Fundamentals of Nuclear Power Generation
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Module - 09
Nuclear Fusion
Lecture - 02
Coulomb barrier & other critical factors

Hello friends welcome back to the second lecture of our week number 9, where we are talking about nuclear fusion. In all the earlier modules, we have restricted ourselves to the topic of nuclear fusion because that is the most predominating power generating technology or I should say that is the only power genetic technology that has been adopted by the industry so, far from nuclear point of view.

However, fusion as we have already seen in the previous lecture is something that can be of even larger importance if at all we can master the technology itself because fusion offers several advantages over the fusion reaction like as a quick recap to the lecture 1.

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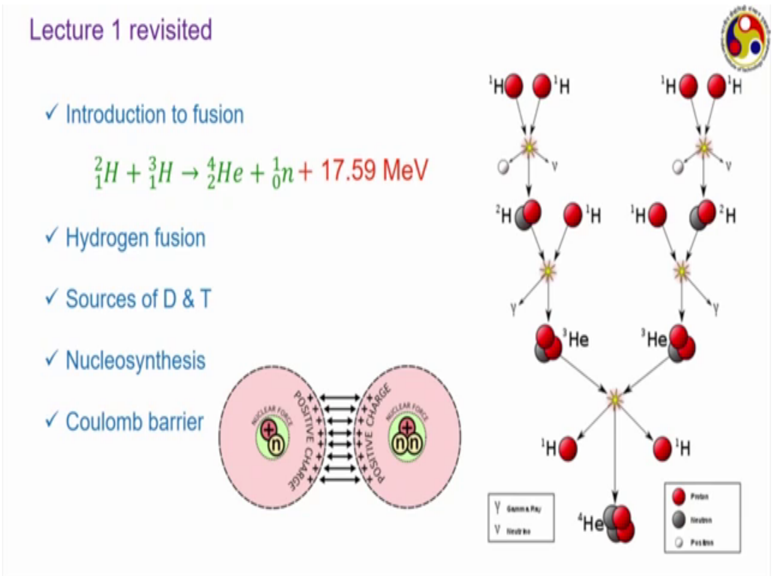

We have seen that fission offers much larger power density compared to or I should say fusion offers much larger power density compared to fission. Like a very simple fusion reaction involving deuterium and tritium as the reactant is able to produce something like 17.6 MeV of energy.

Which gives an energy density of about 3.5 MeV per nucleon, but if we compared to compared that figure to a standard fission reaction something like an in one involving uranium 235 or plutonium 239 you will be getting the same figure that is amount of energy produced per nucleon something like only 0.8 2.85 MeV.

So, in a the energy density in a fission reaction that we get is only about one fourth of that of what a fusion is capable of producing. Also the products of fission generally a radioactive in nature therefore, they go through a series of radioactive decay still they reach some kind of stable isotopes. Of course, a contribution from that radioactive decay of that fission products is energy, but that also creates a lot of problem with the storage of the waste fuel.

Because some of the isotopes which are available in the spent fuel can have very long half life therefore, they can retain their activity for a very long period of time causing yet problem to the storage issue. But in case of fusion reaction, we can say that there is not that much of issue related to the spent fuel.

Because the product of like the one that is already there on the slide the product is a helium 4 which is inert gas. So, that will not have any kind of nuclear or chemical activities and hence we can easily liberate that or release that to the atmosphere without bothering about any kind of encroachment.

Another big issue that we can get with fusion or I should say another big advantage we can get with fusion is in case of an accidental scenario. Of course, all this discussion that I am doing here assuming that we have a proper fusion reaction or fusion reactor; like in the sense fusion reactor if we have some issues and we want to shut down the reactor immediately that will become very very difficult to do. Because of course, we can use a control rods to completely 0 down the nuclear neutron flux.

So, there is no fission reaction, but there will be radioactive fission products and they will keep in keep on decaying; they will producing both energy and some further neutrons over a very very long period of time still there is even a single radioactive nucleus present inside the reactor.

