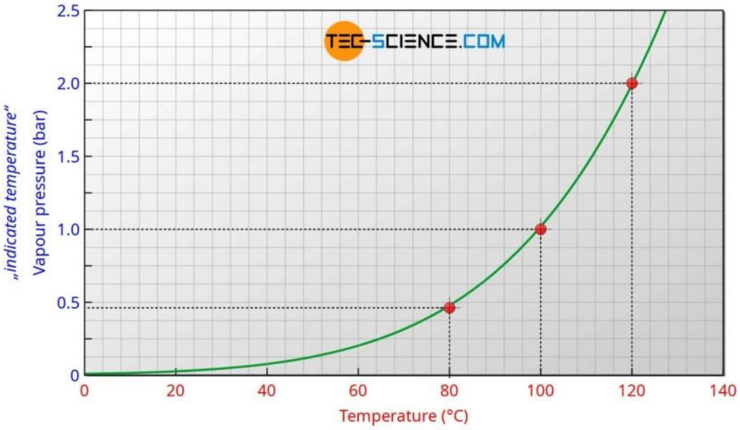


Vapour pressure thermometer consists of a partially filled bulb as shown in figure. This bulb is used as a sensing, element to measure temperature. When bulb senses the temperature, vapour will be formed above the liquid level in the sensing bulb. This vapour will pass through a capillary tube and then to a bourdon tube which is connected to the capillary tube. The vapour pressure causes the deflection in the bourdon tube. This deflection is transmitted through mechanical arrangement causing the movement of a pointer on a scale. The caliberated scale will give the measurement of temperature.

This equilibrium between vapour and liquid depends on the temperature. If the temperature rises, more liquid will vaporize and the vapour pressure will rise. This rising vapour pressure is indicated by a Bourdon tube, as with gas filled thermometers. Conversely, a drop in temperature causes part of the gaseous vapour to condense and the vapour pressure to decrease. The indicated temperature decreases.



The graph drawn between temperature and vapour pressure is as shown in figure below.



Since the vapour pressure curves are not linear, the scale for vapour pressure thermometers is not evenly subdivided. Due to the exponentially increasing vapour pressure curves, the scale distances increase with higher temperature, so that the measurement sensitivity and accuracy increases as a result. Vapour pressure thermometers should therefore be used in the upper third of the scale for sufficient measurement accuracy.

Vapour pressure thermometers can be used at very low temperatures, which are only a few Kelvin above absolute zero.

Advantages:

1. Rigid in construction
2. Versatility. It means this can be used in different tasks
3. Low cost, it means economics
4. Easy to read from nearby distances
5. Sensitivity is high

Disadvantages:

1. Vapour pressure thermometer required liquids are not available plenty.

Magnetic thermometer

A thermometer whose operation is based on Curie's law. Curie’s law states that “the magnetic susceptibility of paramagnetic materials is inversely proportional to absolute temperature”.

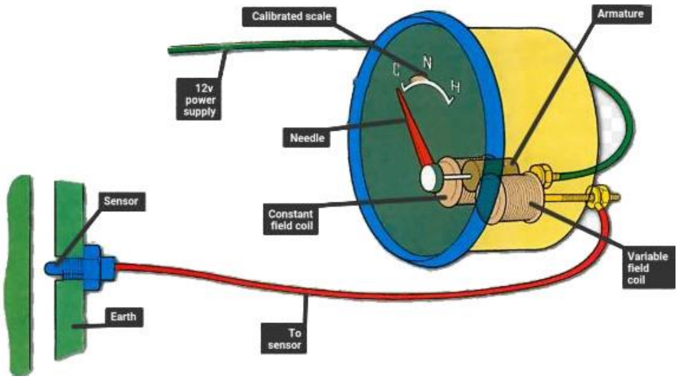
$$Susceptibility\ \chi \alpha\ \frac{1}{T}$$

$$Susceptibility\ \chi = \frac{C}{T}$$

Where C is called Curie’s Constant.

Magnetic thermometers are typically used at temperatures below 1 K (-458°F). The magnetic moments in the thermometric material may be of either electronic or nuclear origin. Generally the magnetic thermometer must be calibrated at one or more reference temperatures.

Magnetic Thermometer measures surface temperature. The thermometer can easily be placed on ferrous substrates with the strong magnet on the back. The surface temperature can be read out in both °C and °F. Measuring Range is -10°C to + 70°C; +14°F to +60 °F. The diameter of the thermometer is 65 mm. Can be used in a vacuum. No plastic parts on the outside of the thermometer.



At temperatures from a few mill kelvins upward, the thermometric material is preferably an electronic paramagnet, typically a non-conducting hydrous rare-earth salt.

