Refrigeration and Air conditioning

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Lecture No. - 1

History of Refrigeration

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Welcome to the NPTEL course on refrigeration and air conditioning. I am Ramgopal from the department of Mechanical Engineering. I would like to begin this course with brief history of refrigeration, and the specific objectives of this particular lesson are to define refrigeration and air conditioning. Then introduce the historical aspects of natural refrigeration methods and artificial refrigeration methods.

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At the end of the lesson you should be able to identify various natural and refrigeration artificial methods of refrigeration, list salient points of various refrigeration techniques and name important landmarks in the history of refrigeration.

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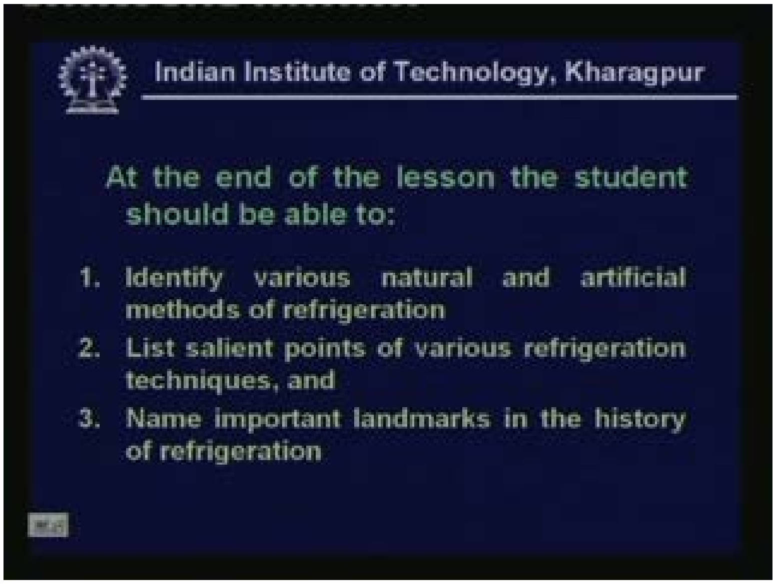

Let us look at the definition of refrigeration. Refrigeration is defined as the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and place.

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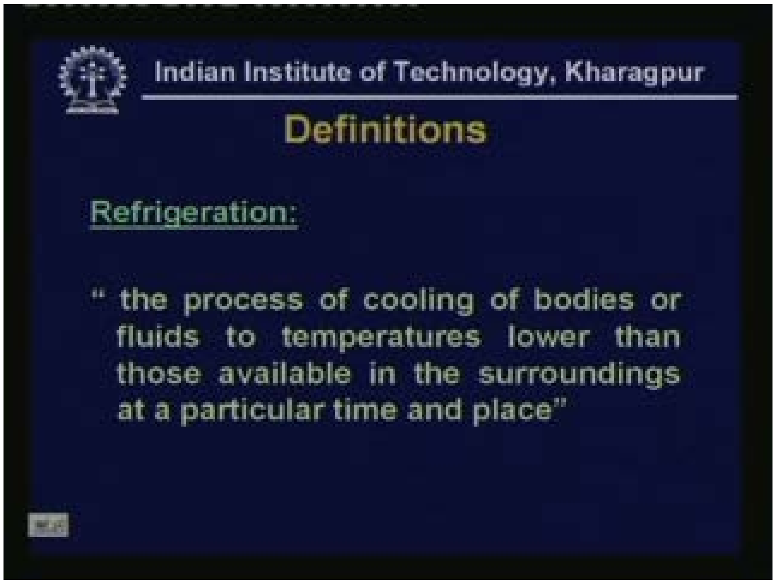

So you can notice that in refrigeration cooling is involved but refrigeration not exactly same as cooling.

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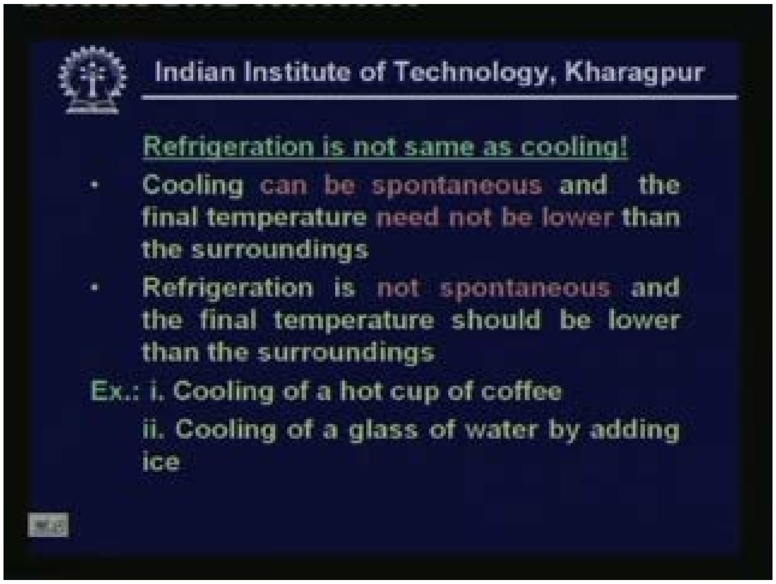

So what is the difference between the refrigeration and cooling? Cooling can be a spontaneous process and the final temperature need not be same as; the need not be lower than the surrounding temperature. Where as in refrigeration not a spontaneous process and the end final temperature should always be lower than the surroundings. So these are main difference between normal cooling process and a refrigeration process. For example, cooling of a hot cup of coffee;

if you take a cup of coffee and leave it on the table it cools down. However its final temperature cannot be lower than the surrounding temperature. Okay so this is an example of a cooling process but it is not an example of refrigeration process because the final temperature is not lower than the surrounding temperature.

Let us look at the second example; Cooling of a glass of water by adding ice. When you add sufficient amount of ice the final temperature of the water will be lower than the surroundings. So this is an example of refrigeration okay.

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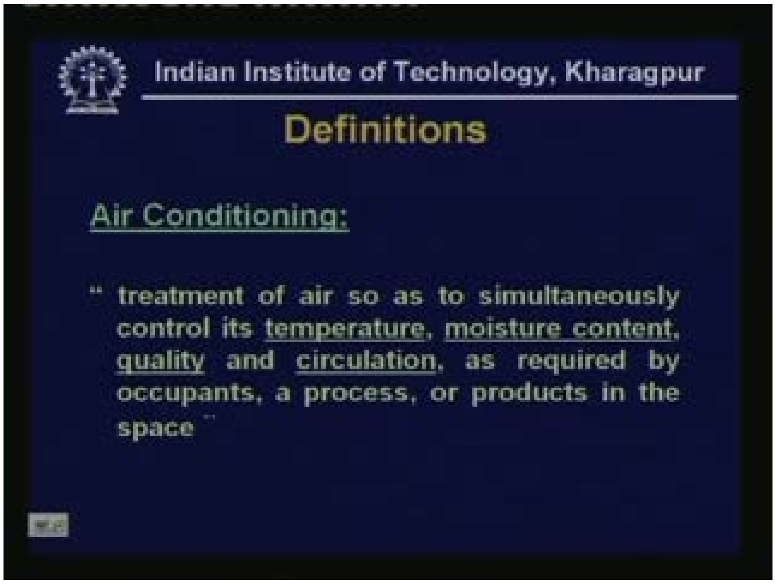

Now let us define air conditioning. Air conditioning refers to the treatment of air so as to simultaneously control its temperature, humid moisture content, quality and circulation. So why do we want to do this because, this is required for occupants in thermal comforts and it required for a process or products in the space. Now, what is the application of air conditioning?

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Refrigeration is mainly required in various food processing and food preservation operations and refrigeration required in almost all chemical and process industries. It is also required for comfort and industrial air conditioning and there are also several other applications of air conditioning and refrigeration such as in medicine, construction, sports extra. Now the history of refrigeration can be define divided into two phases.

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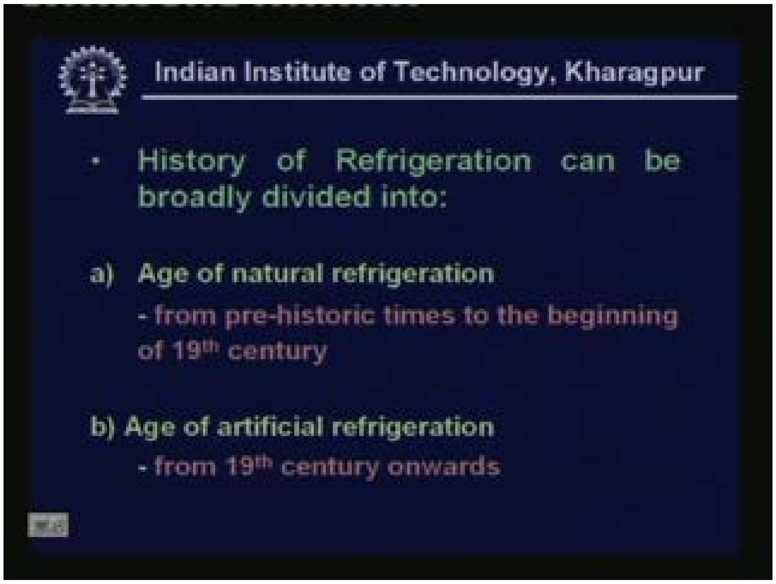

First one is age of natural refrigeration beginning with the pre historic times to the end of nineteenth century or to the beginning of nineteenth century and the age of artificial refrigeration from nineteenth century onwards.