We shall be having that problem of radioactivity that is something what happens in that Fukushima power station in Japan because there because of the power shortage or which was instigated by that tsunami which happens in 2011, there were no power to operate the main cooling water pump and as cooling water supply broke down there their control system also was not properly able to take care of this neutron flux.

But even if the control system at operated properly they would up have only eaten up all the prompt neutrons available inside the reactor and also the reactors which were already available of from earlier reactions. But the neutrons which will be freshly produced because of the radioactive decay of this fission flow fragments it is not possible to take care of that by any kind of control equipments.

So, stopping a fission reaction under emergency situation needs to be something very well planned. Of course, under the generation for initiative that is being done, but older reactors face this issue a lot. But in case of fusion reaction there is no such issue because the product that we are getting from the reactor or from the reaction is not at all radioactive in nature that is um more often than not there you will find a stable isotope.

And so, if we want to stop the reactor we can immediately do that also the quantity of fuel that is available inside the reactor is very very small compared to the mass that we can have inside the fission reactor. So, removing that a small quantity of fusion fuel is also not a very big headache therefore, fusion can definitely be much more advantageous from power generation point of view compared to fission.

But we have seen that the most common fuel that we can have for fusion is deuterium. Deuterium can participating 4 different kinds of fusion reaction two of them with deuterium itself; it can also part of that fusion reaction with tritium or helium 3 isotope. We have discussed in detail about the sources of deuterium and tritium; deuterium is naturally available in seawater or I should say heavy water is naturally available in seawater very small fraction which can be harnessed following quite a few technologies are there.

We have discussed about one of them which is capable of in enriching the water up to about 20 percent, but for further enrichment we need to apply some kind of specialized technique like distillation or advanced distillation. Those techniques of heavy water enrichment or water enrichments are generally quite secret.

And that is why we are not in a position to discuss even further on that, but the countries which are most involved in heavy water production generally are Canada and India. While Canada have nowadays stopped their most of the heavy water producing unitl India have if I am not wrong at the moment.

India is having 6 heavy water processing plant on number maybe 8 also because 2 of them were under maintenance; under maintenance or some late commissioning part in very recently. So, India is not only capable as most of the Indian thermal power stations have been told PSW also they are leaned heavy water for their for its own nuclear reactors.

And nowadays India also in a position to export reactor grid heavy water because they are capable of producing more heavy water then is required by their own plants. Tritium; however, is not available in nature tritium needs to be breed from either lithium or from other sources, but lithium is a most common one; lithium is abundant in the earth.

And therefore, generally every fusion reactor code is covered by a blanket of lithium that offers couple of advantages. One is that does not allow the neutrons to leak out of the fusion code thereby protecting from the proliferation of radioactive elements or neutrons and the secondly, the neutron which gets absorbed in the blanket when it strikes lithium 6 or lithium 7 depending upon its energy level, it can produce tritium.

Lithium 6 can be converted to tritium or can used to breed tritium by neutrons of energy; however, lithium 7 which is more abundant isotope that requires fast neutrons only; so, tritium can be produced from lithium. Then discussed our nucleosynthesis; nucleosynthesis refers to it chain like this where from the very light isotope or from the lightest possible isotope through progressive fusion reaction, we can produce much heavier isotope.

Actually it is extremely important because nucleosynthesis is the process by virtue of which the entire universe has been created. At the start of everything I do not want to go to the big bang theory or something like that, but it is sufficient to say that at the start of the start of this universe, we had only those elemental components like protons and neutrons and they were able to fuse it each other.

Like as you can see here 2 protons or 2 hydrogen nucleus can combine to produce a deuterium which can combine with another hydrogen to produce an helium. And then; once we have 2 helium, so, isotopes that can lead to the formation of one helium 4 and this chain can continue to produce successively heavier elements. And the most important one of them as we have discussed comes from that 3 alpha reaction which leads to a production of carbon 12.

