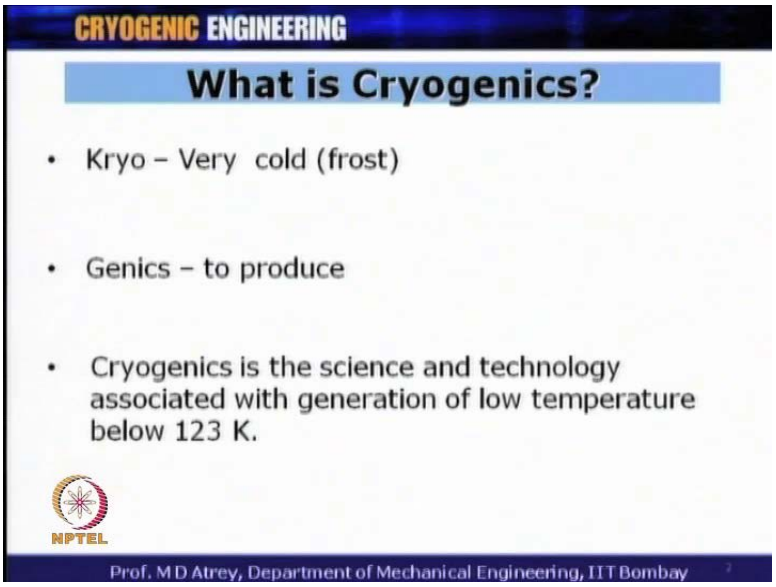
Cryogenic Engineering
Prof. M. D. Atrey
Department of Mechanical Engineering
Indian Institute of Technology, Bombay

Module No. # 01
Lecture No. # 01
Introduction to Cryogenic Engineering

Welcome to this NPTEL lectures on Cryogenic Engineering. I am Millin D. Atrey, Professor in Department of Mechanical Engineering, IIT Bombay and this is my first lecture on Cryogenic Engineering. Before I go into the details of what cryogenic engineering is all about, I just what to let you know what is cryogenics.

(Refer Slide Time: 00:39)

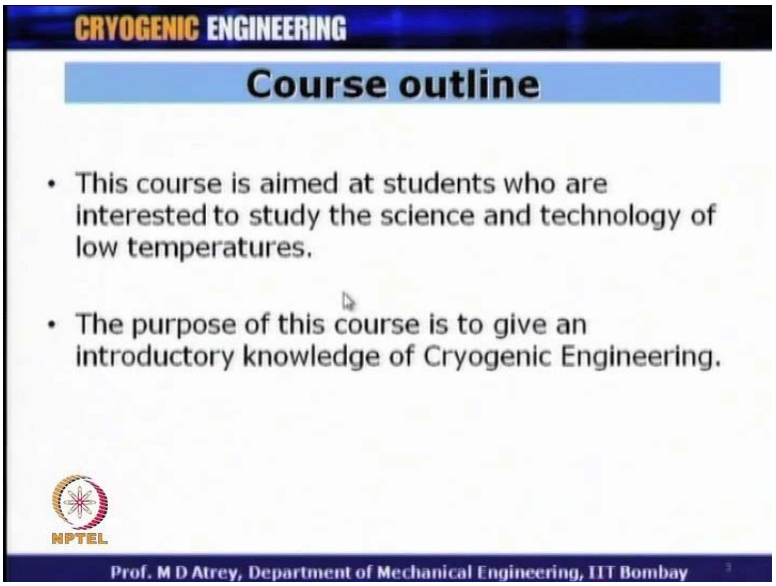


Cryogenics is basically coming from the kryo which means very cold; from greek language this word has come and genics means to produce. So, basically cryogenic means, science and technology associated with generation of low temperature below 123 kelvin.

Now, why it is 123 kelvin; we can study about that later in the next lecture; however, what you have to understand is till 123 kelvin, what you call is refrigeration and if I want to achieve temperature below 123 kelvin, what we call is Cryogenic Engineering or Cryogenics. The funny part about this is kryo is as cold as ice, that is what was thought

about then in the Greek mythology or Greek scientist then, but ice is the very hot temperature for cryogenic and therefore, understand although it meant as cold as ice, it means much lower temperature than ice temperatures.

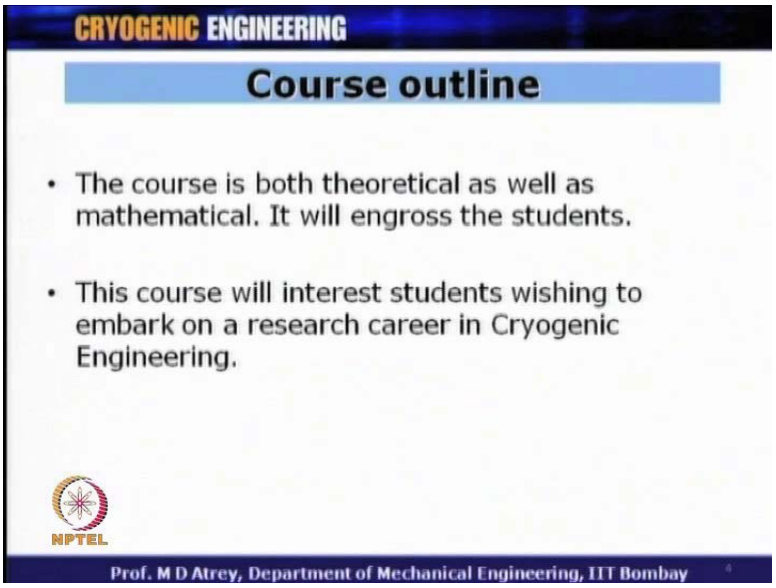
(Refer Slide Time: 01:35)



This course aims at students who are interested to study the science and technology of low temperature. Basically, cryogenic is generation of low temperature. What is the size behind generation of this low temperature? What is the technology to achieve this low temperature? This is all we are going to study in Cryogenic Engineering.

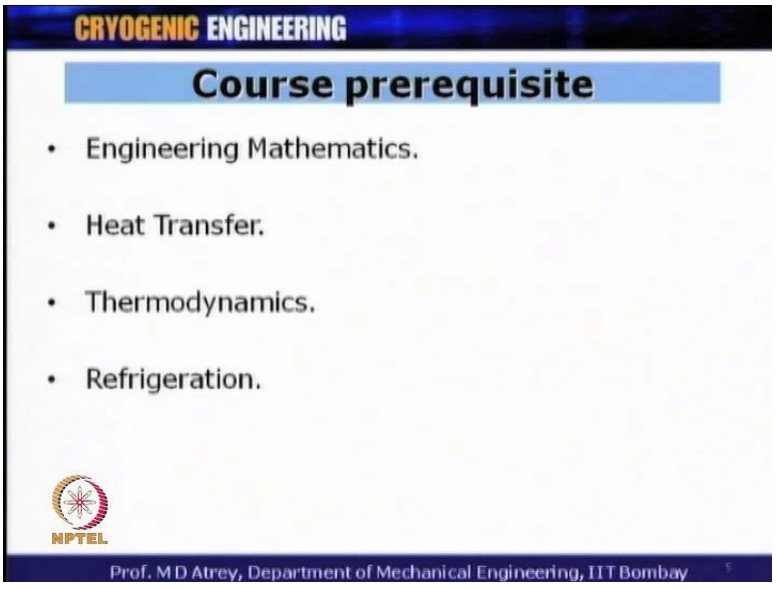
The purpose of this course is to give introductory knowledge of Cryogenic Engineering. This is the course which normally, we will aim at the p g level students or the final year undergraduate students having a good background of various subjects and this course is meant for them.

(Refer Slide Time: 02:05)



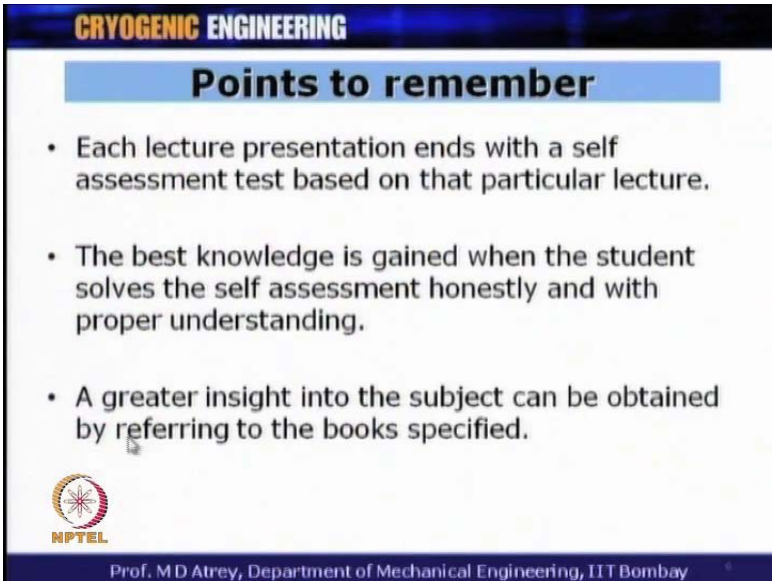
The course is worth theoretical as well as mathematical, I am sure it will engross the students. This course will interest students who want to take career in Cryogenic Engineering. We know that Cryogenic Engineering is very widely used in space and atomic energy and thing like that I am sure lot of students will get motivated from this course, in order to take their research carrier in Cryogenic Engineering.

(Refer Slide Time: 02:30)



The prerequisite of this course are: Engineering Mathematics, Heat Transfer, Thermodynamics and Refrigeration. Those who have done this course, which possibly can have on at the final year undergraduate learning or in the post graduates or M.E or M. Tech, I am sure those students will definitely appreciate this course.

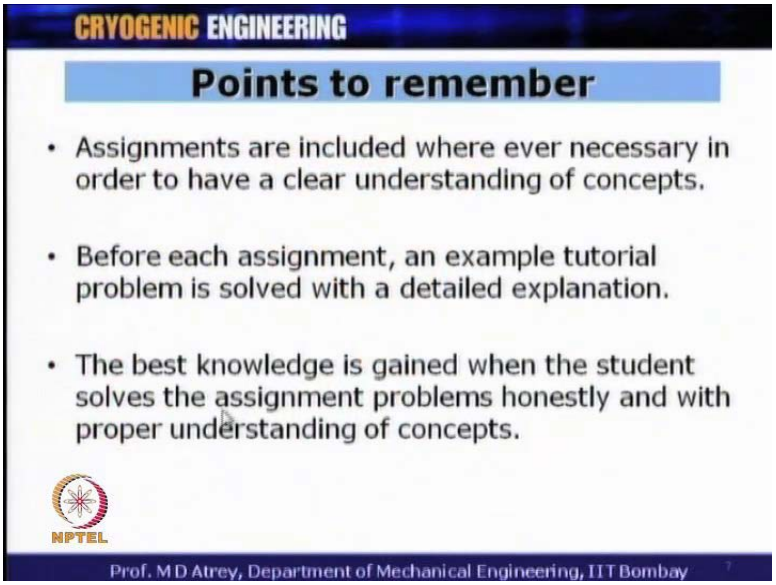
(Refer Slide Time: 02:49)



The points to remember while do in this course are each lecture presentation ends with the self assessment test based on the particular lecture. So, after each lecture or after a few lecture, we will have self assessment test where the student can assess himself or herself in the best knowledge is gained when the student solve in the self assessment test very honestly and with the proper understanding. So, we believe in that, whatever assessment self assessment to be done at the end of each lecture or after few lectures, we feel that the student should take this test very seriously. At the end of the lecture when he or she does this assessment, when they fallow that the particular thing followed or not will be visible to themselves when they do self assessment.