For higher temperatures, an ion is selected with a large magnetic moment in a crystalline environment with a high density of magnetic ions.

In contrast, for low temperature use the magnetic exchange interactions between the magnetic ions should be small, which is accomplished by selecting an ion with a well-localized moment and by maintaining a large separation between the magnetic ions by means of diamagnetic atoms. This is the case in cerium magnesium nitrate (CMN) [2Ce(NO3)3 · 3Mg(NO3)3 · 24H2O].

Here, the Ce3+ ion is responsible for the magnetic moment, which is well localized within the incompletely filled 4f shell relatively deep below the outer valence electrons. To reduce the magnetic interactions between the Ce3+ ions further, Ce3+ may be partly substituted with diamagnetic La3+ ions. Lanthanum-diluted CMN has been used for thermometry to below 1 mK.

Nuclear magnetic moments are smaller by a factor of 103 and are used for thermometry only in the ultralow-temperature region. For this the Curie-law behavior is generally sufficient down to the lowest temperatures. The nuclear paramagnetic thermometer loses adequate sensitivity for calibration purposes above 50–100 millikelvins, unless it is operated in a high polarizing field (H greater than 0.1 tesla).

UNIT-III

PRINCIPLES OF REFRIGERATION

Introduction

The term refrigeration refers to the process of removing heat from an enclosed space or substance for the purpose of lowering the temperature.

This process was witnessed, in the Greeks and Romans period to cool their food with ice transported from the mountains. Preservation of the food is the main idea which leads to the development of the refrigeration process. Refrigeration inhibits the growth of microorganisms like bacteria, yeast and mold thus helping in the destroying of food items. It is mainly used to store foodstuff at low temperatures for a longer period of time.

Refrigeration refers to the process by which energy, in the form of heat, is removed from a low-temperature medium and transferred to a high-temperature medium. This work of energy transfer is traditionally driven by mechanical means, but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications, including household refrigerators, industrial freezers, cryogenics, and air conditioning.

The history of artificial refrigeration began when Scottish professor William Cullen designed a small refrigerating machine in 1755. Cullen used a pump to create a partial vacuum over a container of diethyl ether, which then boiled, absorbing heat from the surrounding air. The experiment even created a small amount of ice, but had no practical application at that time.

Methods of refrigeration can be classified as non-cyclic, cyclic, thermoelectric and magnetic.

Working Principle of Refrigerator

Refrigerators work on the second law of thermodynamics. In the process of refrigeration, unwanted heat is taken from one place and discharged into another. The common refrigerator which we have in our homes, works on the principle of evaporation. A refrigerant is a substance used in a heat cycle to transfer heat from one area, and remove it to another. A refrigerant when passed through the food kept in the refrigerator, it absorbs heat from these items and transfers the absorbed heat to the surrounding with less temperature.

There are two types of refrigeration methods.

1. Natural refrigeration and
2. Artificial refrigeration

Natural Refrigeration

(a) By Using Ice or Snow

The natural methods include the utilization of ice or snow produced naturally cold climate. Ice melts at 0°C, so when it is placed in a space or system warmer than 0°C heat flows into ice and the space is cooled. The ice in turn melts into water by absorbing its latent heat at the rate of 335 kJ/kg. The river water, if it is quite cold, may also be used for cooling certain systems, but the removal of heat will not be as fast and satisfac-tory as in the case when ice or snow is used.

Natural refrigerants are substances that serve as refrigerants in refrigeration systems. They are alternatives to synthetic refrigerants such as chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), and hydrofluorocarbon (HFC) based refrigerants. Unlike other refrigerants, natural refrigerants are non-synthetic and can be found in nature. The most prominent of these include various natural hydrocarbons, ammonia, carbon dioxide, water and air. Natural refrigerants are preferred to their synthetic counterparts for their higher degrees of sustainability. With the current technologies available, almost 75 percent of the refrigeration and air conditioning sector has the potential to be converted to natural refrigerants.

The natural methods of refrigeration were actually used in early days. With the present developments in science and technology and the subsequent rise in the standard of leaving the refrigeration requirements have become so large that the natural methods have become inadequate.

When ice is to be used for refrigeration, winter ice can be stored by packing it in straw and dried weeds, for use in the summer months.

(b) Evaporative Cooling Process

In the old days, it was observed by the people that evaporation of water naturally causes cooling effect and hence they used to put liquids into porus earthenware containers placed in the open atmosphere such as roof.

We have every day experience that water kept in an clay pot becomes cooled because of the evaporation of water absorbing latent heat of evaporation from water in the pot and coming out through the pores. This effect is experienced very well in summer.