And as a by product of there that oxygen 16 and generally carbon and oxygen are the two most important components for the development of life on earth. So, nuclear synthesis is an excellent example of fusion reaction or progressive fusion reaction.

And we ended our last lecture discussing about the coulomb barrier. Coulomb barrier talks about the illustratedic repulsive force that a deuterium and tritium faeces when they are able to or when they are above to collide with each other.

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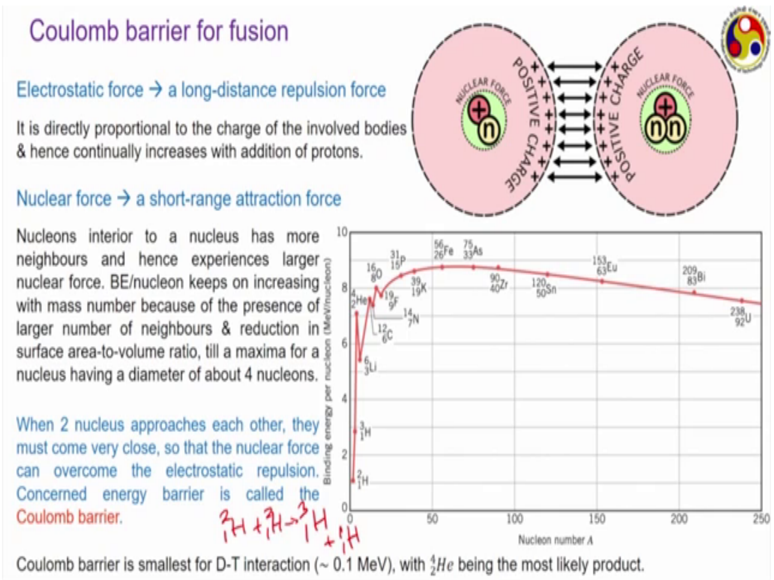

So, I am just repeating the same slide which I had the end of the last lecture. The proton or I should not say proton the deuterium and the tritium nucleus which are trying to collide with each other on interact to with each other that is primarily two forces one is the electrostatic force which is a long distance repulsive force and its magnitude is inversely proportional to the square of their distance.

So, the closer they become; the higher will be a magnitude of this force, the other is a nuclear force which is an attractive or attraction force, but is a very short range at one. The particles that is deuterium and tritium nucleus needs to be very close to each other to come under the action of this nuclear force. And the energy barrier that these two nuclei needs to overcome is something refer to as a coulomb barrier.

And while we have discussed about 4 different kinds of fusion reaction involving deuterium; the coulomb barrier corresponding to this particular one that is the D-T reaction or deuterium tritium reaction that is the smallest that is only 0.1 MeV and that is why this despite having two different kinds of D-D reaction; the D-T reaction is the most prominent one.

If you will remember those 4 reactions that I have mentioned in the last class ah; we can have two different kinds of D-D reaction in one case the product is a helium 3 and a proton. In other case the product is an helium 4 and the neutron; I am sure like if I write quickly 1 H 2 producing 2 H e 3 plus neutron.

So, helium 3 neutron can be one set of product and the other set of product can be ah; I was actually wrong the other set of product can be 1 H 3 plus proton.

So, there can be two kinds of D-D reaction in one case the product is tritium or other the product is helium 3 and both the cases we generally have quite low amount of energy production. And there can be another kind of fusion reaction involving deuterium which is between deuterium and helium 3 which produces energy larger than this D-T interaction.

But this one we are repeatedly discussing about or this is the most popular kind of fusion reaction because of two things. Firstly, the coulomb barrier corresponding this is very small or the smallest among the 4 which is just 0.1 MeV. In fact, it is the smallest possible coulomb barrier that we can have in any kind of a fusion reaction involvement.