So, we expect that the student will do this very honestly. A greater insight into the subject can be obtained by referring to the books specified. We are specifying some books for extra-reading for a more general-reading for more special-reading also and we believe that this students will have hands on this books. They will go through this books and get some extra knowledge.

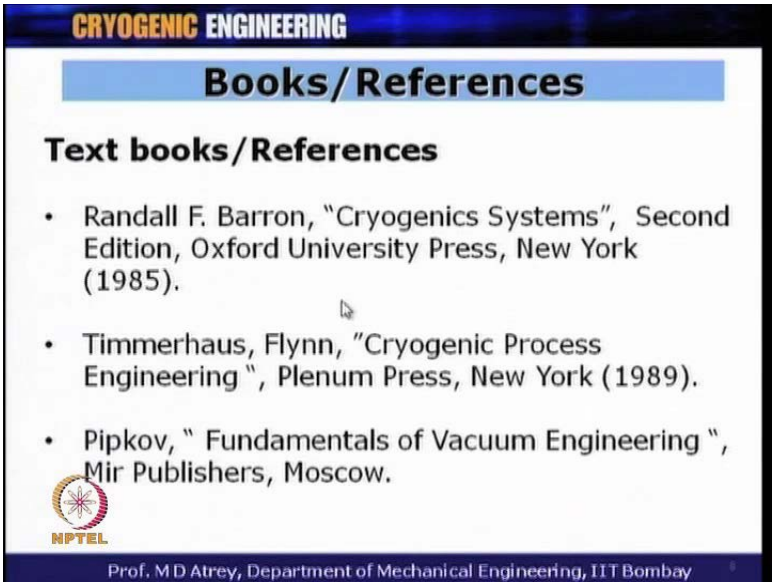
(Refer Slide Time: 03:52)



Assignments are included wherever necessary, in order to have clear understanding of concepts. We believe that whatever knowledge one gains out of this course, we have to do some assignment, where in lot of fundamentals get cleared. A lot of mathematical problems will be there, some theory could be there; it will be clear only when you do this assignment very honestly. Before each assignment, an example tutorial problem will be solved with a detailed explanation.

So, depending on the kind of assignment you want to solve, we will take a tutorial here. We will solve the problem step by step, we will see to it that one follows all the steps involved in those tutorials, in this example or assignment problems and after that, we expect that the student will go through all the assignment honestly and come to an answer. Answers also will be given at the end of this lectures. The best knowledge is gained when the student solves the assignment problems honestly and with proper understanding of concepts. I am sure you have clear with this.

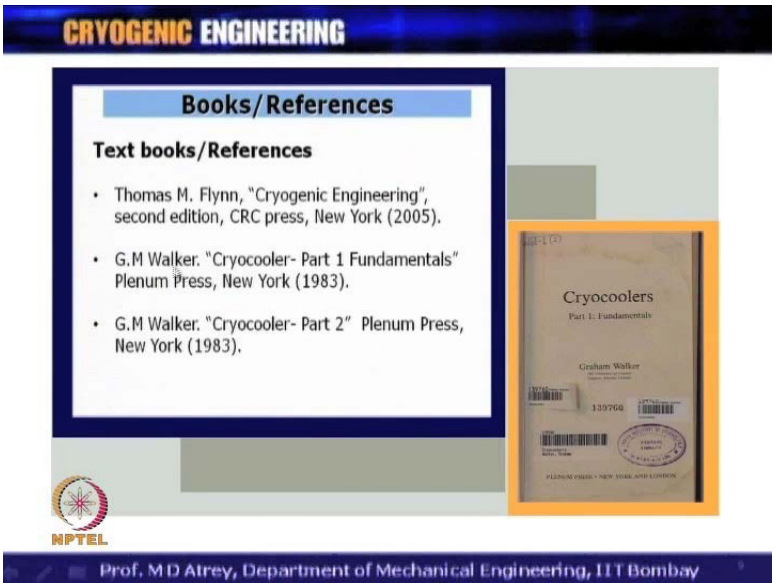
(Refer Slide Time: 04:56)



Now, there are various books available on Cryogenic Engineering. I am giving you some references here so that, while doing this course, you may follow some extra reading with this books. The important book is by Randall Barron on Cryogenics Systems available from Oxford University Press and the edition, the last edition available is of 1985. This gives you in summary on most of the topics I am going cover in this course in short however, but then it will touch up on all the points. For some specialized reading, you have to go to specialize books or journals. Then, book by Timmerhaus and Flynn on Cryogenic Process Engineering by Plenum Press also is available. It is also a good reading for Cryogenic Engineering.

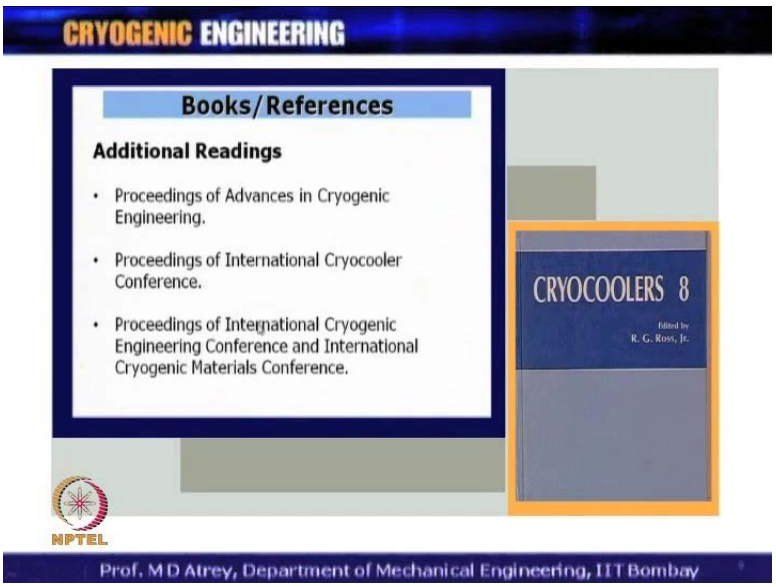
Cryogenic also go with vacuum and therefore, I have given here, a book by Pipkov on Fundamentals of Vacuum Engineering, where some Fundamentals of Vacuum which are necessary from Cryogenic Engineering prospective are given in this book.

(Refer Slide Time: 05:45)



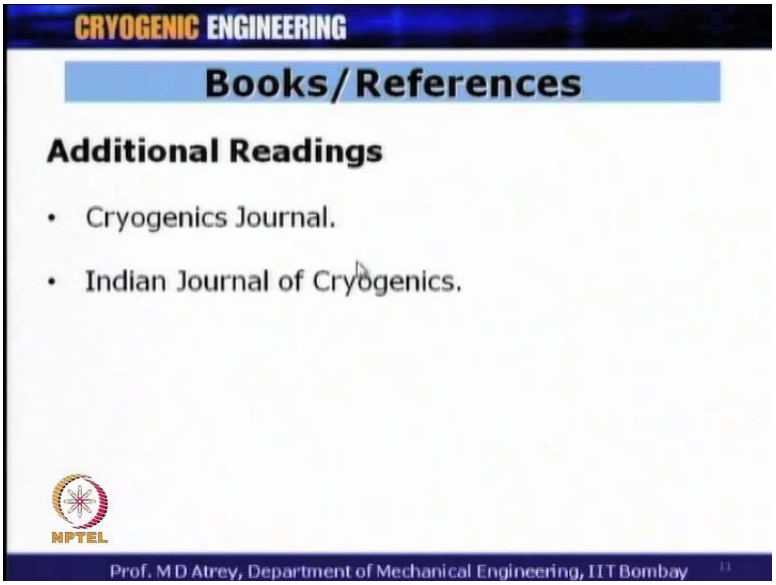
The next book is Thomas Flynn. The book is Cryogenic Engineering, the second addition is available as 2005. It is an interesting reading and lot of problems, assignment could be taken up from this particular book. Then, we have got Cryocooler, I am going to talk about Cryocoolers for about six or seven lectures and we have got books on Cryocoolers part one and part two by a Walker. The very famous books in fact, possible these are the only two books on Cryocoolers as per and this also will give some basic understanding on different Cryocoolers including pulse coolers, sterling coolers.

(Refer Slide Time: 06:17)



In addition to the books which I just talked about, we have got various proceeding of the conferences. That also gives a very interesting results relative contemporary research happening in the world for which we propose of the Proceedings of the advances in Cryogenic Engineering, the Proceedings of International Cryocooler Conference, Proceedings of I C E C or International Cryogenic Engineering Conference or I C M C which is International Cryogenics Materials Conference.

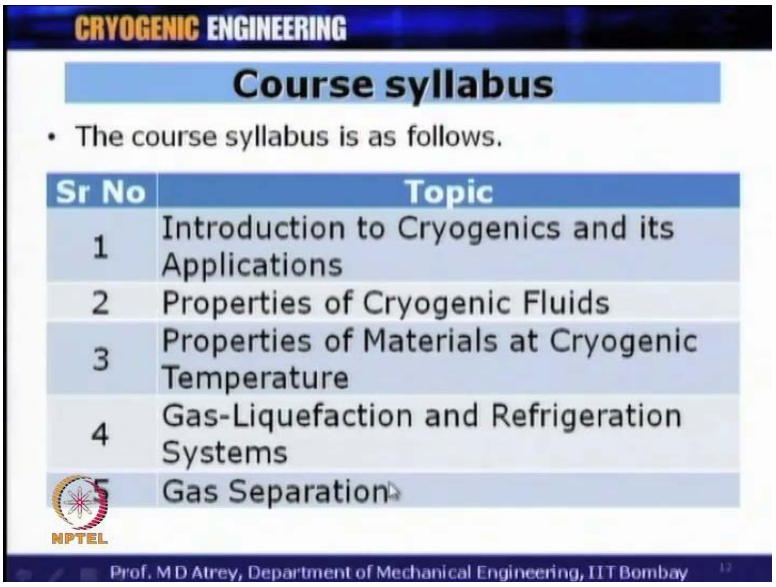
(Refer Slide Time: 06:42)



In addition to these conference proceedings, what we have is Cryogenics Journal and what we have in addition to this is Indian Journal of Cryogenics. Cryogenic journal is published almost every month. It is a very prestigious journal. To get paper in this journal is also supposed very prestigious. In addition to that, we have conferences alternate here, in India which are called national symposium on cryogenics and many times, the papers which we present at this conference in the national symposium are also becoming part of Indian journal of cryogenics and that also can give you a prospective of what kind of research is being carried out in India or elsewhere.

So, all these books in addition to in the proceedings which I gave and the journals will form very interesting and important reading as far as Cryogenic Engineering is considered. With this background I would now talk about what I am going to teach in this course. So, what is the syllabus for this course?

(Refer Slide Time: 07:37)



The course syllabus is as follows, now this course I am going to give under different topics and there will be around twelve topics and under each topic I will give you one or two or five or seven kind of lectures depending on scope of that particular topic, for example, the first topic for today's lecture is on Introduction to Cryogenics and its Application. Today's lecture, I am going to cover the topic number one which is Introduction to Cryogenic and its Application.

The next topic is properties of Cryogenic Fluids. Now there are different Cryogenic Fluids or they are called as cryogens also, for example, we have got liquid nitrogen, liquid helium, liquid hydrogen, liquid neon, liquid oxygen, etcetera all these are normally called as cryogens and they have got very specific properties associated with them for example, liquid nitrogen has got its own properties like what is its boiling point, what is its density, what is a latent heat of it, all this form a very important characteristic of liquid nitrogen for example, liquid oxygen has a boiling point of 90 Kelvin it has got its own density, liquid helium has a boiling point of 4.2 Kelvin.