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Now let us look at some of the natural refrigeration methods. Why do we call it as natural refrigeration methods, because we rely on nature for providing refrigeration? The most important of these is the use of natural ice. Natural ice can be obtained from colder regions and it can be transported to regions where it is not available. For example ice is available in Polar Regions so you can cut the blocks of ice from the polar region and they used to be transported to other areas. This used to be actually a very flourishing business in olden times. Of course the ice use to come all the way from America to even to India, i mean countries like India. Then the second methods are harvest the ice in winter and store it for use in summer.

There are several countries where the winters are very harsh so you can actually make ice lakes and rivers freeze in winter so you cut the ice blocks and store them in ice houses and use them in summer. This is the second popular method. And the third method is to production of ice using nocturnal cooling. This is the method which has been used for centuries in countries like India and Middle East. So now let us look at the principle of nocturnal cooling.

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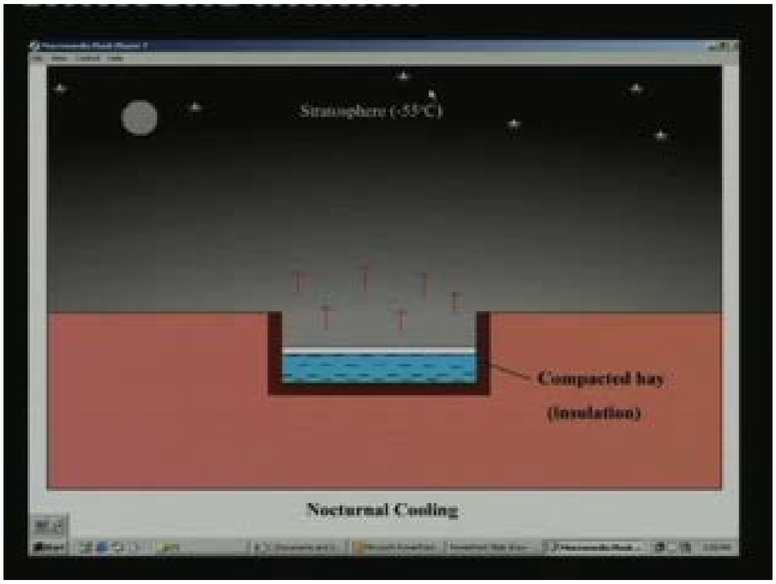

So in nocturnal cooling you leave a shallow pool of water in night sky. Okay, and for the water to become ice its temperature has to be brought down from zero degree centigrade from the initial temperature to zero degree centigrade and at zero degree centigrade it has to lose its latent heat of fusion so that ice can be form from the liquid water. So for this to happen you have to have a heat sink whose temperature is much lower than zero degrees centigrade. And your surrounding air, for example surrounding air and earth cannot be, cannot act as heat sinks because their temperature in tropical countries will always be greater than zero degree centigrade. However if the sky is very clear then the pool of water can lose heat by radiation to the stratosphere and the stratosphere is typically at the temperature of about minus fifty-five degree centigrade so it is possible for the temperature of water to be lower than the zero degree centigrade.

So this is the process or this is the principle behind nocturnal cooling. However it is not, nocturnal cooling has its own limitations for example, what are the limitations of the nocturnal cooling? It's not possible to make ice when the sky is not clear. For example when the sky is cloudy then the reflection radiation gets reflected back and ice formation it become difficult. And for ice to be made you have to have good insulation around the shallow pool of water. So insulation is required. And the third problem is that you cannot make thick slabs of ice it has to be a shallow pool of water. So these are the major disadvantages of nocturnal cooling, ice formation by nocturnal cooling.

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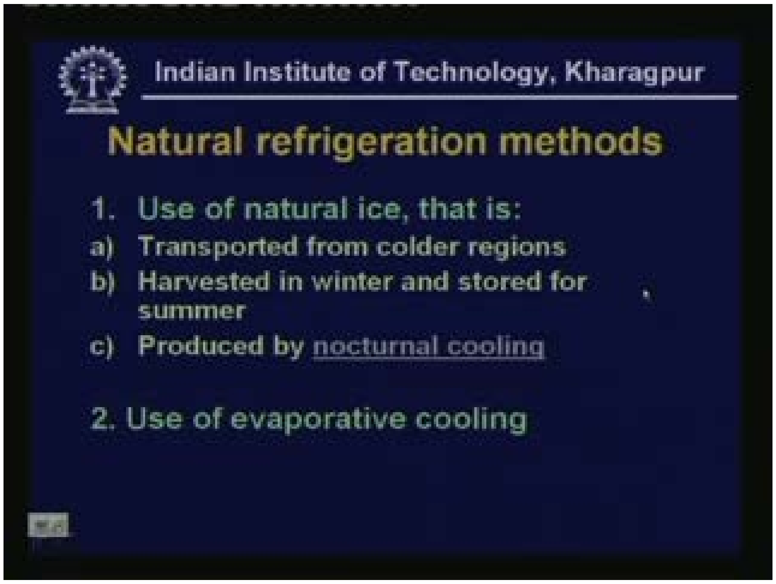

So now let us look at another natural refrigeration method that is use of evaporative cooling.

So whenever water evaporates into surrounding air it produces a cooling effect because evaporation is an endothermic process. So this is the principle behind the cooling of water stored in earth and vessels. And this is also the principle behind the cooling of human bodies on a hot day. That is how that is how we lose the heat on a hot day. However these are the shown limitations the evaporative cooling is very effective when the surrounding air is dry. If the surrounding air is very humid then the evaporation cannot be effective. So that is the reason evaporative cooling works very well in dry area such as desert but it does not work well in coastal regions.

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And the third natural method is cooling by salt solutions. So we know that when we dissolve certain salts and certain materials in water the water temperature drops. Tthis is because of the mixing of these salts with water is an endothermic process. So it takes heat on the surrounding water and the solution resulting solution becomes cold, and by changing the salt you can get different temperatures. However this method again have its own practical limitations because cooling that is produced is generally limited and also the recovery of salt is a difficult process. so let us summarize the limitations of natural methods.

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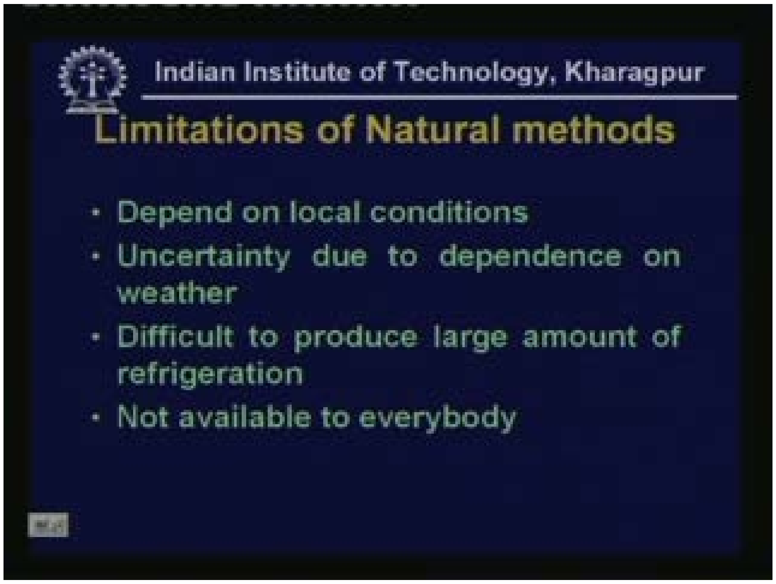

The first limit limitation that they depend on local conditions, and they are uncertain due to dependence on weather, and it is difficult to produce large amount of refrigeration using any of these natural methods, and the they were nor really available to every everybody. So these are the main problems with natural methods hence people have tried to produce refrigeration artificially.