In even for a D-D reaction the coulomb barrier is larger and the second advantage of this one is it also produces quite high amount of energy which is less than deuterium helium 3 reaction, but when we considered the corresponding coulomb barrier this is the best one to have.

And also helium 4 is the most likely product of such a fusion reaction because as the graph shows helium 4 is some kind of anomaly as the generally on this side as the mass number increases binding energy upon nucleon increases continuously apart from this helium 4. Because helium 4 is having higher binding energy for nucleon compared to the next atom or next nucleus is in the line which is lithium 6.

From quantum theory this can be this explain that all the 4 nucleus 2 protons and 2 neutrons which helium 4 comprises of and they can all remain at the ground state and therefore, that provides the highest binding energy point nuclear for this one among all the lighter nucleus. And as the product of this D-T reaction is also helium that is another reason for this to be the most likely kind of fusion reaction.

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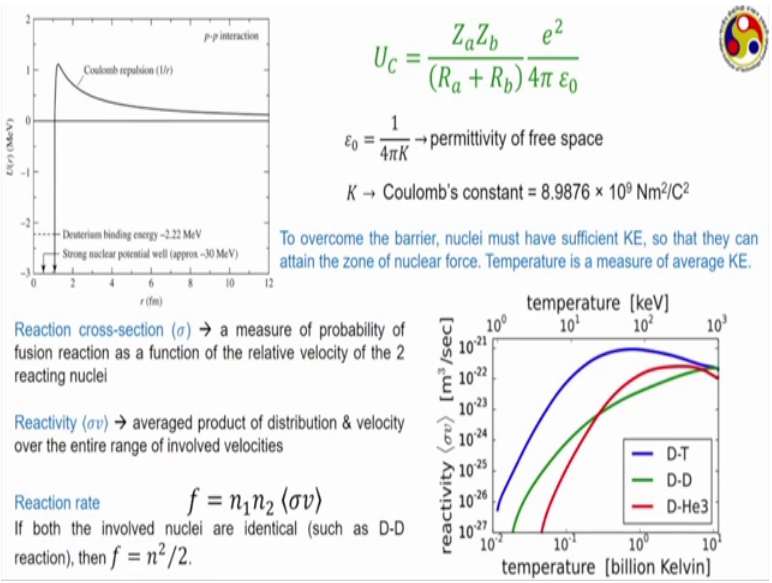

Now, this is the magnitude of that coulomb barrier that we can have that U C refers to the magnitude of coulomb barrier and this is a simple reaction that we get by applying the coulomb law of electrostatics. Here Z a and Z b refers to the atomic number of the two particles involved once you are talking about a D-T reaction both Z a and Z b are one.

Because both of them are actually hydrogen isotopes R a and R b refers to the radius of both the nucleus. In this particular theory, generally both of them are assumed to be to have or to look like a sphere of slightly varying radius.

And the radius you can go back to our earlier module; that is our module number 1; where we have given an empirical relationship between the radius of a nucleus and its mass number. So, generally assumed it to be sphere corresponding relation was you can be used to get this value of R a and R b; e is small e refers to electronic charge and epsilon is the permittivity of the free space which is one by 4 pi capital K

Here this K refers to the coulomb constant given by this value. So, epsilon 1 0 epsilon can also be calculated and this particular portion e square by 4 pi epsilon actually is a constant. And depending upon what kind of reactions we are talking about using parameters for a and b, you can calculate the value of U C the coulomb barrier.

Now this is a pictorical representation for a proton interaction. Here again both elements are same. So, Z a and Z b are one and R a and R b again both are same. So, that refers to the estimated or approximate radius of a typical proton, you can see coulomb repulsive force being inversely proportional to r r square as the radius decreases.

Or I should not say radius it is a centre to centre distance between the two proton decreases, this force continuously keeps on increasing till this particular instant. This is this is the instant where you can say that the nuclear force suddenly becomes dominant over the repulsive force or you can also say that the protons are now entered the domain of a nuclear force.