So, there are various important properties associated with these cryogens or cryogenic fluid. Now depending on the end use of this cryogenic fluid or the requirement of the cryogenic fluid you will select a cryogen, if I want to wait a temperature of 77 Kelvin I will choose liquid nitrogen, if I want to use oxygen then I will use liquid oxygen, if I

want to go below very low temperature in that case I will go for liquid helium which gives me 4.2 Kelvin.

So, these properties are very important data in order to decide what is the cooling effect I am going to get from this particular cryogen depending on to the density, depending on its latent part latent heat I have to select a particular cryogenic and therefore, it is very important to study the properties of this cryogens or this cryogenic fields. So, this will cover in the next topic and under this topic possibly we will have a two or three lectures covering different important cryogens. One of the most important parts for Cryogenic Engineering is the properties of material at cryogenic temperature. The materials are very important and you cannot use all the materials in cryogenic; one can use only specific material at very low temperature it will be understood, I will show a demo some time from now how the material property change at low temperature.

So, there are different materials for example, stainless steel, copper carbon, steel aluminum, the properties of these material change drastically at low temperature. This is a very important property for example, specific heat capacity, what happened to its shrinkage, the material shrinks at very low temperature, what happen to this property, what happen to its conductivity, what happen to its ductility these are very important properties and this will study in detail in the topic called properties of materials at cryogenic temperature.

Now, here I would like to conduct a small experiment to show you cryogen, that is liquid nitrogen and I will show you some material that are available which we write now and you can have look at this experiment. I am sure you will get lot of knowledge after seeing this experiment. So, let us see the liquid nitrogen because you must not have seen liquid nitrogen. So, what you see here in this video is a liquid nitrogen container which is around 1 to 1.5 liter. So, here you can see that is the specially made container which has got special insulation capacity and what you can see also on this person is basically some safety devices because you cannot touch liquid nitrogen directly, also you should be able to see, you should not see the fumes which come as soon as liquid nitrogen exposed to atmosphere. So, one has to be very careful about the safety that has to be taken into consideration while having cryogenic experimentation. In fact, you will refer to my last lecture in this lectures which basically addresses the point related to safety in cryogenics.

Now, what will do this has around 1 liter of liquid nitrogen I will put this liquid nitrogen into this container which is a thermo coal container and let us then put some devices like some materials like rubber or potato and see what happens to the property the simple properties of this materials as soon as they are put or they are subjected to cryogenic condition. So, let us see while we transfer liquid nitrogen, have a look how the liquid nitrogen looks and how it boils of immediately when it is put to the atmosphere. So, you can see the boil of fumes and you can see the liquid nitrogen's like water actually.

No except that this is starts a boiling immediately and evaporation at the fumes are; obviously, there they will always be there; please note the safety devices again. So, here are two materials, one is simple flexible rubber you can see, alright quite elastic in nature and we will put this rubber in the liquid nitrogen, also we have got a potato, you know potato also got a lot of water and as soon as we put this potato and rubber the property will change. So, let us put this two materials for let's say one or two minutes and you can see that evaporation as increased, you can see how vigorous the boiling is, you can see the evaporation happening, you can see the fumes coming out of this and you can see now how boiling is happening now it has become still now, but you can still see the bubbles over there, it's getting settled down, basically you can see some cracks having appeared over here right now only.

Now, let us take out this rubber and let us see what happens to its properties and you can see that it is not standing it is standing like very strong object and you can see now it is actually become very hard, it is no more flexible, it can be broken into pieces. In fact, it can be crushed now it has become as hard as knife also let us see potato and potato one can do the powdering of potato it has become as hard as stone, one can actually make a powder out this potato. So, you can see what has happened to these materials as soon as they were subjected to cooling, they were subjected to cryogenic conditions and you can see these parts. In fact, now this rubber also can be powdered, the potato also can be powdered if they are crushed by some hard device hard rock and this is what happens this is what shows what happens to these materials when they subjected to very low temperature. This shows; obviously, that as soon as engineering materials also when they are subjected to low temperature the properties change.

Now, the forth topic is gas liquefaction and refrigeration system. Liquid nitrogen, liquid oxygen or liquid helium, they become liquid only when you cool the gas for example,

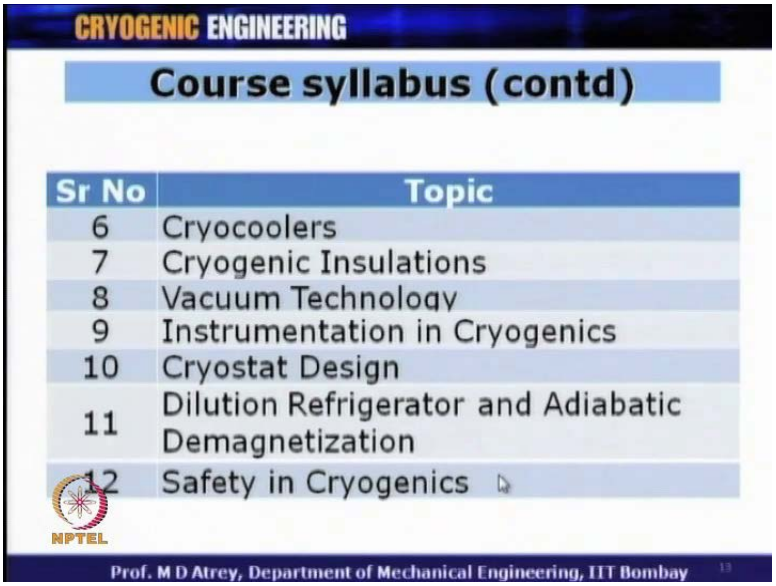
when you cool nitrogen gas slowly from room temperature to its boiling point then what you get is liquid nitrogen, but what is important to understand is how to reduce this gas temperature from 300 Kelvin to its boiling point. This is very important thing for which you have to apply various techniques like compression and expression of gas the way we do in domestic refrigerator in order to reach the lower and lower temperatures nearer to the boiling point of these gases. For example, 77 Kelvin for nitrogen, 412 Kelvin for helium and thing like that. I have to devise the system whereby I reduce the temperature of gas from room temperature to the boiling point of this gases and this is the most important thing not only that it is important that how do I do that thing, but what is most important is how efficient I am doing because in order to achieve a particular temperature I can go by a process A or process B or process C what is important for me to understand is which process is more efficient; that means, my work input should be as minimum as possible in order to reach the boiling point of this particular gases I need not compress the gas to a very high pressure because the compress are work input are very high in those cases.

This is what we will cover different gas liquefaction cycle and for a particular (( )) then will have to select that this particular cycle is the best. Similarly like liquefaction what we have is a refrigeration system also this gases are ultimately utilized for giving cooling effect or the cold or the refrigeration effect for example, when I take the latent heat from these gases at their boiling points what I get is cooling effect at constant temperature if I want to have a object which I want to cool it down to 77 Kelvin, 80 50 Kelvin, 40 Kelvin, 4.2 Kelvin or 2 Kelvin accordingly, I will have to design the refrigeration system for example, to have a magnate what I need to have a refrigeration system or cooling system.

So, this topic number four is a very important topic and very broad topic. I may take around six to seven lecture in order to cover the gas liquefaction and refrigeration systems at lower temperatures. Having done this for industrial gases utilization, what is most important is gas separation. As you know, air is a mixture of various gases. If I want to get my hands on oxygen gas or nitrogen gas or neon, argon, helium, etcetera, ultimately I will get it from air which is a mixture of various gases. I have to ultimately liquefy air which happens at 78 Kelvin around and from there I will have to separate all these gases.

Now, because of the mixture, this whole air as a mixture has got completed different properties because different gases will liquefy at different temperatures or they will condense at various temperature and what important is to understand the phase diagram of this mixture. So, the gas separation will depend on the boiling points of different gases in a mixture. For example, I have got a mixture of nitrogen and oxygen or nitrogen and helium. I got two different boiling points, one if for nitrogen and one is for oxygen or I have got a boiling point for nitrogen and helium which is 77 kelvin and 4.2 kelvin or 90 kelvin for oxygen and 77 kelvin for nitrogen. In order to separate out these mixtures effectively, in order to get pure gases this; I have to device a gas separation system. Basically I have to understand how do I separate this gases? What should my work be? In this cases, this is normally done by fractional distillation, but then you have to device or design a distillation column and this is the most important part of this.

(Refer Slide Time: 18:55)



So, gas separation, along with gas liquefaction or four and five topics are very important to study in Cryogenic Engineering. The next topic is Cryocoolers and this also forms a very important topic of research as I said earlier, there is a international cryocooler conference which happens only to bring out the research work that is being done all over the world at one place. For example, at IIT Bombay also, we have been doing lot of work on Cryocoolers and I will show now a simple cryocooler. Cryocooler is just a refrigerator which produces very low temperature in a close cycle manner. For example, I have got

different type of cryocooler, what is called as sterling cooler, what is called as gifford mcmahon cryocooler, what is called as pulse chose cryocooler. This is a cryocooler which is a sterling type cryocooler developed at IIT Bombay.

What you can see here is, this is a cryocooler and this part houses a compressor. In fact, it is called a linear compressor. It is a dry compressor, there is lubrication in this. So, this is compressor and this is an expander. The way you see in domestic refrigerator, you have got a compressor at the bottom of the refrigerator and you have got expander which is actually a capillary tube. Then you have different heat exchanges also. Similarly in this cryocooler, which is nothing but a refrigerator which produces very low temperature. This has also got a compressor, their houses heat exchanger inside these and there is an expander at the top of this thing.

Now, I will show you what it is here. What you can see at the top is the cold finger. This is called as cold figure and if I want to cool certain object, I have to conductively couple that particular object to get connected with this cold finger. This cold finger is going to generate around 80 Kelvin temperature. For example, this cooler has been design to produce around 0.5 watts at 80 kelvin to cool some other object.

So, in a close cycle manner, there is a gas which is helium in this case is continuously compress and expanded in a close cycle manner in order to produce 80 kelvin temperature at this point. So, this is nothing but a close cycle cooler which works on sterling cycle. That is why it is called sterling cooler. So, its called a sterling cycle cooler placing around 0.5 watts at 80 kelvin. In a very efficient design, if I want to carry a very efficient design of this cryocooler, my power input through this compress should be as minimum as possible so that the coefficient of performers or the c o p is very high.

So, whole design analysis has to be carried you in order to understand or predict the performance of this cryocooler and then one have to device the diameter of this cryocooler fabricated accordingly and see the experimental result for this cryocoolers. In this way, we do sterling cycle cryocoolers, g m cryocoolers or gifford mcmahon cryocoolers or pulse tube cryocoolers and thing like that; the various steps of cryocoolers which one can design.

The next topic is cryogenic insulations. As you know, when I am going to talk about cryogenics, I am going to talk about very low temperature and outside temperature of the

ambient is 300 kelvin which is very high temperature. So, the heat is going to rush from outside to inside which is what we do not want. Otherwise, I want to cool a particular object, but because of the leakage of heat ambient heat from outside, my cooling effect will be nullified. In fact, some of the cooling effect will be getting wasted as loses. So, in order to minimize that, what is more important or what is most important is the insulation.

Now, insulation is a critical part of cryogenics and depending on the low temperature I am talking about for example, if I am talking about 80 kelvin or if I am talking about very low temperature of 4.2 kelvin, I have got different type of insulation and these insulation are in different forms like perlite powder, it could be vacuum insulation; a vacuum is a very important part in cryogenics and my next topic is going to is a vacuum.