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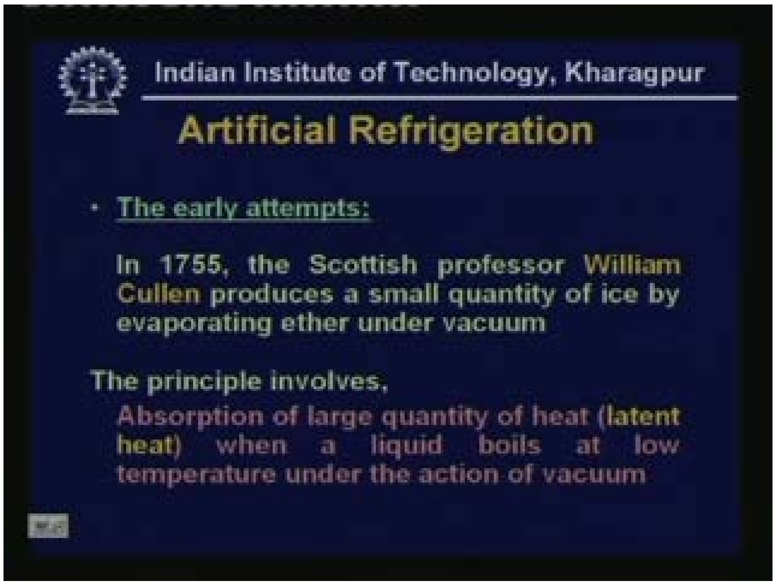

So let us look at artificial refrigeration methods, the early attempt. As per the scientific records the credit for producing artificial ice goes to Professor William Cullen of Scotland. What he has done is, he has brought ethyl ether in thermal contact with water under in evacuated glass bell jar So the liquid water formed from ice found from liquid water as ether boiled. This involved two thermodynamic principles. First principle is that, when you reduce the pressure acting on a liquid its boiling point also reduces. For example ethyl ether has a normal boiling point of thirty-four degree centigrade that means at one atmospheric pressure it boils at a temperature of thirty-four degree centigrade. However if you reduce the pressure then it will boil at lower temperatures and the typical relationship, okay.

So another principle is that boiling is an endothermic process that means heat has got to be supplied from the surroundings so there ice can form. Okay. So these are the two main principles involved behind a Professor Cullen's experiment. That is we summarized here. Okay, so absorption of large quantity of heat when a liquid boils at low temperature under the action of vacuum.

You can see that this process is not a spontaneous process because some external effort is required to maintain the vacuum. That means you have to have some vacuum pump and which required some mechanical energy input, so that continuous vacuum can be maintained in the bell jar. So this is not a spontaneous process. And this process is not also very useful in practice because once all the ether evaporate then there won't be any refrigeration. So if we want to make it practical what we have to do is, we have to recycle the ether. That means what we have to do is, we have to condense the vapour back into liquid and send it back. Okay, so that means this call for a cyclic some kind of a cyclic process okay. So based on this several refrigerant cycles have been devised.

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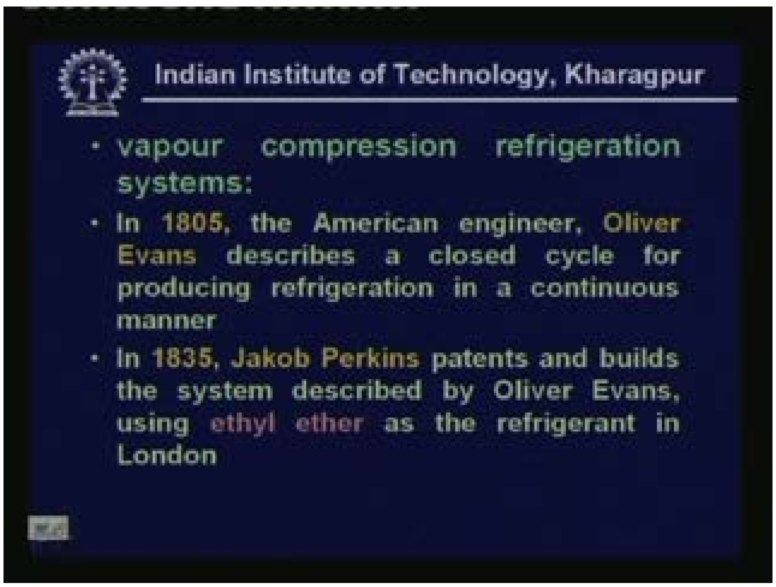

So let us look at one of the most important cycles that is what is known as

Vapour compression refrigeration system. Here refrigeration is obtained again when a liquid boils under low pressures or under pressures in such a way that its boiling point is lower than the surroundings we get refrigeration effect. So this is about is one way of the vapour compression refrigeration system and as we shall see later we use a compressor here for producing the required fraction condition and for enabling condensation.

The concept of vapour compression refrigeration system was first given by Oliver Evans an American engineer in eighteen naught five but we really do not know whether he has built a system based on this principle or not. The credit for building an actual vapour compression refrigeration system goes to Jacob Perkins in eighteen thirty-five. He has built a complete vapour compression refrigeration system using ethyl ether as the working fluid. Even though this system works very well it was not a commercial success. One of the problems with the early system is that ethyl ether is used as a refrigerant. Ethyl ether as i already mentioned has a boiling point of about thirty- four degree centigrade. So if you want refrigeration you have to lower the pressure above that that means the evaporator where the cooling takes place should operate under vacuum. Now when the evaporator operates under vacuum that is the possibility of air entering into the system. Once air enters into the system it can form an explosive mixture with ether. So this is one of the main problems with ether. Second problem with ether is that ether is also toxic so people have tried to develop new refrigerants or new working fluids and systems based on new working fluids.

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Before discussing those things let me show the Jacob Perkin's machine, the you can see that it has four basic components. This is the evaporator. So evaporator is shown here, compressor, condenser, and an expansion wall so these are the four basic components of any vapour compression refrigeration system. The evaporator is submerged in a pool of water which needs to be cooled and the condenser is submerged in a pool of water where heat rejection has to take place.Now let us look at the operation ether which is at a low pressure boils in the evaporator here since boiling is endothermic it takes heat from the surrounding water and surrounding water gets cooled

Now the compressor takes out water vapour is generated and it compresses the refrigerant vapour to a high pressure. And when this high pressure refrigerant vapour flows to the condenser it rejects heat to the surrounding water and it becomes a high pressure liquid at this point you have the high pressure liquid. This high pressure liquid that to complete the cycle flows through an expansion valve and during this process its pressure and temperature drops and the cycle repeats. So this is the basic principle of any vapour compression refrigeration cycle and this is the schematic of Jacob Perkin's system.

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You can see that in Jacob Perkin's system a hand operated compressor is used this is similar to our boring pump. And this photograph shows the working model of Perkin's machine made by John Hague in London.

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Now let us look at other pioneers Alexander Twining in nineteen fifty has suggested vapour compression system that use apart from ether ammonia and carbon dioxide. Then James Harrison actually has obtained patent in eighteen fifty-six for constructing vapour compression refrigeration system using ether alcohols or ammonia. In fact James Harrison's machines were very successful and he is the man who has really commercialized the vapour compression refrigeration systems. Then Charles Tellier of France patented a Dimethyl ether based system in eighteen sixty-four. Dimethyl ether has a lower boiling point compared to ethyl ether but the major problem with this it is that it is also toxic.

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Now let us look at other landmark events. In eighteen seventy-four Raoul Pictet has designed the first Sulphur dioxide based system in Geneva. This {sef} (00:15:18) system was very successful and it way, it was used for all most sixty years in domestic refrigerators.

One advantage of Sulphur dioxide is that it acts as a auto that means you really don't required another lubricating oil in a system and also it has relatively low latent heat of vaporization so it is very suitable for small system such as domestic refrigerators. However one problem with Sulphur dioxide is that when it mixes with water it forms Sulphuric acid and Sulphuric acid is formed it be, it is corrosive and it damages the parts because of this reason Sulphur dioxide was used for almost sixty years and in nineteen thirties it was, the use of Sulphur dioxide is stopped.

Then in eighteen seventy-seven Carl von Linde of Germany has built the first ammonia based system. This is the really, land mark in the history of refrigeration because ammonia is one of the most important refrigeration. Because ammonia is one of the most important refrigerants and even today there are large systems working with ammonia and it is a very important r refrigerant.

And in eighteen eighty-five Windhausen has built the first carbon dioxide based system in Germany. Carbon dioxide is also very important and it was, since it is non toxic and non flammable.

It is a very safe refrigerant and it was used mainly in marine refrigeration for almost sixty years.

However carbon dioxide has some problems, for example it has very low critical temperature that means if the external heat in temperature is higher, then condensation cannot take place.

This is one of the main problems with carbon dioxide. In addition to that the operating pressures are at least one order of magnitude higher than the rest of the refrigerants. As a result carbon dioxide was stopped in again in the nineteen thirties or nineteen forties. But again there is a renewed interesting carbon dioxide because of its many favorable properties. And in nineteen twenty Copeland and Edwards have built Isobutane based domestic refrigerators. Isobutane is a good refrigerant. It is a natural refrigerant. But one problem with isobutene is that it is highly flammable. So because of that reason isobutane was stopped. However again there is a renewed interest in isobutane because of its other favorable properties.

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Now let us look at development of domestic refrigerators. As you know very well domestic refrigerator is used for storing food products in houses and everybody must have seen a domestic refrigerator. The early domestic refrigerator used to be called as an ice box that means, you have, what you have here is, you have a insulated box and ice is stored in a top. So then ice is kept inside the insulated box the air inside the box gets cooled as it comes in contact with ice. When it comes in contact with ice, air becomes heavy so it drops down because of buoyancy. So as it goes down, the cold air cools the food products stored here and it becomes warm and it rises up again due to buoyancies.