And hence you will find a rapid reduction in the value of this U which will allow successive proton interaction. Hence in order to overcome these barrier this coulomb barrier the nuclei must have sufficient amount of energy so, that it is able to reach this particular zone.

And once it is able to reach there then nuclear force will facilitate the fusion reaction, but the energy it needs to a sufficiently high amount of energy and energy means kinetic energy only. And as for such kind of particles temperature is a direct measure of the kinetic energy.

So, we can clearly say or we can explicitly say we can explicitly mention that both deuterium and tritium needs to have high temperature or they should both be in a temperature in an environment of high temperature. But high means what?

From in the very first slide of this particular lecture, this particular module or this not this lecture rather the previous lecture I have mentioned that in to facilitate fusion we have two or more nucleus coming together to get fused into a single nucleus, but both of them need very high energy that high energy term was there which is because of this coulomb barrier or in an afford refer to overcome the coulomb barrier.

Now we have to check this high energy and high temperature refers to what kind of magnitude um. But before that if you term in energies one is reaction cross section; reaction cross section is a measure of the probability of fusion reaction as a function of the relative velocity of two reacting nuclei. And reactivity generally for a given energy level both the nuclei can have a good distribution or a distribution from 0 to finite the distribution of velocity.

So, we often need to integrate it over the entire range of velocities and that is why we use this reactivity, it is the average product of distribution and velocity over the entire range of involved velocities. And if we plot that with temperature or with energy, we get a distribution like this. As the temperature keeps on increasing; reactivity keeps on increasing till it reaches some kind of maxima for this ah; please do not you can ignore the scale for this temperature for the moment.

Because we shall be developing this magnitude very shortly, but one thing you can check here that 3 kinds of reactions as I shown and for all the temperature or energy levels the D-T reaction shown by this blue line is exhibiting a much higher reactivity compared to the other two and in this scale it is a logarithmic scale.

And that is why say if we talk about a this particular; if we talk about a level like this you can clearly say here whether the activity is only about that figure is minus 25 for D-D reaction it is at least two orders higher for a D-T reaction.

And the reaction rate is given is n 1 into n 2 the reactivity where n 1 and n 2 refers to the nuclei density for both involved particles; which generally is deuterium and tritium. If both involve particles are identical like in this of D-D reaction then we can also write this as just as n square by 2 because here we are talking about the same particle and we do not need to go for any kind of averaging between distribution and velocity.

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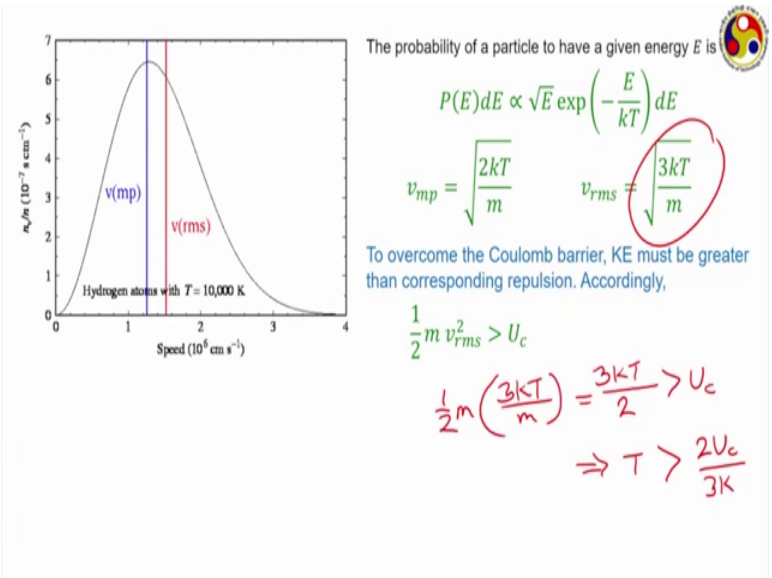

Now for a given energy level again the particle can have void kind of distribution like shown here which can often be represented like this. And this is a P E refers to the distribution of energy and from here we can also get the distribution the maximum distribution of velocity of the particle or the most probable velocity of the particle and the rms velocity of the particle.