So, vacuum basically nullifies all the conduction and convection or removes all the air around a cooler part. If I do not do that thing, the moisture in that air will get flows and down. Therefore, I have to remove all the air around cold finger and that is why vacuum insulation also is very important part. I am going to show a very typical insulation here. What you can see is a very typical insulation and here this is called as multilayer insulation and it has got highly reflecting surface like aluminum, aluminum foil, aluminize mylar like that. We can have very highly poly surface and we can have different layers of this. We can have different layers of this and each layer is separated by a non conduct medium like nylon net. We can have some non metallic stuff which is nylon net or any other things be separate out and this is what is called as multilayer insulation.

Now, this multilayer insulation is a wrapped around for example, this is a cold finger, I will wrap this multilayer insulation in a very typical manner and what is most important is how many layers are there. So, one has to have ten layers or twenty layers or thirty layers; that also one has to optimize depending on the temperature and heat in link and also the vacuum around. So, multilayer insulation works only when there is a vacuum around it making effectively the thermal conductivity across this direction from outside to inside as minimum as possible. It could be 0.0001 conductivity could be of this order alright.

So, the conductivity gets drastically reduced when multilayer insulation is there. So, if I want to reach very low temperature, I have to use multilayer insulation in presence of vacuum in those cases alright. So, insulation is a very important part in Cryogenic Engineering. This has to be taken care of effectively depending on the end temperature or the low temperatures we are going to talking about 77 Kelvin or 4.2 Kelvin or 25 Kelvin; this will decide what insulation I am going to use. As I just said, vacuum technology is a very important part and vacuum is a very integral part of cryogenics.

So, what is this vacuum? What are different types of vacuum? How do you get these vacuums? What are different vacuum pump is also have to be studied in cryogenics. So, this part also will be covered in cryogenics while learning this topic. The next important part is instrumentation in cryogenics. You can understand instrumentation at low temperature and instrumentation at very low temperature has to be different. For example, if I want to carry out temperature measurement, pressure measurement or I got different cryogens kept you know cryostat and therefore, I should know how much liquid nitrogen is left there. So, what I call is a level measurement. I should know that it was hundred liters today, tomorrow it could be ninety liters, day after it could be seventy-five liters; depending on the usage and depending on the loses.

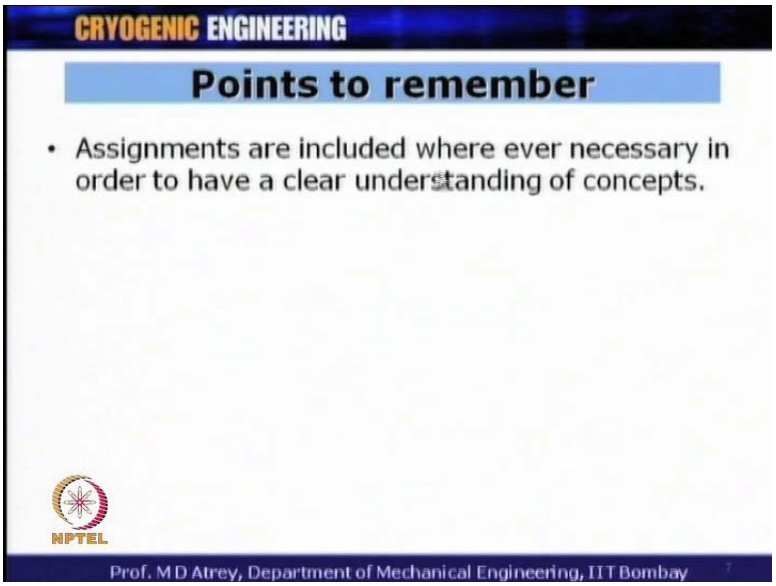
So, I have to measure in cryogenics the temperature, pressure level mass flow rates and whatever technique I device at room temperature are not applicable at low temperature. One has to follow a different technique because the properties or a calibration is complete a different at low temperature. For example, just for today's lecture, if I talk about measurement of temperature at very low temperature, for example, at 4.2 Kelvin or 10 Kelvin, what I use is something called as silicon diode. If I want to show you, this is a silicon diode, this is a very small piece and this has been calibrated to measure temperature up to 1 Kelvin .This is a very costly piece or if you get it calibrated it is a very costly piece still. This is a diode. At lower and lower temperature, the voltage of the resistance start increasing and this is calibrated in terms of temperature at lower and lower temperature.

In addition to this, what I have also is a PT 100. This called Platinum 100 and what you can see form here is PT 100 can measure the temperature up to 30 to 40 Kelvin. Let us say 50 kelvin is greater. From room temperature to 50 Kelvin, I can measure the temperature when I say Pt 100, it has got 100 ohms resistance at 0 degree centigrade. So,

these are two things I can show, I can measure the temperature up to 50 Kelvin using PT 100 and I can measure temperature up to 1 Kelvin using silicon diode. This two are a very important temperature measurement instruments which are generally used in cryogenics alright.

So, one has to understand how do at measure temperature, what is the philosophy behind a temperature measurement, in this cases what are corresponding errors, how do I employ this thing in the actual instrumentation and thing like that are very important aspects of cryogenic engineering instrumentation. Going head from there, what you have is a cryostat design. All the experiments which I do at low temperature, you have to have a cryostat because I want to cool certain objects I will hold liquid nitrogen in a cryostat; I can use liquid nitrogen or liquid helium.

(Refer Slide Time: 28:02)



If I use liquid helium, the liquid helium can get shielded by liquid nitrogen also. And if I want to use this cryostat to study properties of materials at low temperature in a magnetic environment or something like that, I have to design a cryostat accordingly and this is we will cover in a topic of cryostat design.

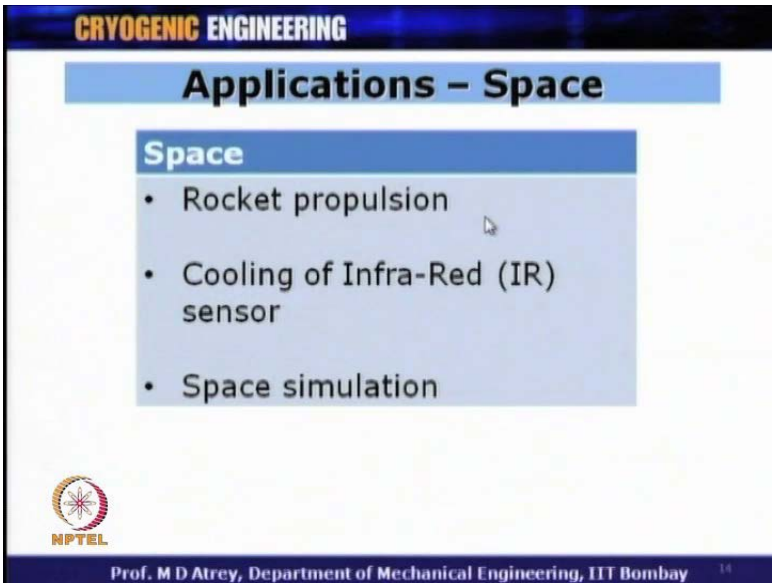
Going a head from here, there are if I want to reach a temperatures below 1 kelvin, what I have to use is something called as dilution refrigerator or adiabatic demagnetization technology. These are very special technologies produced by very few in the world and

therefore, it is a very important task in cryogenic engineering. With cryocoolers, I can possibly go up to 2 kelvin or 3 Kelvin, but if I want to go a below this temperature, I have to go for dilution refrigerator or demagnetization techniques. This can take me down to much less than 1 kelvin, may be very close to 0 kelvin, of course, we cannot achieve 0 kelvin, but these two techniques can take you down to milli kelvin region, alright in less than 1 kelvin region.

And finally, what is most important cryogenic s f t one has to observe certain norms, one has to use certain clones, we have to use googols and thing like that and why do have to do all this things; because we are working at very low temperature, if there is small accident if the nitrogen in atmosphere increases or oxygen level drops down, you can suffer from some sick called as affixation and I will talk about all this things later in the chapter very important chapter or topic on safety in cryogenics. These are different topics which I am going to cover in this syllabus. I will take several lectures under each topic in order to cover these.

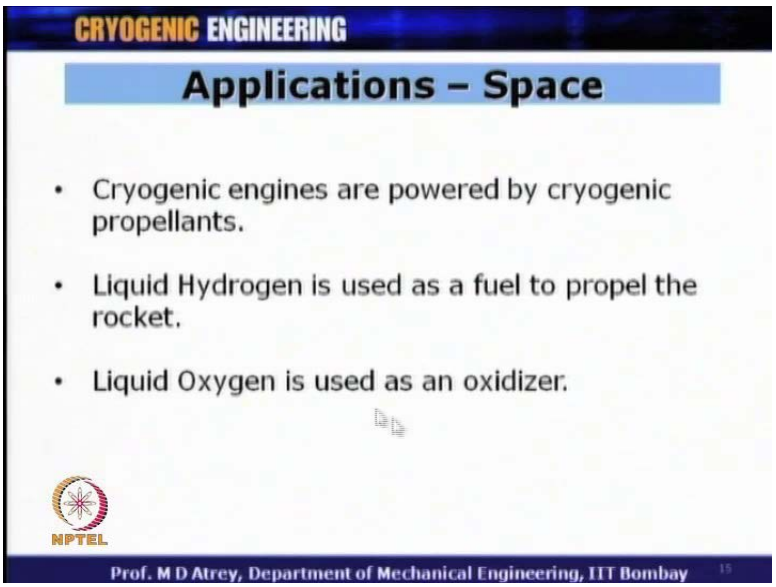
Now, after understanding what is covered in this, what I want to bring your attention to is what different applications of cryogenics are. Now cryogenics has got different application in space, in mechanical engineering, in medicine, in super conductivity and thing like that. I am just showing certain examples. I may not go into the details of each of those applications because each of those applications are chapter by themselves. What I am go is through this slide, you might read that with me and I will just take you through this slide so that you get a glimpse of what those applications are of cryogenic engineering in this different special topics for example, space.

(Refer Slide Time: 30:31)



Under space, I have got cryogenics in rocket propulsion, cooling of infrared sensors or space Simulation. These are very important aspects of cryogenics used in space.

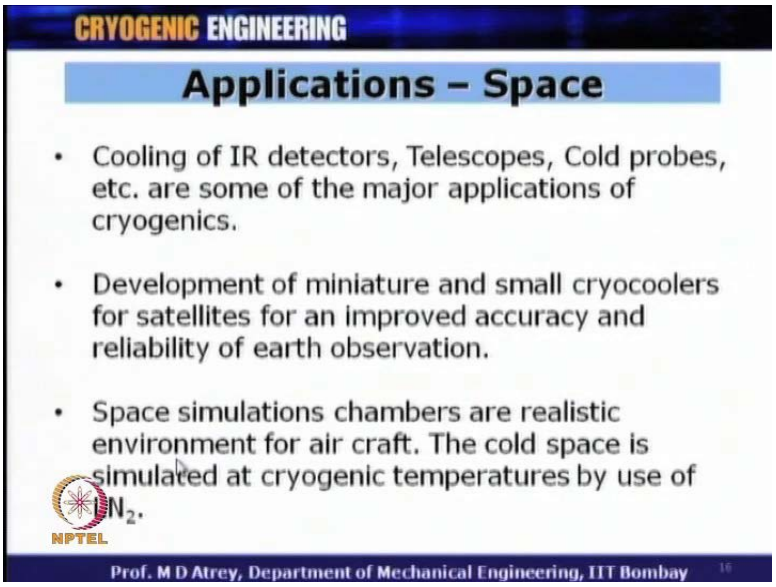
(Refer Slide Time: 30:45)



Now, what are they? Cryogenic engines are powered by cryogenic propellants, you know different propellants are there, but if I use Cryogenic propellants for example, Liquid hydrogen can be used as fuel to propel the rocket. Most of you have heard about Cryogenic engine and Cryogenic Engine uses Liquid Hydrogen as a fuel. It also uses

Liquid Oxygen as an oxidizer. So, these two are important components, Liquid hydrogen is liquid at 20 kelvin, liquid oxygen is liquid at 90 kelvin. These two form the fuel for Cryogenic engine and therefore, it can work as cryogenic propellant and these are very important.