So a natural circulation current is setting inside the ice box because of the presence of the ice. So this is the simple principle of ice box. And it was very widely used for about hundred years without any change. But there are certain limitations with domestic ice box. For example; you cannot get very temperatures, you cannot get sub zero temperatures using ice. This is one of the main problems. Another problem is the refrigeration stops once ice all the ice melts. So you have to continuously replenish ice. And the third problem is that you have to do continuously drain the water that we found because of the melting of ice. So these are the main typical problems with domestic ice box.

As a result people have tried to use artificial refrigeration methods in domestic refrigerators.

So initial refrigerators used vapour compression principle and general electric introduced the first mechanical domestic refrigerator in nineteen eleven in U S A. And this is followed by Frigidaire in nineteen fifteen and Kelvinator in nineteen eighteen.

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Beginning with immediately after the First World War there is a rapid growth in vapour compression refrigeration systems. This is attributed to the following factors that the simultaneous development of electrical motors and compressors because typical compression system require an efficient compressor and an electric motor to drive the compressor. And you read the need good shaft seals and controls are required if you want to maintain the performance and most of the most important factor for the rapid growth is due to the introduction of C F Cs in nineteen thirties. We will see in subsequent lessons how C F Cs have actually revolutionized the refrigeration technology. Okay.

So beginning with nineteen twenties or nineteen right after the First World War, the, that is a sudden rapid growth in vapour compression refrigeration system and other types of refrigeration system all over the world.

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Now let us look at development of air conditioning systems. There are several industries which require control conditions of temperature and humidity. For example take the textile industry. The yarn used in textile is very sensitive to moisture content in the air and it alters to some extent it is also sensitive to temperature. So if we want maintain the output, you must maintain the temperature and humidity inside the textile mill at a required level. So this requires some kind of an air conditioning system which can keep the conditions at the required values.

Also there are other industries like photographic industries which require again controlled temperature and humidity. So as a result reference system were used in air conditioning system to maintain the required conditions

The first air conditioning system was installed by Eastman Kodak the famous photographic film manufacturer in nine eighteen ninety-one in New York to store photographic films. As you know photographic films are very sensitive to moisture and temperature so we required proper storage conditions. So this is the first example of air conditioning system. In fact air conditioning system also introduced in movie theatres and in stock exchanges and all for providing human comfort that is what is known as thermal comfort.

Then the first domestic air conditioning system was installed in eighteen ninety-four in Hamburg. Then in nineteen naught four Willis Carrier has designed a central system using air washers and in nineteen twenty-two the same Willis Carrier has developed the centrifugal compressors for use in air conditioning systems. For his contribution to air conditioning industry and air conditioning science Willis Carrier is known as father of air conditioning.

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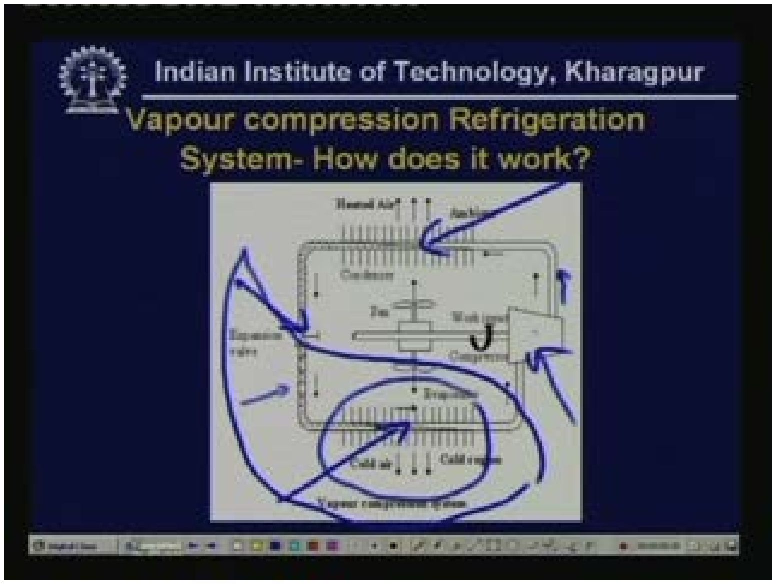

Now let me show the basic principle of a vapour compression refrigeration system, again you have the four basic components here evaporator, compressor, condenser and an expansion valve.Now let us begin at this point right after the expansion valve a low pressure low temperature liquid enters into the evaporator. Where it boils by taking heat from the surroundings. So surroundings get cooled and you get a refrigeration effect in the surroundings. So as a result of this heat transfer liquid become vapour and this high pressure, this low pressure low temperature vapour is compressed to high temperature and high pressure in this compressor.
So the compressor compresses the vapour to high pressure. So that, as it flows through the condenser it can reject the heat of condensation to the surroundings and again it can become liquid at this point. So at this point still you have a high pressure liquid. So the high pressure liquid again its pressure has to be brought down. So it will, it flows through an expansion valve where it gets throttled and its pressure and temperature drops to the required level.

So this is how the cycle continues and as long as the compressor runs you get continuous refrigeration output this could be the refrigeration system of a typical air conditioner. For example in a room air conditioner this portion is kept inside the room, where as this portion is kept outside so the room may get cool and heat rejection takes place to the surrounding air, surrounding outside air. Okay.

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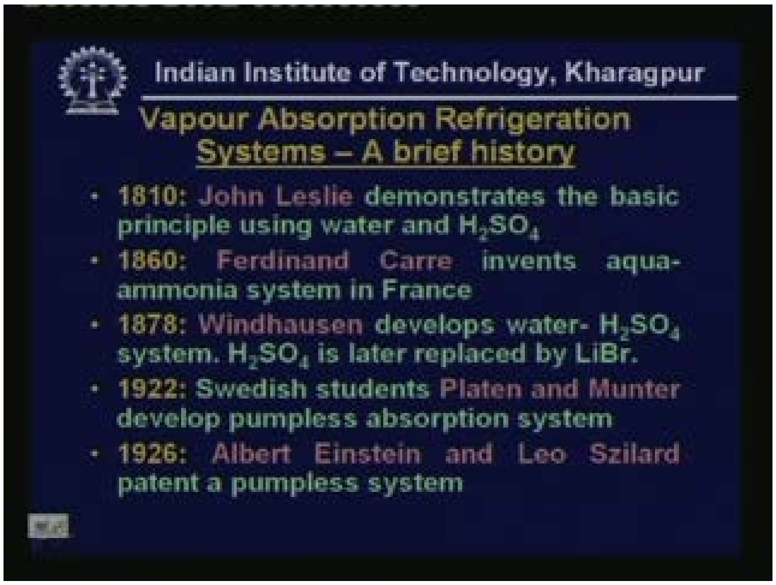

Now let us look at another type of refrigeration system that is known as vapour absorption refrigeration system. You might have noticed that in vapour compression refrigeration system, the energy input is in the form of mechanical energy to drive the compressor and the principle of the refrigeration is evaporation of a volatile fluid. In vapour absorption systems also refrigeration is obtained as a volatile fluid evaporates. However there may basic difference between a compression system and an absorption system life in the fact a life the very fact that in a absorption system you do not use the mechanical compressor you use what is known as the thermal compressor. So there and the main energy input to vapour absorption systems is in the form of heat not mechanical energy.

So let us look at the developments of these systems in eighteen ten John Leslie has demonstrated the basic principle of vapour absorption using water and Sulphuric acid. Now when you keep water in contact with Sulphuric acid, Sulphuric acid has high affinity for water so it can absorb the water vapour formed above the water.

So it as long as it has sufficient potential it can continuously draws the water vapour from the water. Since this is an evaporation process heat has to be supplied so rest of the water gets cooled that means using the principle of absorption and the high affinity of absorbent you produce evaporation effect and thereby you produce a refrigeration effect. This is the principle of vapour absorption refrigeration system. However the process shown by Leslie is a discontinuous process that means once all the, once the Sulphuric acid becomes saturated there will not be any more evaporation. So if you want to make it a practical system you have to have again a continuous system that means again you must have a cyclic process. So this is what is you known as a vapour absorption refrigeration cycle.

The first vapour absorption refrigeration cycle was suggested by Ferdinand Carre in eighteen sixty. He has used ammonia as the refrigerant and water as the absorbent. This is the very important invention and aqua ammonia systems are very important and they are also used even today. And in eighteen seventy-eights Windhausen has developed a continuous water Sulphuric acid and vapour absorption system. In this systems water is the refrigerant and Sulphuric acid is the absorbent.

However Sulphuric acid is corrosive so later Sulphuric acid is replaced by lithium bromine. So water lithium bromine systems have been developed again water lithium bromine systems are very important because they are used ah today for providing air conditioning in large installations.

And in nineteen twenty-two, two Swedish under graduate students Platen and Munters have invented a very interesting vapour absorption system which does not require any mechanical device that means its pump less vapour absorption refrigeration system. And it requires only heat input for its. That is why this is called as pump less vapour absorption refrigeration system. And in nineteen twenty-six Einstein has patented a pump less vapour absorption system this is also pump less system but it is the its principle is dramatically different from the one suggested by Platen and Munters.