This is the most probable velocity and this is the rms velocity and these two expressions are quite standard from a kinetic theory of gases. Here small k refers to the Boltzmann constant capital T is the absolute temperature and m is the mass of that concerned particle and this expression this distribution of energy is given by the Boltzmann distribution.

I am not going to the details of this because these are all standard in kinetic theory. Now to overcome the coulomb barrier kinetic energy should be greater than the corresponding repulsion and accordingly we can write that the kinetic energy of particles which is half into m into vrms square should be greater than the U C that we have.

So, rms velocity is this one; so, we can clearly write this the kinetic energy at least half m into 3 k T by m which should be m cancels out.

So, it is 3 k T by 2 this should be greater than this U C from there we can say that the temperature should be greater than 2 of the U C divided by 3 k and U C it was given in the previous slide once we are talking about deuterium and tritium.

We can put Z a and Z b equal to 1 and we can use suitable values of R a and R b corresponding to deuterium and tritium k is Boltzmann constant. So, putting there we give some idea about the value of the temperature which may be involved or which we have to provide in order to overcome the coulomb barrier and do not be surprised with this number.

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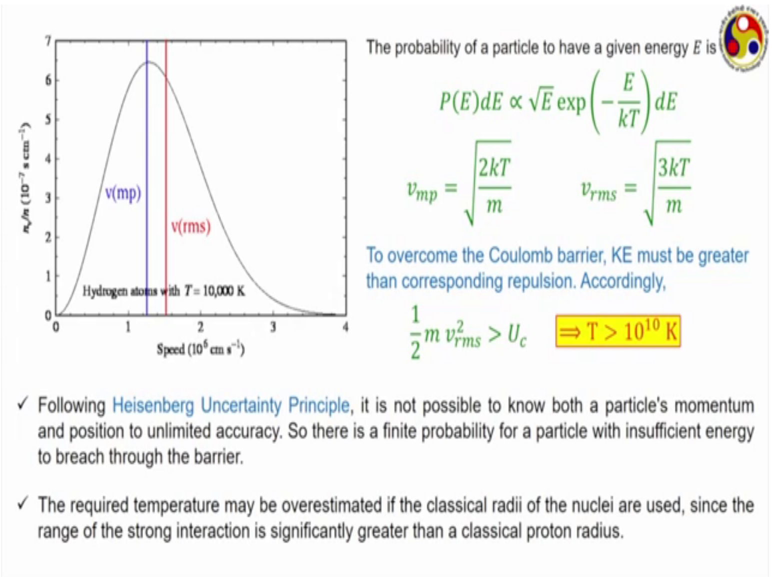

This temperature comes to be something greater than 10 to the power 10 Kelvin we are talking about a temperature of the order of 10 billion Kelvin's just to facilitate the interruption of 1 deuterium and 1 tritium isotope. And that is where the challenge lies with fusion; from the very beginning only I am repeatedly saying that if we at all can control the fusion reaction then it will be very advantages and the control issue is here.

Achieving this temperature is near impossible as per the present day technology, but everything is not that grim let us proceed further there are couple of factors which says that the value of temperature that we are getting this may be over prediction. Because one factor comes from the Heisenberg's uncertainty principle.

It says that as all of you know from the school level physics that the particles momentum and position both cannot be predicted together with certainty. So, there is always a finite possibility that once a energy level is given the particles position can be anything and hence even with an insufficient energy the particle may can breach through the barrier and reach the other side to have the injection.

And another probability which is more mathematical the values of this radius that we are using those are more empirical in nature which are obtained from classical mechanics, but in practical point of view this radius value or this radial value may not be correct.