(Refer Slide Time: 31:23)



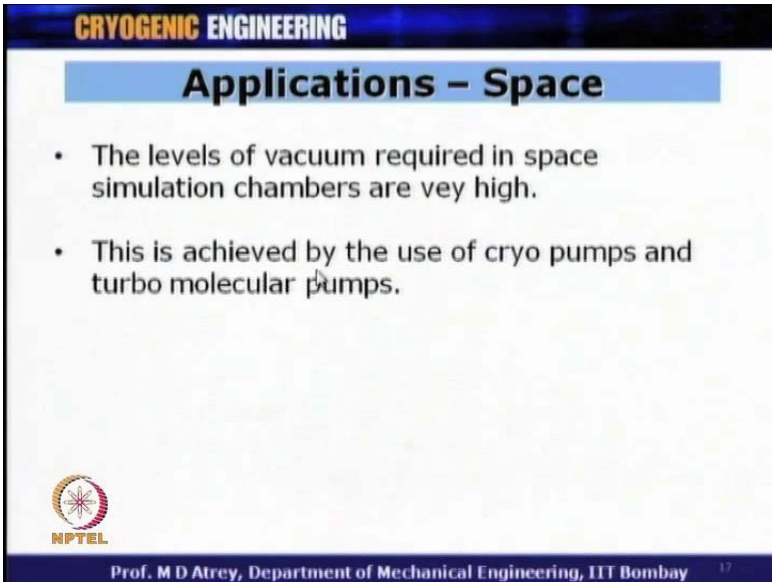
The next is cooling of infrared detectors or telescopes or cold probes are some of the major applications of cryogenics. I have to use infrared detector in space because when I am taking night surveillance, when I taking picture, I have got infrared detectors. Now, in order to get a good signal to noise ratio; that means, in order to get a good image, I have to have detector at very low temperature. In fact, lower the temperature of this detector is better the picture or less is the noise and therefore, infrared detectors have to be kept cool at 80 kelvin or less than that as I said lower the temperature better it is.

Similarly, I have got lot of electronic circuits in space. If I cool this circuits down, for example, amplifiers or any electronics which gets heated over period of time, if I got cold probes, I can keep it very cold and therefore, the noise level will be minimum in this case. This form a very important applications of cryogenics in space. In order to do that, what I do is normally develop miniature cryocoolers which goes in space and the cold finger as I just showed earlier, sterling cooler as example is very widely used to cool the infrared detector in space and what is important therefore, is to design a miniature

version of sterling coolers; less weight and less volume which are very important things for space.

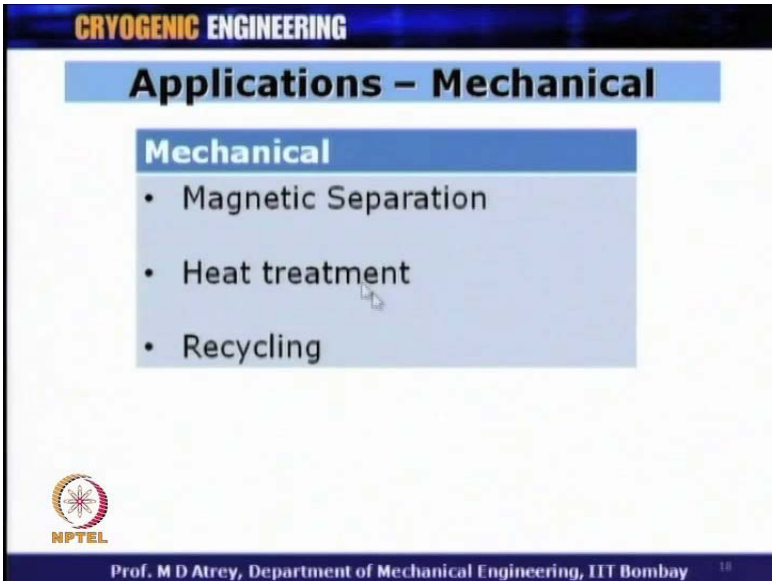
Space simulation chamber are the realistic environment for air craft. The cold space is stimulated at cryogenic temperature by use of ln2 or liquid nitrogen. So, space simulation chamber basically simulate space. What is space? Space has got very less of around 4 kelvin and very less pressure that is vacuum. All this thing simulated have to be simulated on the ground if any part you want to take in space it has to first gets space qualified which will what will happen is space simulation chamber. Its a small, it is a small test which was done on the ground which stimulates condition in a space where in, the low temperature are generated by different cryogenics like liquid nitrogen, liquid oxin, etcetera. At a same time, different levels of vacuum are required in space and what we do for these we use cryo pumps or turbo molecular pumps.

(Refer Slide Time: 33:32)



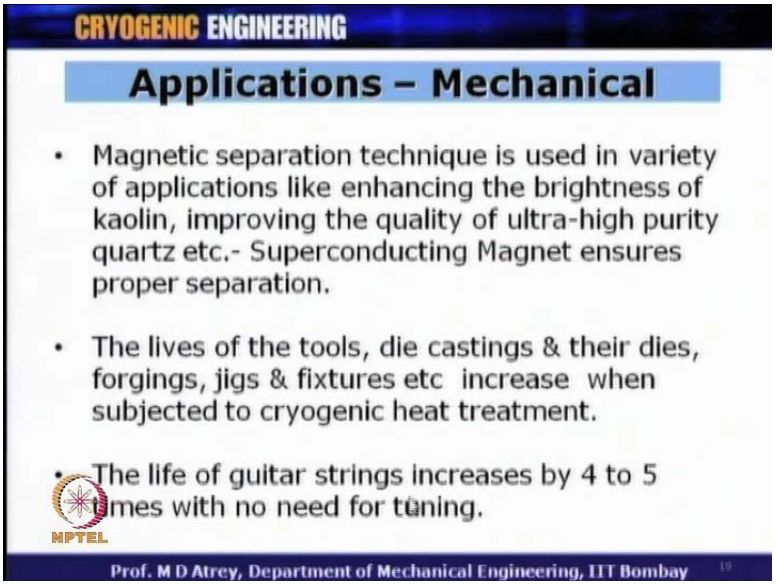
In this way, we can achieve lower and lower vacuums to simulate condition like what it is in space. This is a very important applications of cryogenics in space.

(Refer Slide Time: 33:51)



If I move away from space, I go to mechanical engineering now where in, the applications of cryogenic engineering are in Magnetic Separation, Heat Treatment of different materials or Recycling of certain materials. There are various applications, but I will touch up on only three of these aspects in this particular lecture.

(Refer Slide Time: 34:07)

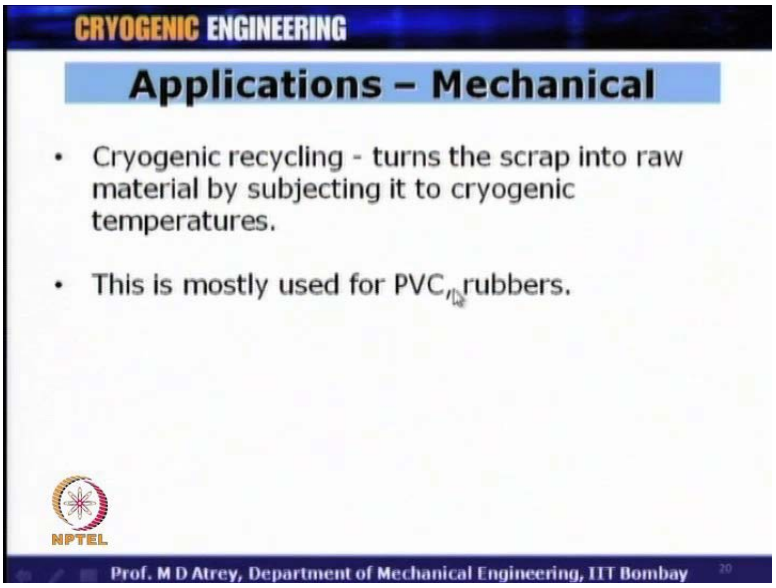


What is magnetic separation? The magnetic separation technique is used in variety of applications like enhancing the brightness of kaolin, this is the clay improving the quality of ultra high purity quartz etcetera. What we use is the superconducting magnet ensures proper separation.

So, what I am do basically when I get this kaolin clay from different or mines on the eastern part of India for example, it get associated with lot of metals and in order to separate this materials or metals like silicates etcetera, what I use, I pass the whole thing through some magnate and this materials or metals will get attracted toward this magnate, after that the kaolin will be free of this metals; however, in order to separate out this materials from the kaolin clay, what I need is a very high magnetic fields and this high magnetic fields can be achieved only by super conducting magnets and not by electro magnates. If I were to use electromagnetic, then my current passing through this wires is very high and therefore, losses will be very high.

So, what I have to use for this is basically superconducting magnet. This is very widely use techniques. Superconducting magnets are meant for magnetic separation is very big magnates through with the kaolin passes and it comes out without these metals at the other end. Similarly, cryogenic heat treatment gives lot of metals. As you go on cooling the object for example, what we do in tempering and analyzing is you first go to a very high temperature and start cooling the object and which talked at ambient temperature. If I do not stop at ambient temperature and go below to cryogenic temperatures, there is something called as retain (( )) which will get converted to martin sight and what we want. The return (( )) which will get converted to martin sight and which is what we want the retain is very brittle sometimes and therefore, I would like to have complete conversion of this ostinite to martinsite and therefore, cryogenic treatment of very special metal is carried out and you get a better metal at the end of the heat treatment what do get at the end is the lives of the tools die castings, their dies forgings jigs and fixtures etcetera increase when subjected to cryogenic heat treatment. This is very important. The life of guitar string increased by 4 to 5 times with no need for tuning. So, here you can see that the life increase is there because of cryogenic heat treatment carried out to liquid nitrogen temperature.