Air flowing over the surface of water whose temperature is less than the incoming air, then the air is cooled because of the evaporation during which latent heat is taken from air and water sump.

The direct emissions of natural refrigerants have no, or only a negligible, impact on the climate, should they escape into the atmosphere.

(c) Cooling by Salt solutions

A method capable of generating a cooling effect without using electricity could help to lower energy usage in hot climates, and provide a greener alternative to refrigeration is called a cooling by salt solutions.

We add salt into a mixture of ice and water, the melting/freezing point of the mixture decreases and the ice begins to melt. In order for a phase change to occur, the ice draws the heat of fusion from its surroundings, which allows the temperature to decrease.

Sodium chloride salt (Nacl) can yield temperatures upto -20^{o}C and calcium chloride (cacl$_2$) upto -50^{o}C in properly insulated containers.

Artificial Refrigeration

The process of removing heat from an enclosed space or from a substance for the purpose of lowering the temperature is called refrigeration.

The history of artificial refrigeration began when Scottish professor William Cullen designed a small refrigerating machine in 1755. Cullen used a pump to create a partial vacuum over a container of diethyl ether, which then boiled, absorbing heat from the surrounding air. The experiment even created a small amount of ice, but had no practical application at that time.

In India and Egypt evaporative cooling was employed. If a liquid is rapidly vaporized, it expands quickly. The rising molecules of vapour abruptly increase their kinetic energy. Much of this increase is drawn from the immediate surroundings of the vapour, which are therefore cooled.

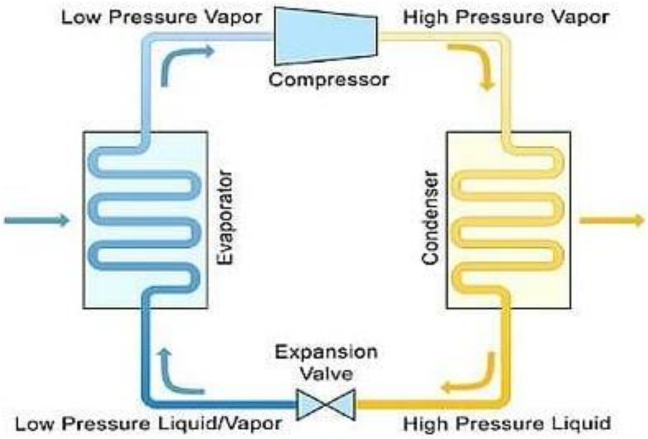
Cooling caused by the rapid expansion of gases is the primary means of refrigeration today.

Stages of refrigeration

In simple terms, a refrigeration cycle mission having the heat absorption and the heat rejection. The refrigeration cycle, sometimes called a heat pump cycle, because of routing heat away from the area you want to cool. This is accomplished by manipulating the pressure of the working refrigerant (air, water, synthetic refrigerants, etc.) through a cycle of compression and expansion.

There are certainly other components in most loops, but most would agree the four fundamental elements of a basic cycle are as follows:

1. The compressor
2. The condenser
3. The expansion device
4. The evaporator



The compressor

Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas.

Types of compressors

Compression can be achieved through a number of different mechanical processes, and because of that, several compressor designs are used in refrigeration today.

a. Reciprocating compressors
b. Scroll compressors
c. Rotary compressors

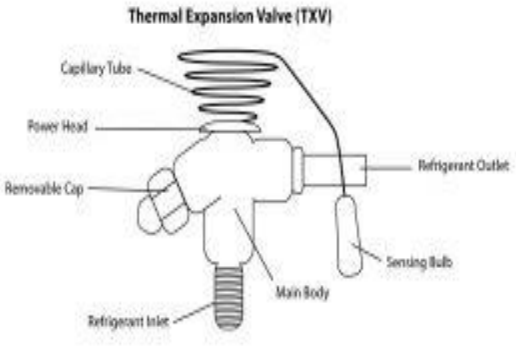
The condenser, or condenser coil, is one of two types of heat exchangers used in a basic refrigeration loop. This component is supplied with high-temperature high-pressure, vaporized refrigerant coming off the compressor.

Condenser

After leaving the compressor, the hot vapor refrigerant enters the next stage of the cycle, condensation. During the condensation stage, the refrigerant enters a condenser and flows through a series of S-shaped tubes. As the hot vapor flows through the condenser, cool air is blown across the tubes by a fan.