Because, the zone of this strong interaction can practically be much larger than what we get in theory. The effect of these two factors are factors is a reduction in the required temperature level. Temperature of the order of 10 to power of 10 Kelvin we are getting considering a very simple kind of mathematical framework, but t his Heisenberg's uncertainty principle and also this possible over prediction in the radius value of this radius values of the nuclei the correct value of temperature may actually will lower.

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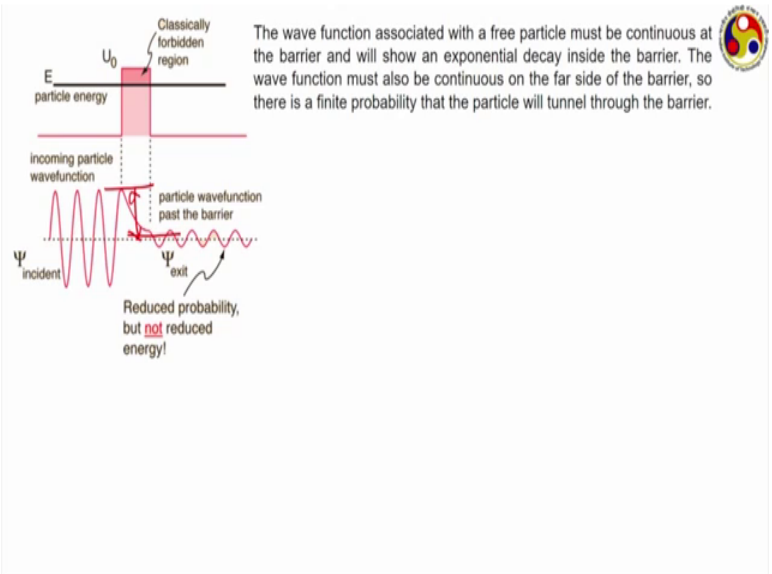

Without going into the detail of the kinetic sorry the quantum mechanics we can say that the wave function associated with the free particle must be continuous at the barrier and that we will show an exponential decay; once it passes through the barrier.

The wave function must also be continuous on the far side of the barrier. So, we are saying that as the particle is passing through; it is having a high wave function is the amplitude of that and on the it is continuous on the other side of the barrier it is also continuous, but there will be an exponential decay in between.

That is the amplitude of the particle oscillation that will decrease inside the barrier and the magnitude that can be something like this. So, there is a finite probability that despite having insufficient energy level, the particle will tunnelled through the barrier. This is sometimes called tunneling which refers to this reduction in the wave in a function of the particle where this is passing through that coulomb barrier.

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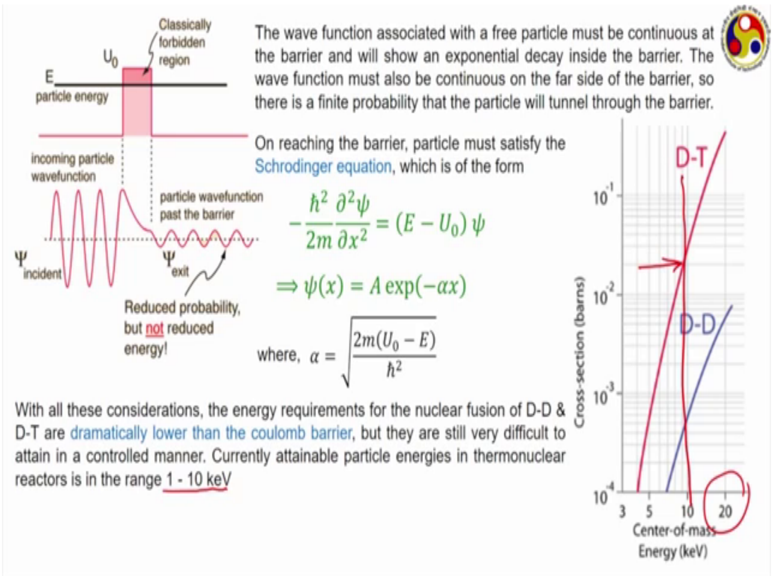

On reaching the barrier particle must satisfy the Schrodinger equation which is of this particular form here h bar refers to Plung constant divided by 2 pi or you can say 2 pi into that is that number is a Plung constant h bar is Plung constant divided by 2 pi a Plung constant is 2 pi h bar m is the mass again e is the energy level and U naught is that same coulomb barrier that we are using.