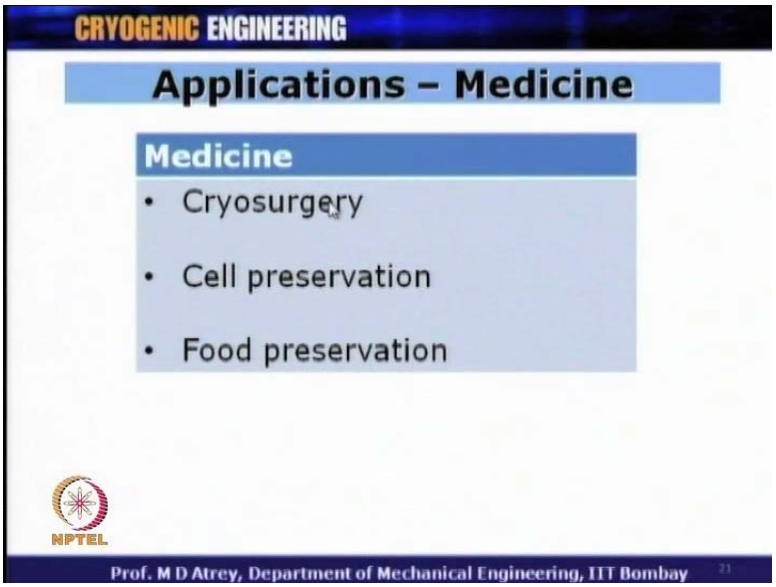
(Refer Slide Time: 36:07)



Cryogenic recycling turns the scrap into raw materials by subjecting it to cryogenic temperatures. There are certain materials like rubber or plastic which we want to scrap and it is not very easy to scrap these things. So, what you do you expose this material to very low temperature we put them it is a liquid nitrogen bath, as soon as you do that thing as we saw in the experiments this material become very hard, it becomes very rock hard and then one can use some kind of press in order to crush the whole scrap, can be crushed like a metal in those cases and it will ultimately get converted to powder, it is very easy to scrape in the form of powder.

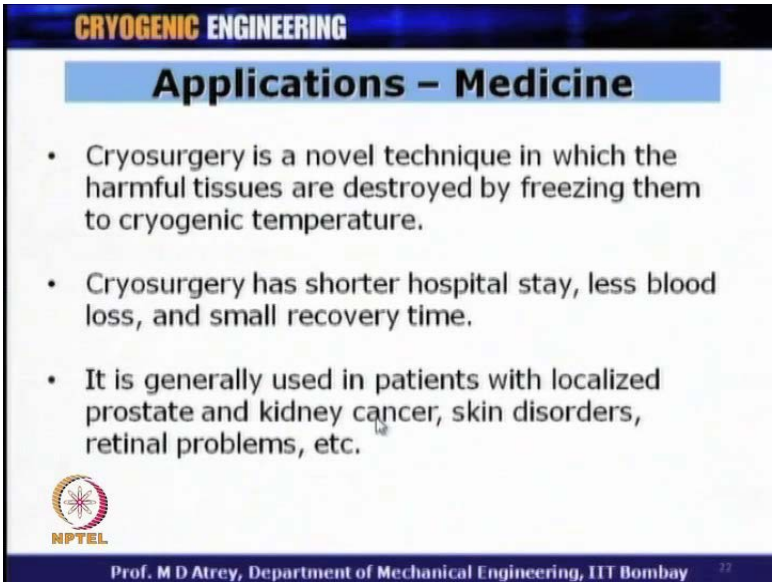
So, if I got a huge raw material for example, PVC, rubbers and plastics etcetera you can give a cryogenic treatment to those things, you can give a cryogenic recycling treatment to those subjected to low temperature and crush it to powder, various designs are available, various system are being fallowed all over the world this forms a very important applications of cryogenics in mechanical engineering. Moving away from mechanical engineering to medicine this is again is a very important aspect of cryogenic engineering usage in medicine.

(Refer Slide Time: 37:42)



One can use Cryogenics in Cryosurgery, Cell Preservation or Food Preservation. Preservation industry is a huge as for as cryogenics is concerned from the medical point of view I will show you what its usages are.

(Refer Slide Time: 37:56)

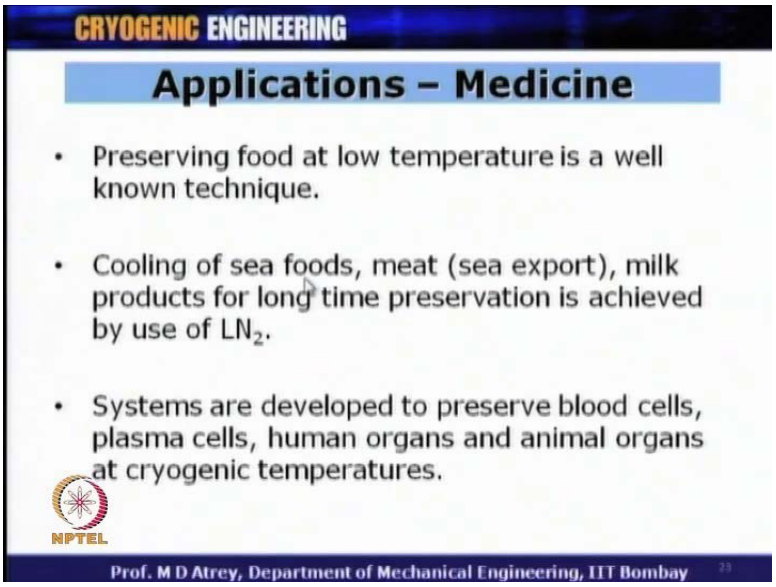


Cryosurgery is a novel technique in which the harmful tissues are destroyed by freezing them to cryogenic treatment. This surgery is carried out for various aspects, for example, Dermatology's use this surgery just to remove unwanted moles or something like that on

your body, some treatment is given on your skin by doing a small surgery at very low temperature. Why? Cryosurgery has shorter hospital stay, less blood loss and small recovery time, this very important aspect one can go in the morning and come back in the evening that kind of cryosurgery also possible which is done at very low temperature.

It is generally used in patients with localized prostate or kidney cancer, skin disorders, retinal problems etcetera. This list is actually increasing with time; however, the data's keep coming, there are certain hard elements also that could be treated using cryogenic techniques.

(Refer Slide Time: 38:54)

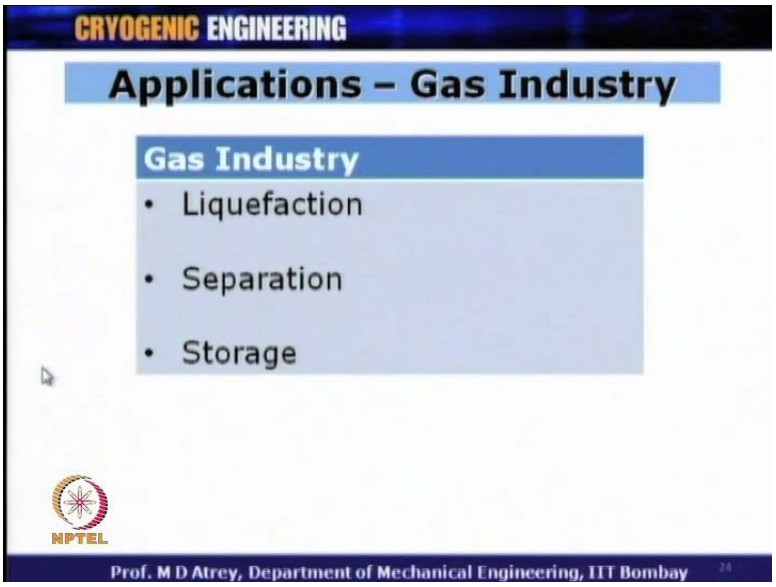


When you come to preservation, the preserving food at low temperature is a well known technique this is what we do in a domestic refrigerator. Cooling of sea food meat, milk products long time preservation is achieved using liquid nitrogen; liquid nitrogen is very widely used for transporting sea food or meat or milk from a port A to port B one can keep everything reserved in a original form, frozen at cryogenic temperature and therefore, is a very important technique, very massive work is being carried out as far as preservation of food is using cryogenic technique is considered.

Systems are developed to preserve blood cells, this is again a usage in medicine you can preserved blood cells, plasma cells, human organ and animal organs at cryogenic temperature. So, the preservation using liquid nitrogen bath to preserve blood cells,

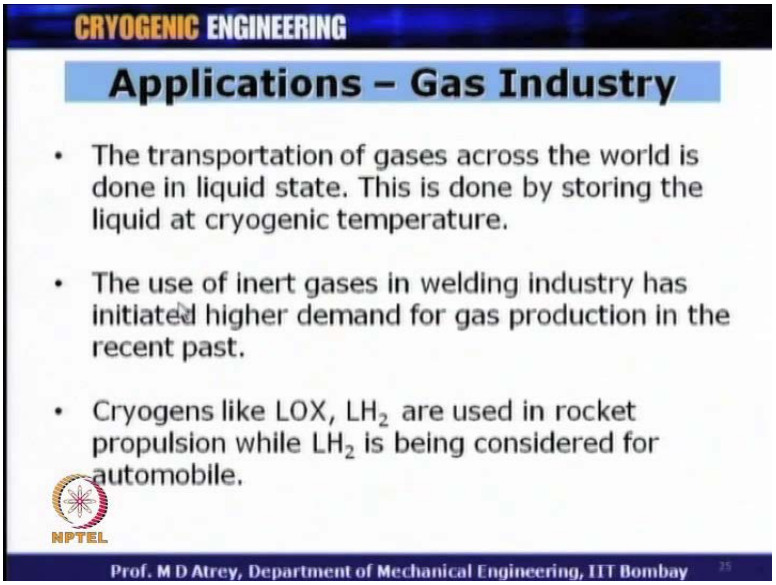
plasma cells, human cells, stain cells also is latest addition to this list, this all thing is done at cryogenic temperature.

(Refer Slide Time: 39:51)



Coming next from here to the gas industry; as you know gas industry is basically the gases the industrial gases is a very sort after for example, oxygen, nitrogen are used. Oxygen is used in medical hospital and therefore, the gas industry is a very big industry and gas industry therefore, use as cryogenic techniques for Liquefaction Separation and Storage the very important aspect of cryogenics very important usage of cryogenics.

(Refer Slide Time: 40:21)

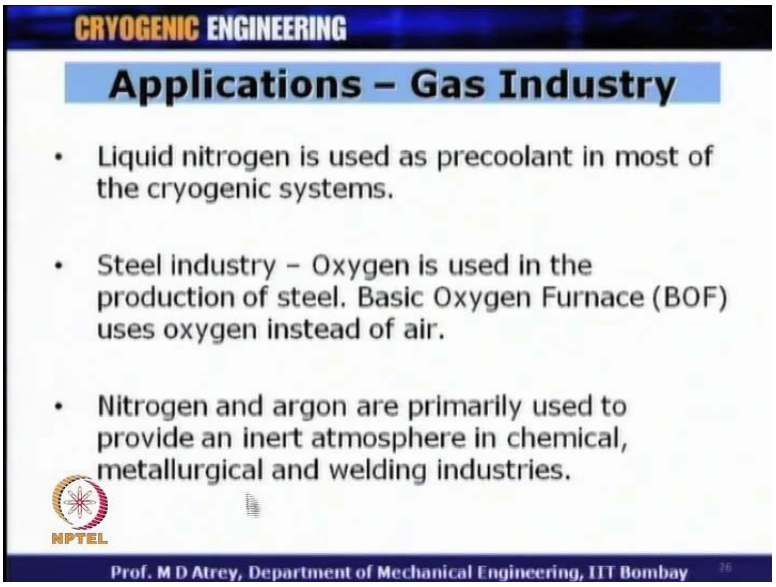


The transportation gases across the world is done in liquid state, one need not do the transportation of the gases in the gaseous form because if you want to do the transport of gases in gaseous form the gases are compressed at very high pressure which is sometimes unsafe, which is not excepted sometimes.