Because the air being blown across the tubes is cooler than the refrigerant, heat transfers from the tubing to the cooler air. This heat transfer causes the hot vapor refrigerant to reach its saturated temperature, which then changes its state to a high-pressure liquid. Once the refrigerant is in a high-pressure liquid state, it is ready to leave the condenser and move on to the metering and expansion stage of the cycle.

The expansion device



These components come in a few different designs. But regardless of configuration, the job of a system’s expansion device is the same - create a drop in pressure after the refrigerant leaves the condenser. This pressure drop will cause some of that refrigerant to quickly boil, creating a two-phase mixture.

The evaporator

The evaporator is the second heat exchanger in a standard refrigeration circuit, and like the condenser, it’s named for its basic function. It serves as the “business end” of a refrigeration cycle, given that it does what we expect air conditioning to do – absorb heat.

This happens when refrigerant enters the evaporator as a low temperature liquid at low pressure, and a fan forces air across the evaporator's fins, cooling the air by absorbing the heat from the space in question into the refrigerant.

After doing so, the refrigerant is sent back to the compressor, where the process restarts. And that, in a nutshell, is how a refrigeration loop works.

Vapour compression Refrigeration system

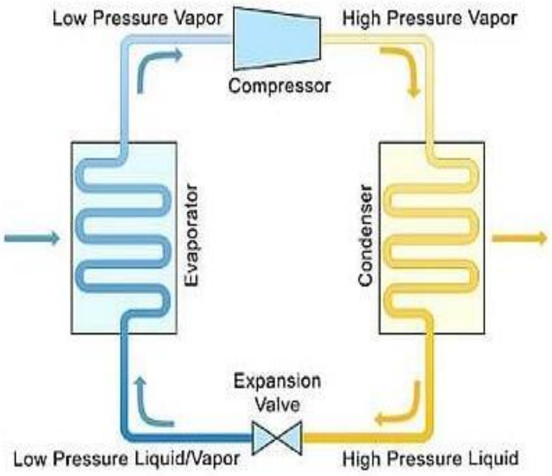
The main functioning of Vapour-compression refrigerator or vapor-compression refrigeration system (VCRS) is in which the refrigerant undergoes phase changes. This is one of the many refrigeration cycles and is the most widely used method for air conditioning of buildings and automobiles.

This process is designated as a Vapour compression refrigeration system because the vapor in this system is compressed to produce vapor. The Vapour compression refrigeration systems is the most commonly used refrigeration system among all refrigeration systems.

In this system, the phase of the working fluid changes from one state to another state. Refrigerant evaporates at low temperatures providing cooling effects in the vapour pressure compression system.

During evaporations, it absorbs heat from the cold body and is used as its latent heat to convert this heat from the liquid to vapor, while in condensing or cooling, it rejects heat to external bodies Gives, thus creating a cooling effect in the working fluid.

Vapor compression refrigeration systems have four main components used to create the refrigeration cycle.



Stage 1: Compression

In the first stage of the refrigeration cycle, refrigerant enters a compressor as a low-pressure vapor. The compressor compresses the refrigerant to a high-pressure vapor, causing it to become superheated. Once the refrigerant is compressed and heated, it leaves the compressor and enters the next stage of the cycle.

There are several styles of compressors that can be used in the refrigeration cycle, including scroll, screw, centrifugal, or reciprocating compressors.

Stage 2: Condensation

After leaving the compressor, the hot vapor refrigerant enters the next stage of the cycle, condensation. During the condensation stage, the refrigerant enters a condenser and flows through a series of S-shaped tubes. As the hot vapor flows through the condenser, cool air is blown across the tubes by a fan.

Because the air being blown across the tubes is cooler than the refrigerant, heat transfers from the tubing to the cooler air. This heat transfer causes the hot vapor refrigerant to reach its saturated temperature, which then changes its state to a high-pressure liquid. Once the refrigerant is in a high-pressure liquid state, it is ready to leave the condenser and move on to the metering and expansion stage of the cycle.

Stage 3: Metering and Expansion valve

The third stage of how compression refrigeration systems work consists of the high-pressure liquid refrigerant entering a metering device or expansion valve. The metering device works to maintain high-pressure on the inlet side, while also expanding the liquid refrigerant and lowering the pressure on the outlet side. During the process of expansion, the temperature of the liquid refrigerant is also reduced.

Stage 4: Evaporation

In a cool, low-pressure liquid state, the refrigerant is now ready to enter the evaporation stage, which is where the heat is finally removed from the space being conditioned.

In the evaporation stage, the cool liquid refrigerant leaves the metering device and enters coiled tubes in an evaporator. Fans are then used to blow warm air from the conditioned space across the evaporator coils. The cooler refrigerant in the evaporator coils begins absorbing the heat out of the warmer air, reducing the temperature in the conditioned space.