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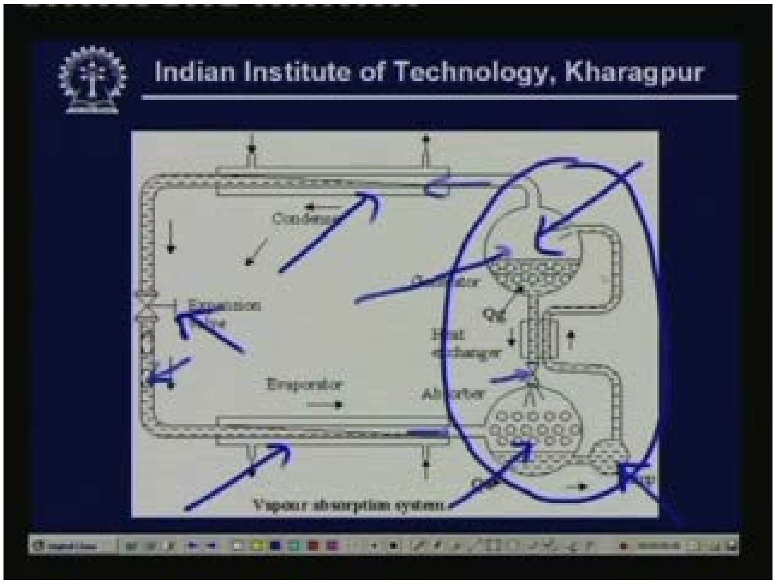

Now let me show the working principle of vapour absorption Refrigeration system. You can see that compared to the vapour compression system the three components condenser, expansion valve and evaporator are common between these two systems. The only different lies here. In a vapour compression system we had a compressor here. The compressor was compressing the low pressure vapour to a high pressure. Whereas in vapour absorption system instead of with mechanical compression we have an arrangement which produces the same effect.

Let us see how this is done. Here instead of mechanical compressor we have a component called absorber here and a component called generator and a solution pump. Let me explain the working principle here. Again let us begin right after the expansion valve. After the expansion valve we have low temperature low pressure liquid and this low temperature low pressure liquid enters in to the evaporator where it takes heat from the surrounding water in this case and produces refrigeration effect in the surroundings. And during this process the liquid becomes a vapour. Now what happens is, when this vapour comes in contact with the absorbent in this absorber since the absorbent has high affinity for water it absorbs the water vapour that means, this absorbent continuously draws the water vapour from the evaporator.

So you have a continuous generation and continuous drawing or withdrawal of the water vapour from the evaporator. This is like the suction of a mechanical compressor. Then what happens is as the absorbent absorbs water vapour it becomes strong in refrigerant. So what we have to do is, we have to make it again weak. So how do we make it weak? Using a solution pump here, we compress this strong solution that means strong in refrigerant to high pressure using the solution pump and then we pass it on to a component called generator. In the generator what happens is you supply high temperature heat to the solution strong in refrigerant. When you supply heat to the solution, refrigerant and absorbent get separated. When refrigerant and absorbent gets separated the refrigerant vapour flows to the condenser and since it is at high pressure it condenses in the condenser and forms a high pressure liquid which flows through the expansion valve and the cycle is completed. In this pro, in this way. And the solution which is now weakened in refrigerant has to go back to the absorber so it flows through a heat exchanger and then, its pressure has to be reduced. So we have an expansion valve here where the pressure of the solution is reduced from the high pressure to the low pressure.

So the low pressure solution which is weak in the refrigerant goes back to the absorber. So the cycle is completed. That means a combination of absorber, solution pump, and generator replaces the single component, a compressor in a vapour compression system.

And you can see that here the major input is in the form of heat. So these systems are very convenient, very advantageous, where you have abundant forces of waste heat. For example you can use a solar heat or you can use waste heat available in industries for providing refrigeration. So absorption systems have their own advantages. And you can see that in this particular absorption system a small amount of mechanical energy is required to run the pump. But compared to a compressor the work required here is very small. Because the work input is equal to integral vdp where v is the specific volume and d p is the pressure difference.

So since we are pumping a liquid here whose specific volume is very low. The required mechanical energy here is almost negligible compared to the heat energy. So this is the principle of vapour absorption refrigeration system.

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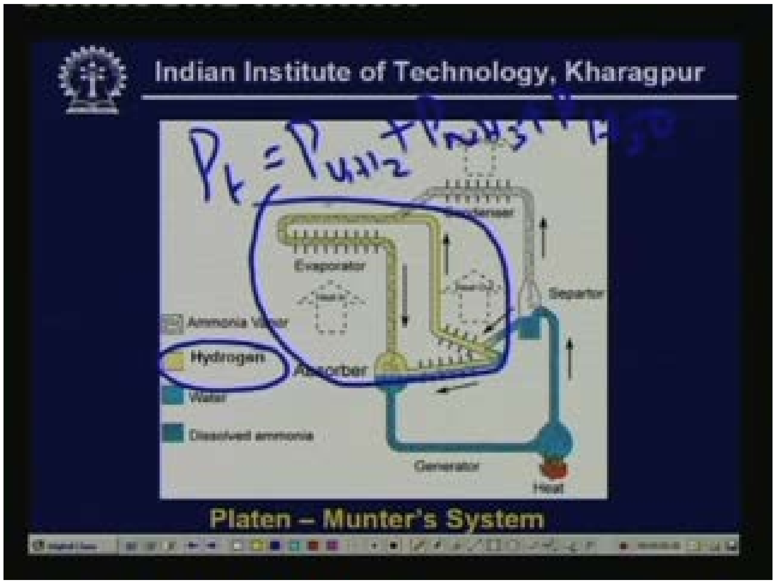

Now let us look at the Platen-Munters System. As i was mentioning, a Platen-Munters system is a pump less system. That means you do not find any mechanical pump in this system. And the total pressure of the system is constant, that means at every point the total pressure remains constant. If the total pressure remains constant, how do you get refrigeration in the evaporator? So this is done by introducing the third gas Hydrogen. This third gas is inert. Okay. So when you introduce that into the system it does not react with any of these other absorbent or refrigerant. So this third gas is confined to the low pressure part of the circuit. That means it is confined to evaporator and absorber. So because of the presence of the hydrogen what happens is, the even that the total pressure remains constant. The partial pressure of the refrigerant reduces.

That means you know that the total pressure is equal to partial pressure of the hydrogen plus partial pressure of ammonia plus partial pressure of water vapour. So if you have, if you introduce sufficient amount of hydrogen you can see that the total pressure is constant. So the partial pressure of ammonia has to reduce. That means ammonia will be boiling at low pressure. Okay.

So this is what produces the cooling effect in the evaporator. And here you can see that the major input is in the form of heat only. And here we use a component called bubble pump for pumping the solution from a low level to high level. And this system have many advantages. For example since you do not have any mechanical component here they are extremely reliable and they are also silent in operation. That is the reason why these systems are typically used in small domestic refrigerators in hotel rooms etc. where you need a silent operation. So the main use of this system is mainly confined to this kind of applications. However they are not used in large systems because their efficiency is typically very low.

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Now let us look at solar energy based refrigeration systems. Right from nineteen fifties people have been trying to use solar energy for providing refrigeration. Actually this is the perfect match. If you can use solar energy for providing refrigeration, if you good match, because the availability of solar energy matches with the demand for refrigeration. For example on a hot day we require refrigeration, on a hot day sun is available. So this is the motivation for developing solar energy based systems. So you see solar energy can be used in two ways. You can use it directly in the form of heat and have a vapour absorption refrigeration system. And you can also convert solar energy into electricity using, for example photo old type cells and use electricity to run a motor and a compressor and use a vapour compression refrigeration system. That means solar energy base system can be either compression system or absorption systems.

So as I was mentioning the development began in ninety fifties and it really picked up since nineteen sixty-fives and the major reason behind this is that people have realized that our fossil fuels reserves are really limited. And refrigeration is a typically low, what is known as low grade application. And it is said that for low grade application you should not use high grade energy like electricity. Okay. It is like, for examples you want to buy something in India and you have rupees and dollars in your pocket obviously it makes sense to spend rupees not dollars. If similar analogy applies here. When you want refrigeration and when you have low grade energy is available you should be used the low grade energy for providing refrigeration rather than wasting non renewable fossil fuels. This is the main reason behind developing solar energy base systems and as i said it is started in some time in nineteen fifties.

Professor G O G Loaf of America is one of the pioneers of solar base energy refrigeration systems. And when the first verify, i am just giving you few examples U S S R has developed a two fifty kg per ice {kk} (00:35:10) kg ice per day system using parabolic solar collectors.

There are different types of solar collectors. You can have flat plate solar collectors, parabolic solar collectors and other concentrating some types solar collectors depending upon the type of solar collectors that you use, you know differ, you get different temperatures outputs. So they have used parabolic solar concentrators and they have built an absorption refrigeration system which could produce two fifty kg of ice per day. And the first solar air conditioning system that means, solar energy was used to run a refrigeration system which was then used for providing air conditioning was developed in Queensland Australia in nineteen sixty-six.