So, what you do, you convert those gases to liquid by lowering the temperature by liquefying those gases using cryogenic techniques and this is done by storing the liquid at cryogenic temperature, if I get liquid of those particular gases I can store those liquid at cryogenic temperature and in this way I can do transportation much easily as compared to those in case of gases. The use of inert gases in welding industry has initiated higher demand for gas production in the recent past. Nitrogen, oxygen all these are very widely used in the industry and therefore, this gases require cryogenic technique to liquefy those gases and transport those gases and store those gases and it is a very high demand of gases or cryogenic gases like nitrogen, oxygen, neon, argon etcetera. cryogenic likes lock which is liquid oxygen LH2 liquid hydrogen are used in rocket propulsion as we have just seen earlier; well liquid hydrogen is also being considered for automobile, you may know that lot of research being carried out to use hydrogen as a fuel in a automobile. In fact, a car is already ready which uses liquid hydrogen as a fuel like what we do in using petrol or diesel.

So, here all these gases, all these liquefied gases play very important role as they are needed to be consumed in these forms.

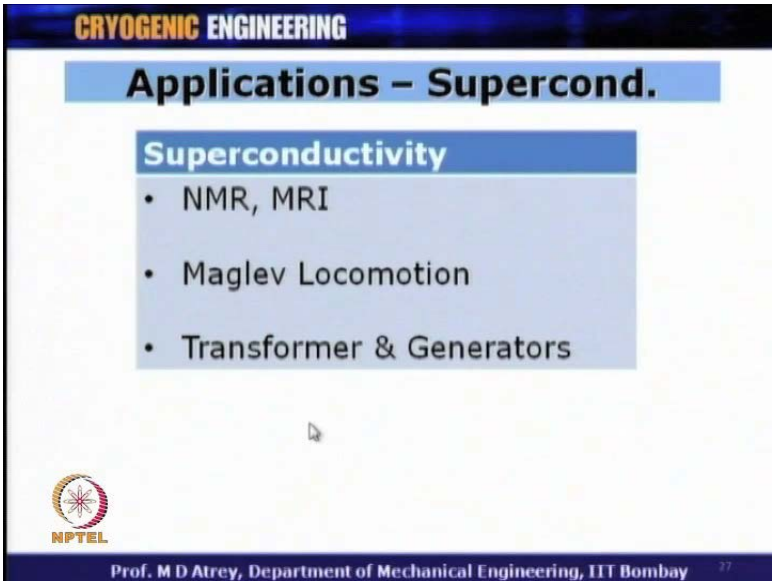
(Refer Slide Time: 41:59)



Liquid nitrogen is used as precoolant in most of the cryogenic systems. Whenever I want to do cooling, I got liquid nitrogen as a very cost effective way which we will reduce from room temperature to 77 kelvin. As you know, nitrogen is available in air. So, nitrogen is freely available one can say, it is a very cost effective solution to reach 77 kelvin and most of the liquefaction cycles, nitrogen is used as a precoolant in order to reduce the temperature from room temperature 77 kelvin.

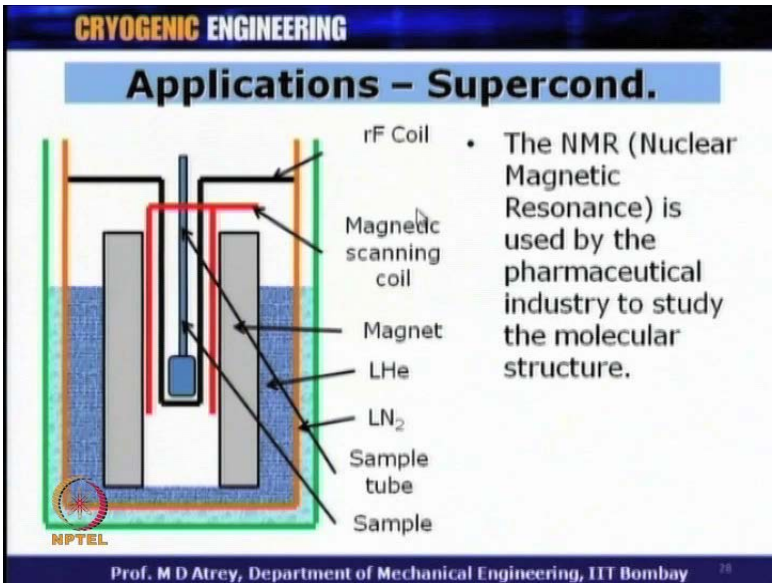
The steel industry is a very important consumer of these gases and you can find lot of liquid oxygen plants on the campus where the steel industry is housed. So, in steel industry oxygen is used in the production of steel. Basic oxygen furnace uses oxygen instead of air. So, we will find lot of places, liquid oxygen becomes a very important requirement for the steel industry. Nitrogen and argon are primarily used to provide an inert atmosphere in chemical, metallurgical and welding industries. So, these gases being inert gases, they are stored in the form of liquid nitrogen or liquid organ, instead of storing in the forms of very highly compressed cylinders. It create problems for a safety considerations are taken.

(Refer Slide Time: 43:16)



The next biggest application is super conductivity. Superconductivity has got various uses in NMR, MRI, magnetically levitated trains, transformers and generators. This is a very important aspect of cryogenics. In fact, super conductivity came into existence because of cryogenics and it has got important usage in various aspects important being The NMR or the nuclear magnetic resonance and MRI; it is a magnetic resonance imaging which you find in hospitals.

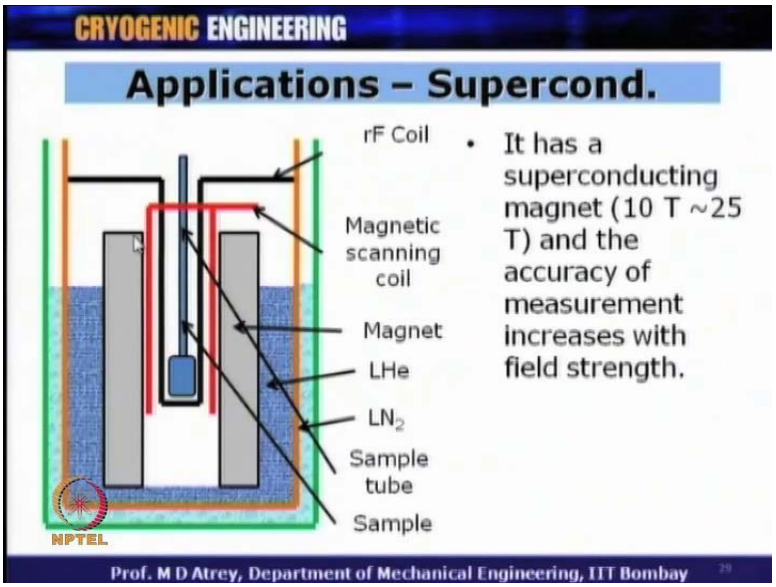
(Refer Slide Time: 43:41)



So, one of the major important usages of super conducting magnet is a NMR which is a nuclear magnetic resonance. It is used by the various pharmaceutical industry to study the molecular structure. If I want to device a new drug against any particular disease, I have to do NMR in order to understand the molecular structure in three dimensions. What I do for that is NMR and NMR has super conducting magnets here. What you can see here is super conducting magnet and in this super conducting magnet, what I have got is a small sample of a chemical of which I want to study certain properties. In order that this magnet become super conducting, this magnet could be kept dip in liquid helium and one can have liquid nitrogen outside.

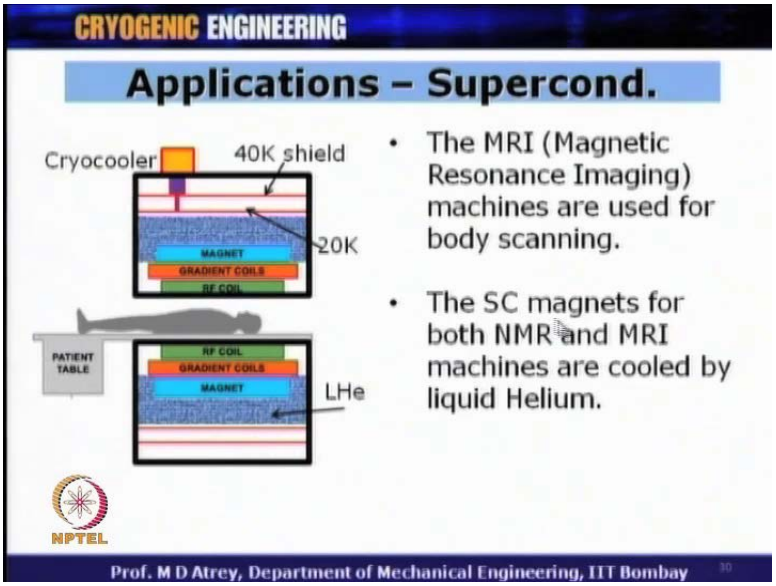
So, if you have seen any NMR facility, we can always see that NMR facility will continuously require a liquid nitrogen or liquid helium in order to keep this super conducting magnets in a super conducting state all the time because slowly the liquid helium level starting down and slowly liquid helium state also will start going down and therefore, we need cryogenics to be supplied all the time.

(Refer Slide Time: 44:48)



The magnetic field which is generated by this is around 10 to 25 Tesla, higher the magnetic field better is the structure that is visible to us and therefore, the need of super conducting magnate in this case.

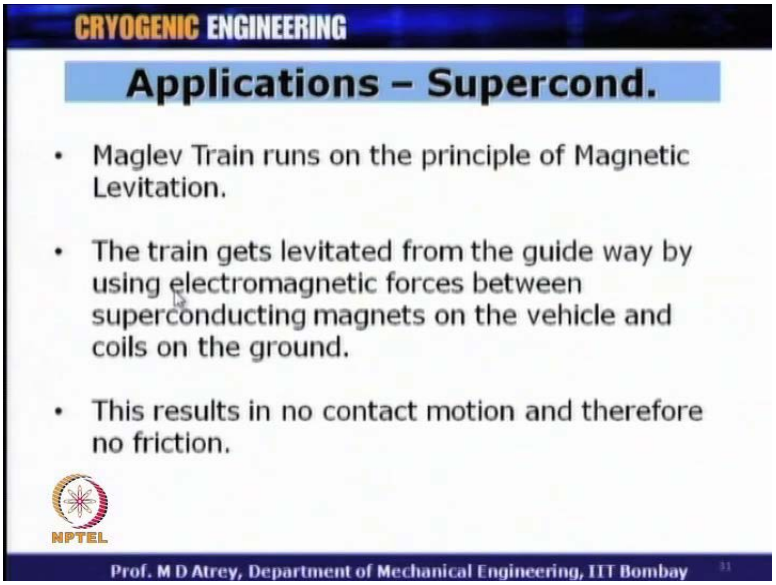
(Refer Slide Time: 45:09)



Similar to that, what you have got is an MRI which is a magnetic resonance imaging and this is again used for body scanning. As you can see the picture over here, this is a magnet and then we have got a different coils which take a signal of this person setting

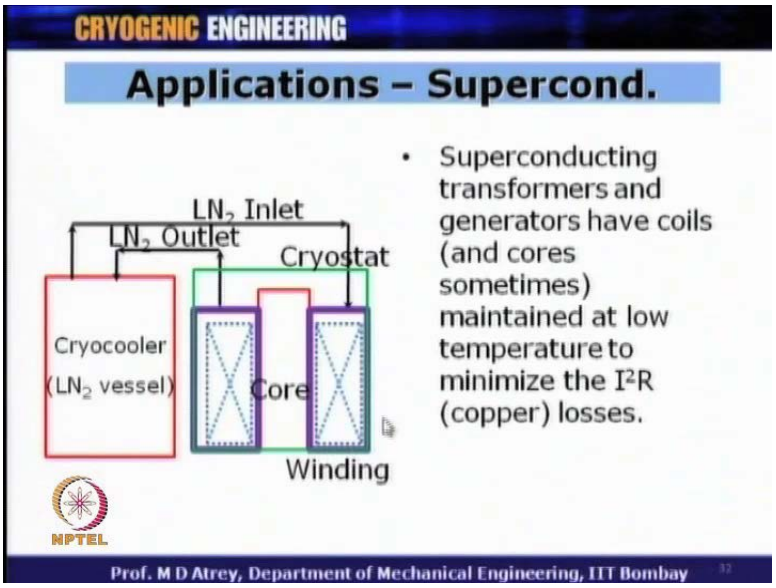
over here. MRI is meant for basically body scanning while NMR is meant for chemicals in order that this magnet are kept in super conducting state also the time their dip in liquid helium here and then you can find different shields outside. Sometime this liquid helium will be surrounded by liquid nitrogen or we can use a cryocooler which can produce shields of 40 to 50 kelvin or 20 kelvin outside of this liquid helium so that the boil of is minimum in this case. This is a very important applications of cryocoolers in MRI field. In fact, MRI field has really initiated the research better and better efficient cryocoolers and functioning and also minimum vibration in this cases and this is the way MRI will be done. The super conducting magnets for both NMR and MRI machines are cooled with liquid helium and now a days with cryocoolers also.