Meanwhile, as the refrigerant absorbs heat from the air, it begins to boil and changes to a low-pressure vapor. The low-pressure vapor is then pulled back into the compressor, and the cycle starts over.

Coefficient of Performance – Refrigerator, Air Conditioner

The coefficient of performance (COP) of a refrigerator is defined as the ratio between heat removed from the cold reservoir Q_{cold} (i.e., inside a refrigerator) to the work W done to remove the heat (i.e., the work done by the compressor).

$$Coefficient\ of\ performance\ COP = \frac{Q_{Cold}}{W}$$

As can be seen, the better refrigerator can be removed more heat Q_{cold} from the inside of the refrigerator for a given amount of work.

According to the first law of thermodynamics must be valid also in this case

$$Q_{cold} + W = Q_{hot}$$

We can rewrite the above equation

$$Coefficient\ of\ performance\ COP = \frac{Q_{Cold}}{W} = \frac{Q_{Cold}}{Q_{hot} - Q_{Cold}}$$

For an ideal refrigerator (without losses and irreversibilities) can be derived that:

$$Coefficient\ of\ performance\ COP = \frac{T_{Cold}}{W} = \frac{T_{Cold}}{T_{hot} - T_{Cold}}$$

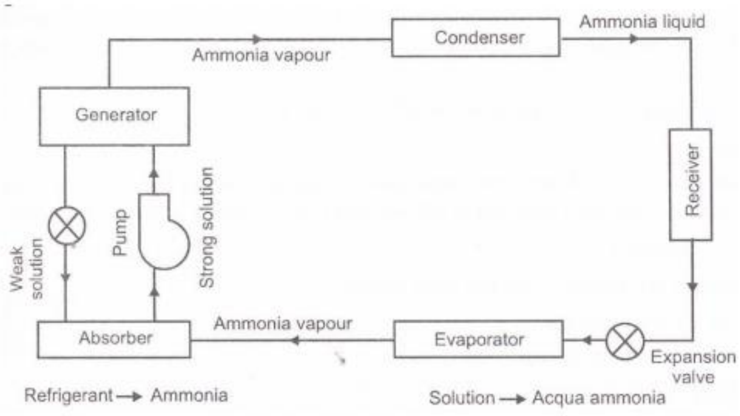
These formulas are also applied for an air conditioner, which works very much like a refrigerator.

Applications of Vapour Compression Refrigeration System

1. It is used in domestic refrigeration for keeping the food.
2. It is helpful in food processing and cold storage.
3. It is useful in Industrial refrigeration for chemical processing, heating, and cooling.
4. It is useful in Cryogenic refrigeration, Medical refrigeration, Transport refrigeration, and Electronic cooling.
5. It is useful in Oil refineries, petrochemical and chemical processing plants and natural gas processing plants.
6. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services.

Vapor absorption refrigeration systems

Vapour absorption refrigeration system consists of evaporator, absorber, generator, condenser, expansion valve, pump & reducing valve. In this system water vapor is used as refrigerant and solution used is LiBr+water. Strong solution of LiBr+water contains as much as water as it can and weak solution contains less water. The compressor or vapour compressor system is replaced by an absorber, generator, reducing valve and pump.



The VARS system uses two working fluids for refrigeration i.e. refrigerant and absorbent. In the NH_3-H_2O refrigeration system, ammonia (NH_3) is used as a refrigerant while the water (H_2O) is used as an absorbent. In H_2O-LiBr, VARS refrigeration water is used as a refrigerant while the LiBr is used as an absorbent.

The vapour absorption refrigeration system consists of the following components:-

a) Absorber

The purpose of the absorber is to absorb the low-pressure refrigerant vapours in the solution of the refrigerant and absorbent.

The weaker solution from the generator and the low-pressure refrigerant vapours from the evaporator enters the absorber. Here the refrigerant vapours are absorbed to form a stronger solution.

During the absorption, the vapours of the refrigerant lose the latent heat to change their phase from vapour to liquid. Thus it raises the temperature inside the absorber which can lower the absorption capacity of the absorbent. To avoid this, the solution is cooled with the help of cooling water.

b) Pump

It is used to suck the strong solution from the absorber & deliver it to the generator at higher pressure.

c) Generator

It is used to heat the strong solution by use of heating coils, solar energy or waste heat. As the refrigerant has a lower boiling point than the absorbent, the refrigerant inside the solution gets vapourised leaving the solution weaker.