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Now let us look at another common and important type of refrigeration system that is known as gas cycle refrigeration system. This gas cycle refrigeration system is slightly different from the vapour refrigeration system. In vapour refrigeration system we call it as vapour cycle because in those cycles like vapour absorption vapour compression systems refrigeration is obtained as the working fluid undergoes a phase change. For example in the evaporator a liquid becomes vapour and in the condenser vapour becomes liquid that means the cycle involves two phase change processes so that is why we call them as vapour cycles.

Where as in the gas cycle, the cooling is obtained because sensible cooling. So that means there is no phase change involved here. So this is the different between the gas cycle system and a vapour cycle system. And the major principle behind gas cycles refrigeration system is that there are basically two principles. Most important principle is that when a high pressure gas expansion a turbine and produces external work its temperature and pressure drops. So you can use the low temperature air or low temperature gas for providing refrigeration. That means you send have, you first compress the gas to a high pressure and then low it to flow through a turbine where it can do external work and in that process it can reduce its temperature and pressure and this low temperature low pressure {ga} (00:37:09) gas can then be used for producing refrigeration.

This is the principle of gas cycle refrigeration.

Let us look at some of the developments. The first gas cycle refrigeration system was developed by John Gorrie in eighteen forty-four. Actually John Gorrie is a, he is not a scientist but he was a doctor. Not a scientist means he is not a mechanical engineer or refrigeration engineer. But he was a doctor. And he while treating his patients suffering from fever he was in need of large quantities of ice. And he had difficulty in getting ice base using any of the natural methods, i mean in the natural methods are they said are not reliable so ice for some times it was not available So as a result of this he has decided or he wanted to build a system which is independent of your external circumstances and which guarantees a continuous provision of ice.

Now this led to the development of the first gas cycle refrigeration system. And the variable, even though he has proved the principle and he has built a system we really do not know the commercial fate of this system. Even though it is said that some of these systems were exported to other countries. They were not big commercial successes.

After John Gorrie, Alexander Kirk in eighteen sixty-two has developed another gas cycle refrigeration system. This is a very important gas cycle refrigeration system. Behind this is very efficient also because this is based on what is known as reverse sterling cycle.

We will see the cycles a little later. So this is based on reverse sterling cycle and it is quite efficient. And right now these systems are used in very low temperature cryogenic applications and Bell and Coleman have carried out several improvements to the basic air cycle refrigeration system proposed by John Gorrie. So sometimes air cycle refrigeration systems are also called as Bell and Coleman cycles. And Paul Gifford has perfected an open type of air cycle refrigeration system in eighteen seventy-five. And this open type systems are very widely used in air craft air conditioning systems now.

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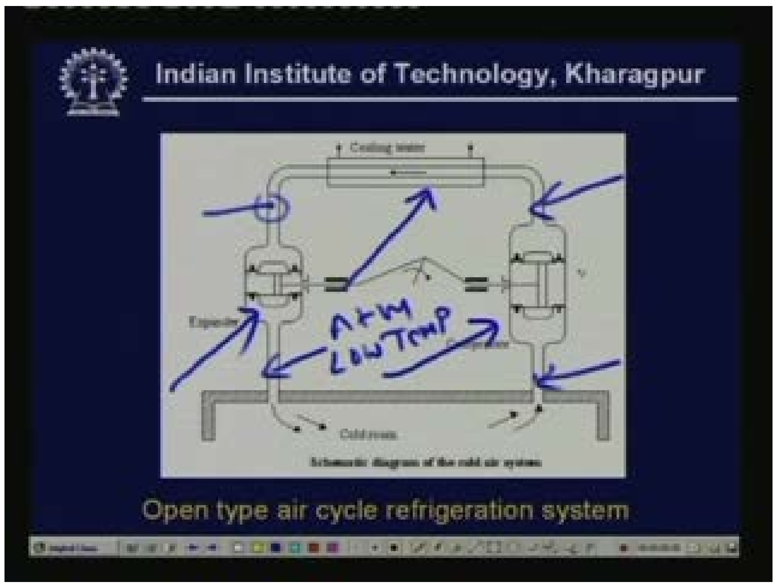

So let me show the working principle of an open type air cycle refrigeration systems. You have three major components here a compressor, a heat exchanger and an expander. So let me start at this point here you have an atmospheric pressure and low temperature air. Low temperature means the temperature is slightly lower than the surrounding temperature. So you have air which is, whose temperature is slightly lower than the surrounding temperature and whose pressure is same as atmospheric pressure. So this air is compressed in the compressor too high pressure so at the exit of the compressor you have a high pressure air. So because the compression process, its temperature also increases so it can reject heat in this heat exchanger to the cooling water that is flowing through the heat exchanger.

So in the heat exchanger of the high pressure air rejects heat and its temperature drops. So at this point you have high pressure and warm air, not hot air but warm air. So this high pressure warm air then flows through an expander or turbine. So as it flows through the expander or turbine it produces the external work. Since energy is required for producing external work it takes energy from itself. That means its temperature and pressure drop. So what you have here is an atmospheric pressure and low temperature low temperature air. So this low temperature air is sent to the cold room where it can provide refrigeration, cool the products and all. And in that process it picks up some heat and its temperature increases and from here again it goes back to the compressor and this cycle is repeated. This is what is known as open {ty} (00:41:05) open type air cycle refrigeration system. Then as I mentioned this is mainly used for providing air conditioning in air Crafts.

This system is not very efficient and it is also bulky. But why may we use this in air craft is that the components required for this system, typically the compressor and turbine which are the main bulky components are already there on the air craft. So in air craft engine requires a compressor and a turbine. So instead of adding a fresh compressor and turbine for the air conditioning system you can use the existing compressor and turbine. So this is the reason why this system is mainly used in air craft air conditioning systems. And you can also have a close cycle refrigeration system using gases in principle anything other than air. You can also use other gases, for example you can use helium okay or any other gas.

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Now let us, let me discuss another important and commonly used refrigeration system what is known as vapour jet refrigeration system. This, here all this also vapour cycle that means here also you produce refrigeration by evaporation. But again the major difference between this and compression system lies in the way you, in which you maintain the pressure in the evaporator and the way in which you compress the evaporated vapour. So that is why the major difference lies.

The basic principle I will explain here, whenever you have, Okay. I will show the schematic little later. But let me just explain the history here. The first vapour jet refrigeration system was designed and developed by a French engineer Maurice Leblanc in nineteen naught seven.

So he has used steam. Then in Westinghouse has commercialized these systems in nineteen naught nine in Paris. And from nineteen ten onwards these systems has been used very widely in warships breweries etcetera. And the Russian engineer Badylkes has developed the closed cycle vapour jet system in nineteen fifty-five. So he did not use steam. But he used other refrigerants for providing the refrigeration.

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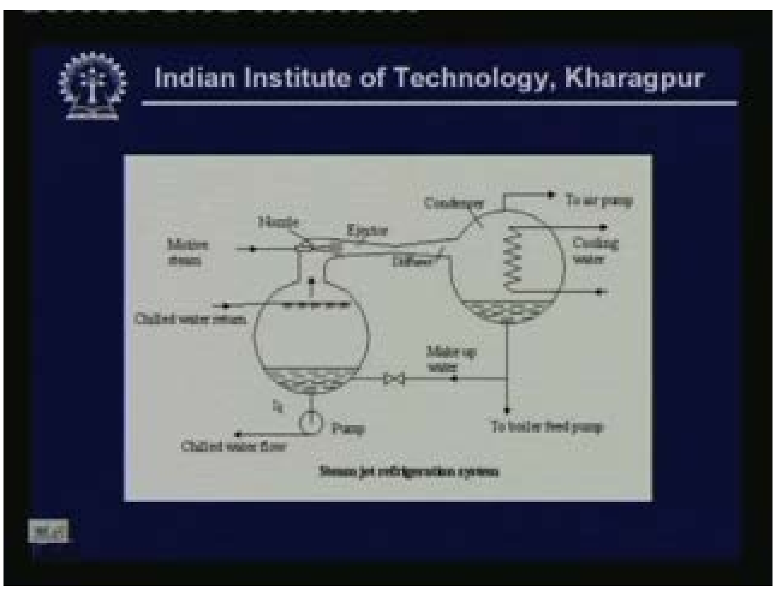

Let me explain the working principle of this. This is a typical steam jet refrigeration system. What we have here is an evaporator drum and a condenser drum. So this is the condenser drum and this is an evaporator drum. This evaporator drum consists of water. And this condenser drum also consists of water. And the motive force are the prime energy input to this system is in the form of motive steam. Motive steam means high pressure steam.

So when this high pressure steam flows through this nozzle its pressure reduces and it gains kinetic energy. That means at the exit of the nozzle you have a fast moving motive steam. So because of its high velocity it can entering the vapour from this drum. That means water vapour is there in this drum gets entering by this fast moving motive steam. Why it so vapour is removed from this drum. So once vapour is removed more vapour is formed by evaporation of the remaining water. That means the water evaporates to provide the continuous vapour. So as a result rest of the water gets cooled because evaporation is endothermic. So you have production of cold water here. Okay.