(Refer Slide Time: 46:16)



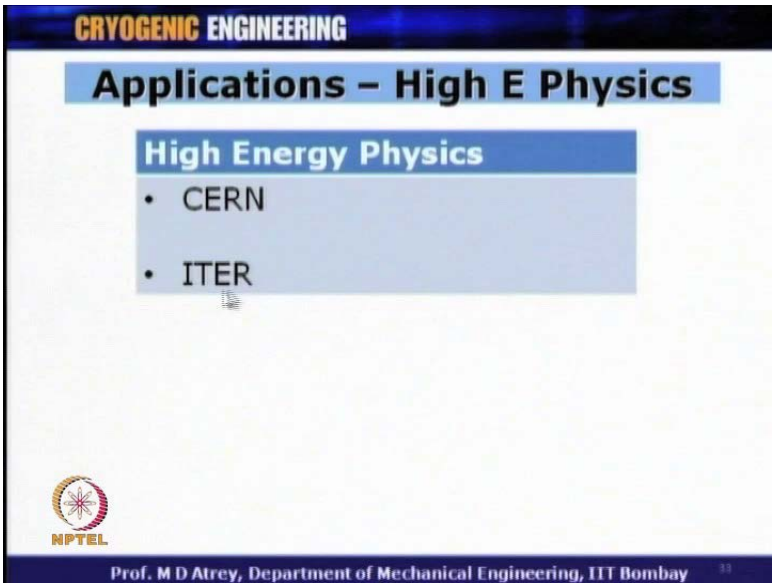
Next application is magnetically levitated trains which run on the principle of magnetic levitations. The train gets levitated from the guide way by using electromagnetic forces between superconducting magnets in the vehicle and coils on the ground. This is the very important applications of super conducting magnet which uses cryogenics to go into super conducting region. This particular thing results in no contact motion and therefore, no friction. So, imagine a train running with a speed of 600 kilometer per hour, having no contacts with the rails and therefore, no friction. Therefore, no wear and tear therefore, no service in requirements. So, great application of cryogenics.

(Refer Slide Time: 46:54)



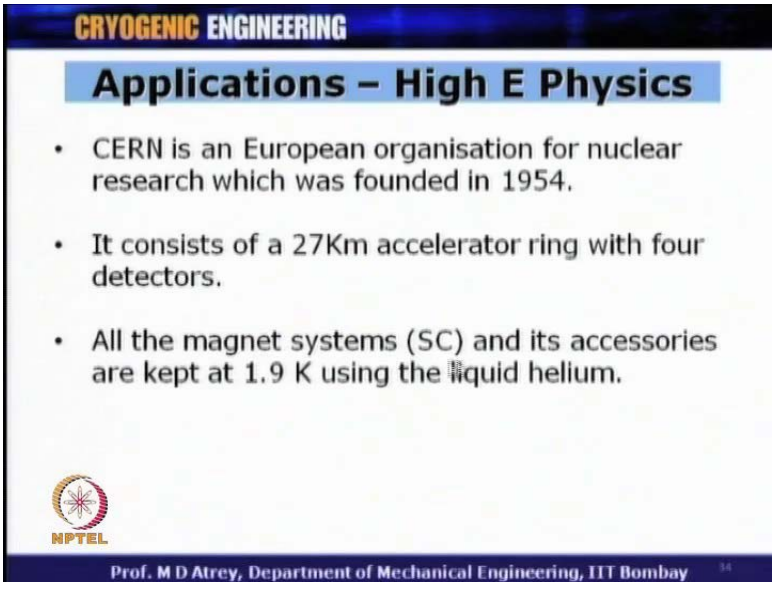
Similar to this, the next applications are superconducting transformers, motors and generators. Wherever there are windings involved, wherever there are I square R losses are there, if we could put those winding in liquid nitrogen or liquid helium, the I square R losses are going to be absolute minimum or 0. There are different ways in which the super conducting wires could be achieved. Super conductivity of this wires could be achieved by various cryogenics arrangements, cryogenic systems that we have to study; however, because of superconducting transformers, generators and motors, cryogenic is reaching to a commercial state now.

(Refer Slide Time: 47:34)



lastly, I would say the recent experiments which most of you have seen at CERN and now, at the biggest project on earth is ITER are the important applications of cryogenics in high energy physics.

(Refer Slide Time: 47:46)

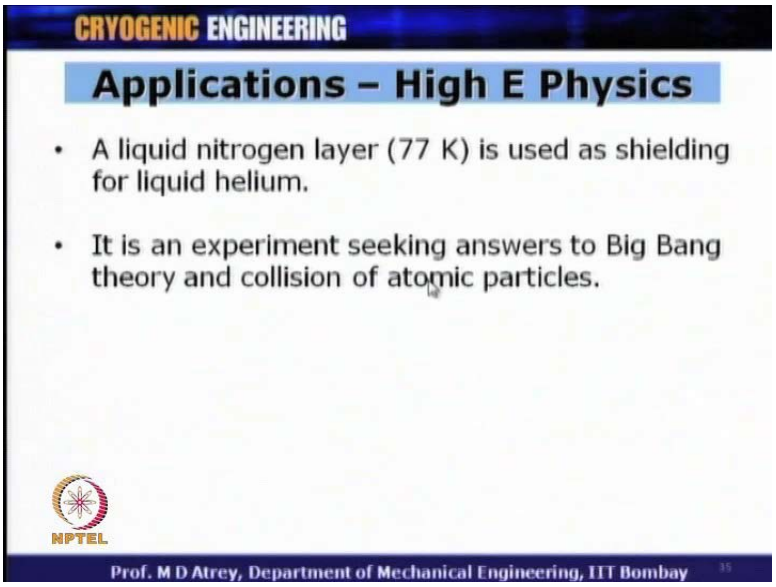


CERN is an European organization for nuclear research which was founded in 1954. It consist of a 27 kilometer accelerator ring with four detectors. Possibly most have you have heard recently, the results what you got at CERN. It houses superconducting

magnetry. All the magnet systems which is there in this 27 kilometer accelerator, it has got superconducting magnets and all this magnets are kept at 1.9 kelvin using liquid helium.

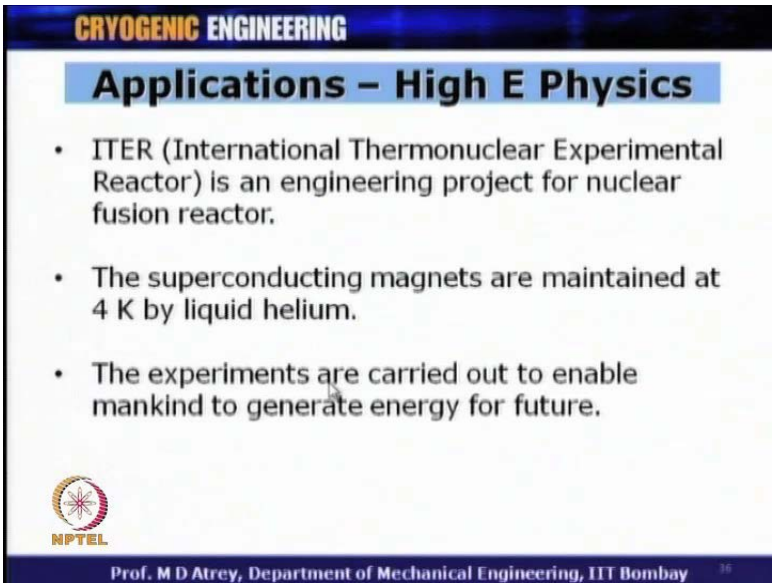
So, you can imagine an immensely applications of cryogenics, a biggest applications of cryogenics at CERN. In fact, lot of research in cryogenics originated from CERN because of these big applications. A liquid nitrogen layer of 77 kelvin is used as shielding for liquid helium.

(Refer Slide Time: 48:32)



It is an experiment, most of you know. It is an experiment seeking answers to big bang theory and collision of atomic particles. Basically it studies the origin of universe in this way.

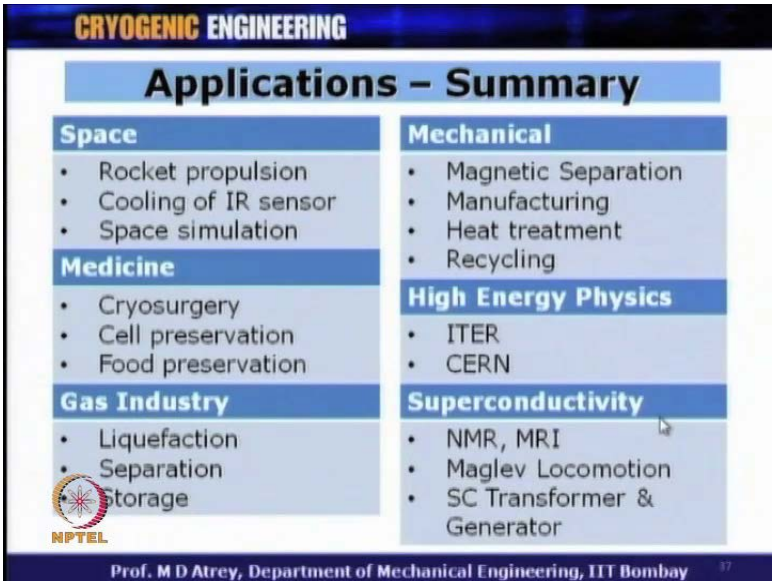
(Refer Slide Time: 48:45)



The next big application after CERN has been ITER; International Thermonuclear Experimental Reactor. This is an engineering project for nuclear fusion reactor. This is a very important project which is I think the biggest project right now on the earth where the superconducting magnets are again used and they are maintained at 4 kelvin using liquid helium.

These experiments are carried out to enable mankind to generate energy for future. So, ITER experiments, if you go on net, you can get lot of information on CERN and ITER experiments and these experiments, we seek that this will possible solve our problems for energy in a future. So, I have given you various applications of cryogenics.

(Refer Slide Time: 49:26)



And just in summary, I would like to give space application, application of cryogenics in medicine, application of cryogenic in mechanical engineering, high energy physics then gas industry and superconductivity. This is in short all the applications of cryogenics in various fields which are very important. In addition to that, what we have is cryo biology, biotechnology in cryophysics and things like that whether got fantastic applications of cryogenic in this field also.

I will stop here. Thank you very much and in the next lectures will cover different aspect of cryogenic engineering.

Thank you.