If this weak solution goes to the condenser, it may damage the system. Hence the weak solution from the generator returns to the absorber through pressure reducing valve (PRV).

d) Condenser

The high-pressure refrigerant vapours from the generator enter the condenser. The condenser has a cooling medium to cool the hot vapours of the refrigerant. Here the refrigerant vapours get converted into the high-pressure saturated liquid refrigerant.

e) Pressure reducing valve (prv)

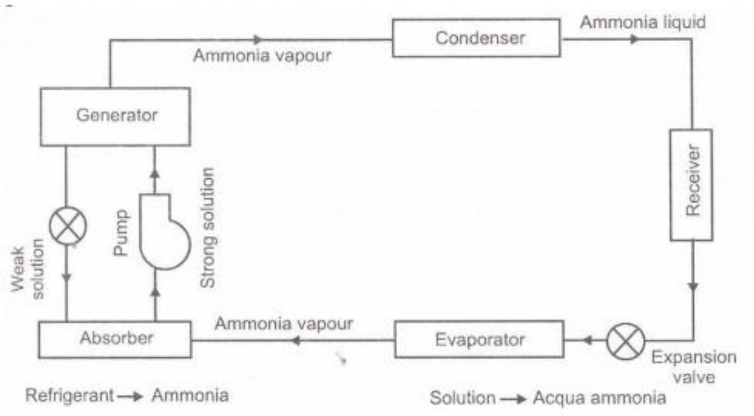
The pressure-reducing valve is connected between the generator (works at high pressure) and absorber (works at low pressure). It lowers the pressure of weak solution coming from the generator and then it is passed to the absorber.

F) Expansion valve

Expansion valve is located between the condenser & evaporator. After the condenser, the high-pressure liquid refrigerant enters the expansion valve. Here the high-pressure liquid refrigerant is converted into a mixture of low-pressure refrigerant (liquid + vapour).

G) Evaporator

The evaporator is located in the enclosed space where cooling is carried out. In the evaporator, the low-pressure liquid refrigerant absorbs the heat in the enclosed space to provide a cooling effect. Due to the absorption of heat, the liquid refrigerant gets converted into low-pressure refrigerant vapours.



Working of Vapour absorption refrigeration system

The above diagram indicates aqua-ammonia (H2O-NH3) vapour absorption refrigeration system. Here the ammonia is used as a refrigerant while the water is used as an absorbent.

The VARS system works in the following manner:-

COP of vapour absorption refrigeration system

Where,

Q_G = heat supplied to the generator

T_G = Temperature at generator

Q_E = Heat gained at evaporator

T_E= Temperature at evaporator

Q_A = Heat rejected from absorber

Q_C = Heat rejected from condenser

T_S = Surrounding temperature

The COP of the VARS can be given by,

$$Coefficient\ og\ Performance\ COP = \frac{Required\ heat}{Heat\ supplied}$$

$$Coefficient\ og\ Performance\ COP = \frac{Q_E}{Q_G}$$

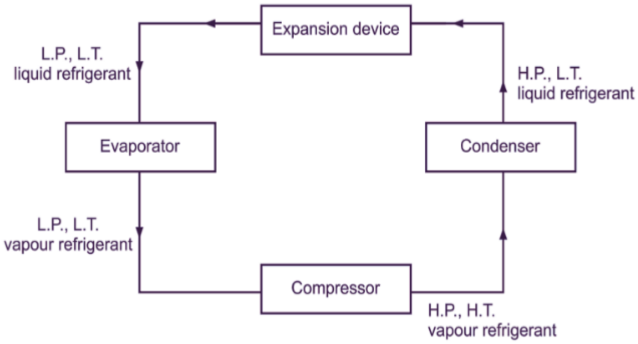
$$Coefficient\ of\ Performance\ COP = \frac{Q_E}{Q_G} = \frac{T_G - T_S}{T_G} . \frac{T_E}{T_S - T_E}$$

This is the equation to find the maximum COP of the VARS refrigeration system.

The vapour absorption refrigeration system has the following applications:-

1. Large-capacity refrigeration in bigger plants.
2. Suitable for larger air conditioning or water chilling.
3. Used in places having electricity problems for refrigeration and air conditioning.
4. Electrolux refrigerator.
5. VAM chiller

Refrigeration cycle and block diagram



Stage 1: Compression

In the first stage of the refrigeration cycle, refrigerant enters a compressor as a low-pressure vapor. The compressor compresses the refrigerant to a high-pressure vapor, causing it to become superheated. Once the refrigerant is compressed and heated, it leaves the compressor and enters the next stage of the cycle.

There are several styles of compressors that can be used in the refrigeration cycle, including scroll, screw, centrifugal, or reciprocating compressors.