Now what happens to this vapour? This motive steam plus the vapour that is evaporating in the evaporator both get mixed and then they flow through a diffuser. In the diffuser what happens is you convert the kinetic energy back to pressure. that means at the end of the diffuser you again have a high pressure steam. Okay. This high pressure steam now comes in contact with the cooling water that is flowing through this heat exchanger. When it comes in contact with the cooling water flowing through the steam it rejects a latent heat of condensation and it condenses. So ultimately you have condenser water here.

That means you evaporate the liquid water in this the evaporated drum using the motive steam and then condense the motive steam and the evaporated vapour using the diffuser increase its pressure in the diffuser. Then using the cooling water you take the heat out of the vapour and condense it. Then to complete the cycle what we have to do is we have to again split this liquid into two parts. And you have to send the makeup water back to the evaporator drum. And the rest of the water again go back to the boiler feed pump to complete the circuit. This is the principle of steam jet refrigeration system. And we use here as you can see we do not use any mechanical compressor here or the mechanical compressor is replaced by combination of a nozzle ejector diffuser and all. So this is sometimes known as an ejector refrigeration system. And the principle of ejector was actually used in the beginning to pump out air leaked into the condenser of power plants. So this is the first application of ejectors. Later the same principle was extended to the refrigeration systems.

In principle you can us any other working fluid other than steam. You can also have close cycle systems using refrigerants. Okay you need not use, if you use refrigerants you can have produce lower temperatures. When you are using water you cannot get temperature lower than zero degrees centigrade. That is one limitation of water. Okay. These systems were used in the beginning in several as I said in warships and breweries and all. And this is also used for providing what is known as vacuum cooling in food products. That means in the evaporator drum what you have seen earlier you can put the food products itself and take out the moisture from the food products using an ejector. So when we are taking out moisture from the food products using an ejector the food products get cooled. Okay. So this is the principle behind vacuum cooling, right. So this is the steam jet refrigeration system.

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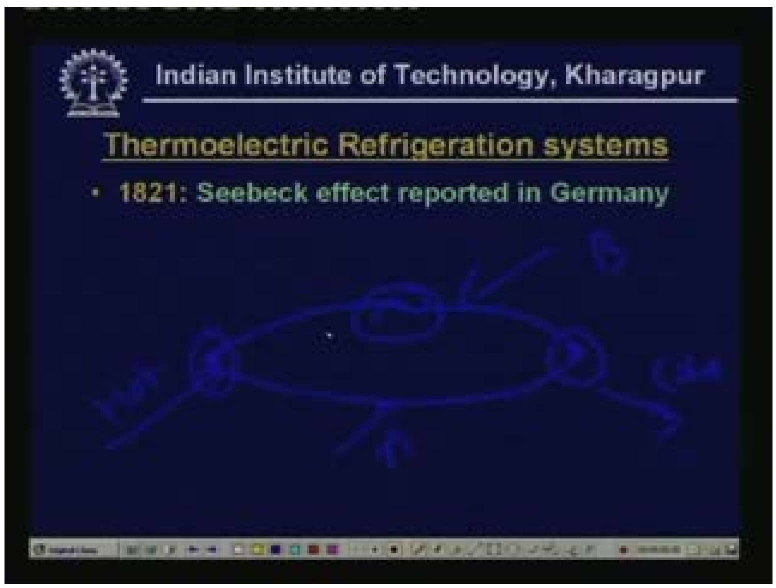

Now let us look at thermoelectric refrigeration system. So Seebeck effect. Seebeck effect is reported in Germany. And I am sure most of you are familiar with {se} (00:47:24) Seebeck effect. Any way let me just recapitulate this. What we have here is in a Seebeck effect you have two dissimilar metals. And when you maintain these two junctions you have let us say that metal A and a metal B. And these are the two junctions. And let us say that you are maintaining these two junctions at two different temperatures. Let me say that you have this junction is a hard junction and this junction is a cold junction. So once you have two dissimilar metals joint together and when you are maintaining the junctions at two different temperatures and e m f will be developed in the in the circuit. That means we will see that the current flowing through the circuit. This is what is known as Seebeck effect. And this is reported in Germany in eighteen twenty-one.

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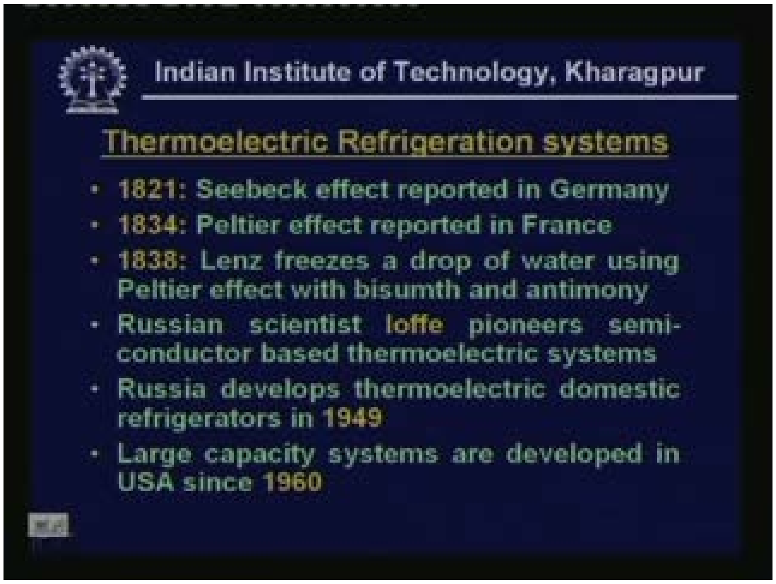

Next Peltier has found an effect which is the reverse of Seebeck effect. Okay. This is, this happen in eighteen thirty-four. So let me explain what is the Peltier effect? You have seen the Seebeck effect and let us look at the reverses Peltier effect. That means you have let us say that again two different materials A and B. Okay. And then now let us say that you are passing electrical current through this. Okay you connect it to a battery and allow current to flow through this. When current flow through this, that means when electrons flow through this you find that one junction becomes cold and the other junction becomes hot. That means by joining two dissimilar metals and by allowing current to flow through this you can produce refrigeration at one end and you can reject heat at the other end. So this becomes let us say hot end and this becomes your cold end. So you get refrigeration effect at this point. So this is the principle behind Peltier effect.

So using the Peltier effect Lenz George actually demonstrate the Peltiers effect by freezing a drop of water in eighteen thirty-eight. And he has used bismuth and antimony are the materials. But later it was found that the metals are not really the ideal materials for use in thermoelectric refrigeration systems. Because of as you know very well metals have very high electrical conductivity which is required in a thermoelectric system. But they also have high thermal conductivity. Because the high thermal conductivity it is difficult to maintain the cold and hot junctions at the particular temperature. Because heat will always flow from hot junction to cold junction. And since thermal conductivity is high the temperature radian tends to ah reduce. So this is the problem with metals. That means metals typically have low, what is known as the low thermoelectric powers. So if you want to develop a good thermoelectric system you have to have a material having high electrical conductivity but low thermal conductivity. For almost hundred years people could not find any suitable materials. However in nineteen forties people have invented the semi conductor materials. And semi conductor materials have reasonably high electrical conductivity and low thermal conductivity. That means they have high thermoelectric power.

So now you can the, systems are ready. You can make thermoelectric systems using semi conductor materials. Semi conductor materials typically you know that have p type and n type. You can have two types of semi conductor materials p and n type. So a typical semi conductor thermoelectric element consists of a p type element and n type element joint together. So you have two junctions joining the p and n type elements. And when you give a power supply a d c power supply at low voltage electrons will flow. And when the electrons jump from p to n they absorb energy. And when they jump from n to p they reject energy. That means you get cold junction on one side and hot junction on the other side. Okay. This is the principle of semi conductor based thermoelectric refrigeration system. However you cannot use just one p element and one n element because the cooling that provided with just with just one element is too low of any {prac} (00:51:29) ah to be of any practical use. So in practice what is done is you start large number of thermoelectric elements in series and you make a thermoelectric module. So that you can produce sizable amount of refrigeration. Okay. So this is the principle of modern day semi conductor based thermoelectric devices.

And later actually Russian scientist Ioffe is one of the major pioneers in the area of semiconductor based thermoelectric systems. And Russia has developed several domestic refrigerators using this principle. And in U S A in nineteen sixties they have developed large air conditioning systems using the thermoelectric principle. One major problem with thermoelectric principle is that the efficiencies are typically low compare to vapour compression systems.

However they have the advantage that they are silent in operation and they are very reliable because you are not really using any mechanical component there and you can use the same thermoelectric module by changing the direction of currents electron flow either for heating application or for cooling application. This is one of the advantages of thermoelectric systems.

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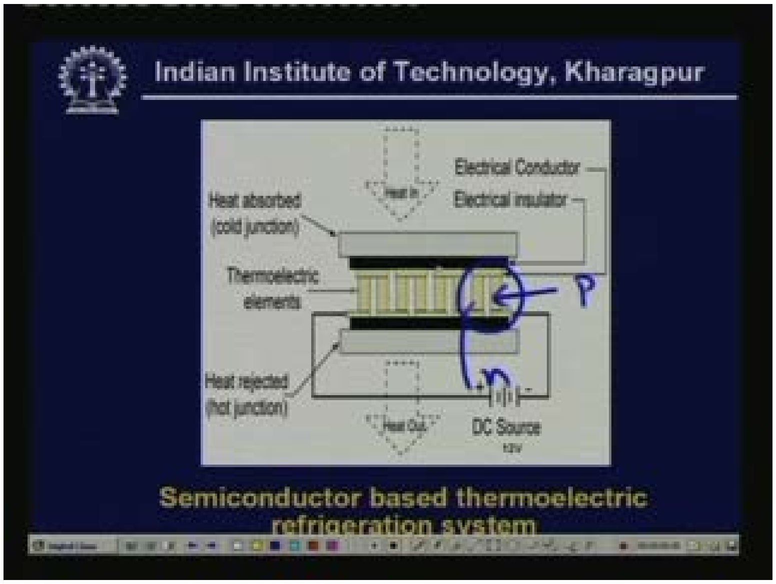

Now let me show the working principle of a thermoelectric module. As I was mentioning it consists of a p element and a n element. So this makes one thermo thermoelectric element. So such several, such elements are stand in series and this forms a thermoelectric module and all the cold junction are connected on one side. So this is the cold junction and all the hot junctions are connected on the other side.

Now when you connect these thermoelectric module to a d c source let us say at twelve volts and when you start giving the power supply electron will flow through the p and n elements through the electro thermoelectric module. And as I mentioned as electrons flow from p to n they produce a cooling effect. So you have cooling on this side. Okay. And when it flows from n to p you get a heating effect. So you can see that this junction is hot. So by designing them in this manner and by stacking them together you get cooling on one side and heating on the other side. Okay. And we of course, we have some electrical insulators to avoid the sorting in on that. And as I was telling depending upon your requirement if you reverse the current flow you can use the same side for, you can have either cooling on this side or heating on this side just by reversing the direction of the flow. So this is the principle of your thermoelectric refrigeration system based on semi conductors. Right now these systems are used in small portable refrigerators. For example you can carry it along with you. And this is also used for carrying vaccines and all to remote areas. These are the main applications of thermoelectric systems at the present movements and they are also used in certain high efficiency computers for cooling the computer chips.

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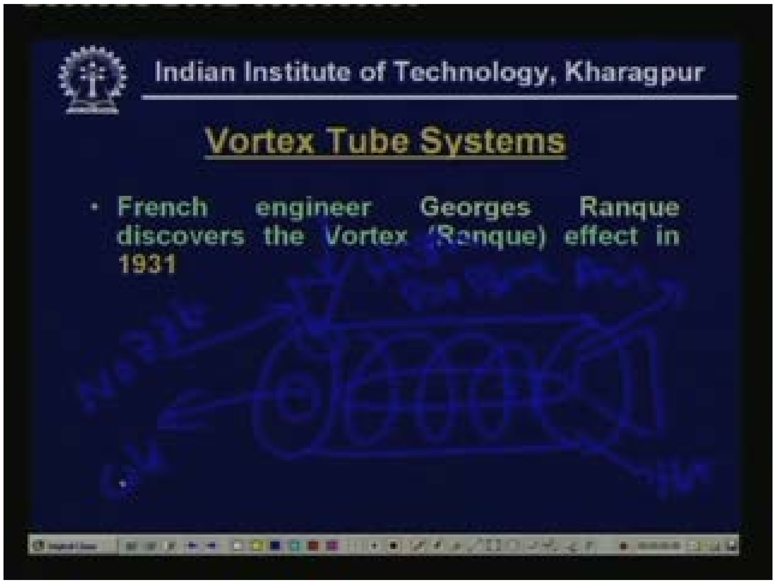

Now let us look at the another interesting system called Vortex Tube System. Let me again explain the working principle of this. This is a very simple system. What you have is a long tube with a valve one side and central hole on other side. And let us say that using a nozzle, this is the nozzle and through this nozzle you allow high pressure air, high pressure. So when you allow high pressure air to enter into this tube though this nozzle, at the end of the nozzle at this point the pressure is converted into kinetic energy. That means its velocity increases tremendously. And when this high velocity air enters into this tube it undergoes swirling motion so you get a swirling motion air undergoes a swirling motion. And during this motion and during its passage from one end to other a cold core is developed near the axis. That means you have a cold air stream at the axis and hot air stream around the cold air stream.

So you have near the periphery you have hot air and at the central portion you had cold air. So the hot air escapes in this, through this and the cold air comes out through the opening on the other side. So this is known as a counter flow type of vortex tube. So you can see that what you need here is a simple tube and a supply of high pressure air all that is required is that. Okay. And depending upon the valve position you can get different temperatures of cold air and different amounts of cold air. So this is the principle of vortex tube refrigeration system .Vortex tube refrigeration system are not very efficient but they have certain advantages. See for example now it is very simple and all that you {nee} (00:56:20) need is a compressor air supply. Okay. So that is why these systems are mainly used for cooling machine elements and all.

For example in machine tools we want some localize cooling. You can use the vortex tube and you supply compressor air to the vortex tube and get the refrigeration effect and this is also used in jackets worn by the miners when the miners go in to deep mines. They required cooling because it is very hot in mines. So they can carry the vortex tube in their jackets and with vortex tube is typically connected to high pressure air supply and they get cooling because the jacket by supplying cool air to different parts of the body and the different parts of the body get cooled.

In addition to this you can also supply the fresh air continuously to the miners so this is the advantage and is the reason why vortex tube systems are used in mines.

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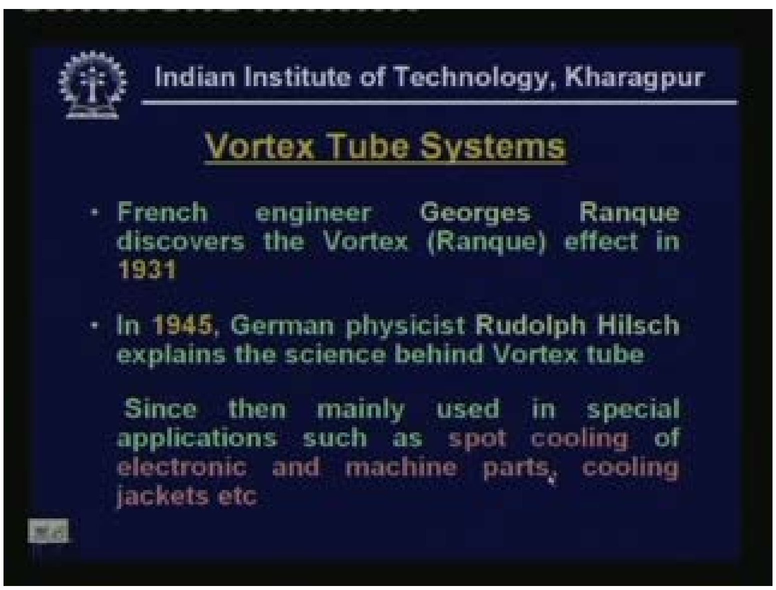

And as I was mentioning in nineteen thirty-one Georges Ranque has discovered the vortex tube effect. And in nineteen forty-five, actual principle behind vortex tube is very complicated I mean the analysis also very complicated for many years even though the people have demonstrated the effect. They could not really explain the physics behind the vortex tube operation. And in nineteen forty-five German physicist Rudolph Hilsch has given a scientific explanation for vortex tube effect. That is why the vortex tube is some time known as Ranque and Hilsch tube. And since then as I was mentioning this is main use for spot cooling when machine elements, in electrical components and also in mines for cooling the miners.

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Now let me conclude this lesson.

We have in this lesson, we have defined the refrigeration and air conditioning and we have out lined the historical aspects of various natural and artificial refrigeration methods. And while doing so we have also explained the working principle of these systems in brief. And when we discuss these systems we will explain the working principle once again in detail. Okay.

And right now the main focus is to develop refrigeration system. In the modern life you cannot imagine in modern life with a, without refrigeration and air conditioning it has become an essential part of our life. So almost all the industries are required ah refrigeration or air conditioning. And we need air conditioning for thermal comfort. So air conditioning systems are very wide widespread and it is almost a common item in all households in the form of a domestic refrigerators.

So what are the issues right now with air refrigeration and air conditioning? The main issues are developing systems that are energy efficient. Because typically in a refrigeration systems and air conditioning systems requires energy input. So you have to make systems which are efficient, energy efficient. And there are also certain environmental issues related to refrigeration systems.

So whatever systems you develop should be environment friendly and they should be affordable. If you want to make it available to everybody you have to make them affordable.

So these are the main issues current issues in refrigeration development and the studies are going on these aspects. And we will discuss these aspects in detail in subsequent lessons.

Thank you.