Stage 2: Condensation

After leaving the compressor, the hot vapor refrigerant enters the next stage of the cycle, condensation. During the condensation stage, the refrigerant enters a condenser and flows through a series of S-shaped tubes. As the hot vapor flows through the condenser, cool air is blown across the tubes by a fan.

Because the air being blown across the tubes is cooler than the refrigerant, heat transfers from the tubing to the cooler air. This heat transfer causes the hot vapor refrigerant to reach its saturated temperature, which then changes its state to a high-pressure liquid. Once the refrigerant is in a high-pressure liquid state, it is ready to leave the condenser and move on to the metering and expansion stage of the cycle.

Stage 3: Metering and Expansion

The third stage of how compression refrigeration systems work consists of the high-pressure liquid refrigerant entering a metering device or expansion valve. The metering device works to maintain high-pressure on the inlet side, while also expanding the liquid refrigerant and lowering the pressure on the outlet side. During the process of expansion, the temperature of the liquid refrigerant is also reduced.

Stage 4: Evaporation

In a cool, low-pressure liquid state, the refrigerant is now ready to enter the evaporation stage, which is where the heat is finally removed from the space being conditioned.

In the evaporation stage, the cool liquid refrigerant leaves the metering device and enters coiled tubes in an evaporator. Fans are then used to blow warm air from the conditioned space across the evaporator coils. The cooler refrigerant in the evaporator coils begins absorbing the heat out of the warmer air, reducing the temperature in the conditioned space.

Meanwhile, as the refrigerant absorbs heat from the air, it begins to boil and changes to a low-pressure vapor. The low-pressure vapor is then pulled back into the compressor, and the cycle starts over.

Refrigerants

A refrigerant is a working fluid used in the refrigeration cycle of air conditioning systems and heat pumps where in most cases they undergo a repeated phase transition from a liquid to a gas and back again.

Refrigerants are used in a Direct Expansion system to transfer energy from one environment to another, typically from inside a building to outside (or vice versa) commonly known as an "air conditioner" or "heat pump".

Refrigerants are controlled substances due to 1) High Pressures 2) Extreme temperatures (-50°C to 145°C), 3) Flammability.

The first air conditioners and refrigerators employed toxic or flammable gases, such as ammonia, sulfur dioxide, methyl chloride, or propane that could result in fatal accidents when they leaked.

In 1928 Thomas Midgley Jr. created the first non-flammable, non-toxic chlorofluorocarbon gas, Freon.

The name is a trademark name owned by DuPont for any chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), or hydrofluorocarbon (HFC) refrigerant.

Ideal refrigerant

The ideal refrigerant is nontoxic, non-flammable and physical properties compatible with the system needs, and has a high latent heat of vaporization.

a) The ideal refrigerant would be nontoxic and nonflammable
b) zero ozone depletion potential (ODP),
c) zero global warming potential (GWP),
d) Short atmospheric lifetime.

Desirable Properties of an ideal Refrigerant are

1. Thermodynamic Properties:

(i) Low boiling point

(ii) Low freezing point

(iii) Positive pressures in condenser and evaporator.

(iv) High saturation temperature

(v) High latent heat of vapourization

2. Chemical Properties:

(i) Non-toxicity

(ii) Non-flammable and non-explosive

(iii) Non-corrosiveness

(iv) Chemical Stability in reacting

(v) No effect on the quality of stored (food and other) products

3. Physical Properties:

(i) Low specific volume of vapour

(ii) Low specific heat

(iii) High thermal conductivity

(iv) Low viscosity

(v) High electrical insulation

4. Others Properties:

(i) Ease of leakage location

(ii) Availability and low cost

(iii) Ease of handling

(iv) High COP

(v) Low power consumption per tonne of refrigeration

(vi) Low pressure ratio and pressure difference

Properties of refrigerants

The refrigerant is nontoxic, non-flammable and physical properties compatible with the system needs, and has a high latent heat of vaporization. Desirable Properties of Refrigerants are

1. Thermodynamic Properties:

   (i) Low boiling point

   (ii) Low freezing point

   (iii) Positive pressures (but not very high) in condenser and evaporator.

   (iv) High saturation temperature

   (v) High latent heat of vapourization

2. Chemical Properties:

   (i) Non-toxicity

   (ii) Non-flammable and non-explosive

   (iii) Non-corrosiveness

   (iv) Chemical Stability in reacting

   (v) No effect on the quality of stored (food and other) products

3. Physical Properties:

   (i) Low specific volume of vapour

   (ii) Low specific heat

   (iii) High thermal conductivity

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Eco-friendly refrigerants

The refrigeration process works due to the physical process of evaporation in which a refrigerant absorbs heat from its environment as it evaporates. The amount of heat removed, and how efficiently it is done, depends on factors such as the compressor, evaporator, insulation, and in large part, the type of refrigerant used.

The earliest chemical refrigerants commonly used were generally toxic and often dangerous.

Freon in particular has been found to be especially harmful to the environment, and it’s a refrigerant we have been dependent upon for years. Fortunately, there are some alternative refrigerants that are more eco-friendly and others continue to be discovered, tested, and developed all the time.

The major categories of refrigerants are:

Chlorofluorocarbons (CFCs):

CFCs are compounds consisting of chlorine, fluorine & carbon atoms. They are used in making aerosol sprays, blowing agents for foams and packing materials, as solvents, and as refrigerants. Due to their high ODP (Ozone Depletion Potential) and high GWP (Global Warming Potential), they are considered non-eco-friendly refrigerant gases.

Examples: R11, R12

Hydrochlorofluorocarbons (HCFCs):

HCFCs are compounds consisting of hydrogen, chlorine, fluorine and carbon atoms. HCFC refrigerants have medium ODP and medium to high GWP; often used in refrigerant and air conditioning equipment. These also are not environment friendly refrigerant gases, and in most countries are either phased out completely or undergoing phase out.

Examples: R22, R141b

Hydrofluorocarbons (HFCs):

A combination of fluorinated hydrocarbons, HFCs have zero ODP and medium to high GWP thus offering a more environment friendly alternative to CFCs and HCFCs. HFCs are used as an alternative to CFC's in foam production, refrigeration and other processes. HFCs can contribute to global warming but do not affect the ozone layer directly.

Examples: R32, R134a

Hydrofluoro-olefins (HFOs):

HFOs comprise hydrogen, fluorine and carbon atoms connected by single bonds between the atoms. HFO refrigerants have zero ODP & comparatively very low GWP and are currently considered the most eco-friendly refrigerants available.

Example: R452a, HFO1234yf, HFO1234ze, HFO1234yz

CFCs, HCFCs & HFCs are chemically synthesized, they do not exist as compounds naturally. As their medium to high ODP & GWP is considerably detrimental to the environment, they are being phased out under the Montreal Protocol held in the year1987.

HFOs are synthetically made unsaturated HFCs with no ODP & low GWP, resulting in lowest adverse effect on environment and thus are eco-friendly refrigerant gases.

Natural refrigerants have zero ODP & extremely low GWP due to which they are ideal replacements for the CFCs, HFCs & HCFCs. They are the naturally occurring substances like

CO_2, ammonia, water & air. They can be hydrocarbons as well propane, isobutene, propene or propylene.

Benefits of Eco-Friendly Gases

1. Recycling or disposal, after their usage in cooling systems is comparatively easier than CFCs, HCFCs & HFCs.
2. These gases are typically more energy efficient than F-gases.
3. Eco-friendly gases can be used in almost all RAC (Refrigeration and Air Conditioning) applications.
4. These refrigerants are not patented by the chemical industry & are cheaper than HFCs.
5. These gases do not harm the environment & can be handled safely with care.
6. These gases can also be obtained as by-products from other processes.
7. It is easier to make them readily available if proper distribution structures can be established.

Natural Clay Refrigerator

This all-natural clay refrigerator is rooted in the concept of going back to our roots to revisit a healthier, more robust lifestyle. Made from terracotta clay, the natural clay refrigerator is ideal for storing water, milk, fruits and vegetables. This award-winning product provides efficient cooling without electricity.

1. Runs without electricity
2. Modern design
3. Naturally cool vegetables, fruits, Milk,Water etc.
4. Very easy to use
5. Variety of health benefits

Using Technique:

a) Before starting to use the fridge, fill the top water tank with water and empty it after 12 hours so that the clay gets used to water.
b) Up to first 3 months of use, only fill in 1 litre of water in the tank so that it does not leak to the lower chamber due to high porosity.
c) After 3 months, you can slowly increase the volume of water in the tank up to 10 litres.
d) It is suggested to put a tray below the fridge so that the water which leaks due to porosity won't dirty your flooring.
e) You can store up to 5 Kg. of fruits and vegetables in the lower chamber which will remain fresh up to 5-7 days.
f) You can use a soft sponge or similar material to clean the refrigerator.
g) It is advisable to store clean water for better results.
h) The inner temperature goes down by 10-15 compared to the room temperature to give you a unique experience of natural and hygienic food.
i) The original nutrients are preserved and also it does not emit any carbon gases that are harmful to health and the environment.