You could have represent this one with U also and psi is the corresponding potential. So, this a quite as others are constant like h bar is a constant m is a constant and U and U naught is also a constant for a given interaction and if we fix up the e then it is a very simple solution, where this alpha is having this particular form.

With all this consideration that is those which are shown in the previous slide and also whatever solution you are getting from this Schrodinger equation; the outcome of that the energy requirement for nuclear fusion for both deuterium and deuterium tritium collisions can be dramatically lower or drastically lower than the coulomb barrier.

That is; if we calculate the energy like we have done in the previous slide we have just calculated or try to do a balance between the kinetic energy and the coulomb barrier. Or we have considered that the kinetic energy has to be greater than the coulomb barrier and accordingly got a velocity level and hence the temperature level.

But because of this tunneling kind of actions and also possible wrong or possible wrong prediction of the radius of the particles we can actually see that practical value of temperature requirement may not be that much of may not be that much of or may not be that high maybe slightly lower than that astonishing figure that we have got in the previous slide. And that is applicable for any kind of fusion interaction like DD or D-T reactions.

But still the numbers that we may get that will be quite substantial presently the particle energies that we can get in case of thermo nuclear reactors is in a range of 1 to 10 keV. And this is a figure that we can see in the centre of mass frame of reference; if we calculate the energy the cross session in that particular what we can achieve at the moment that is 1 to 10 keV refers to something in this level of this.

And in the corresponding cross session is still quite significant of course, there is still improvement like if we can go up to something like 20 keV, we can get even larger cross section also a larger reaction rate, but at least for D-T reaction this is still quite significant.

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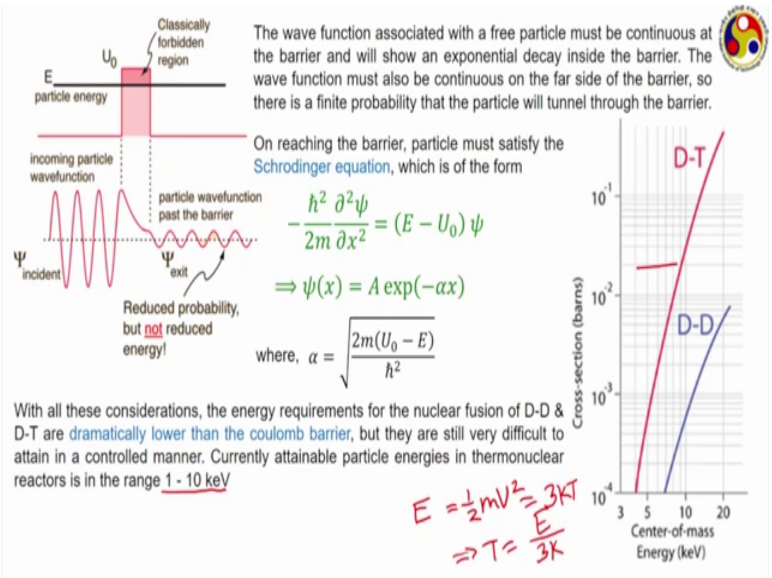

But 1 to 10 keV is also not a matter of joke how to calculate the corresponding temperature? We know that the particle energy can be directly related to the kinetic theory that is kinetic energy that is half I should not put this n here half m into V square should be equal to 3 k T.

From there we can or we can calculate the temperature just as by 3 k and putting the numbers into the corresponding formula and also associated things.

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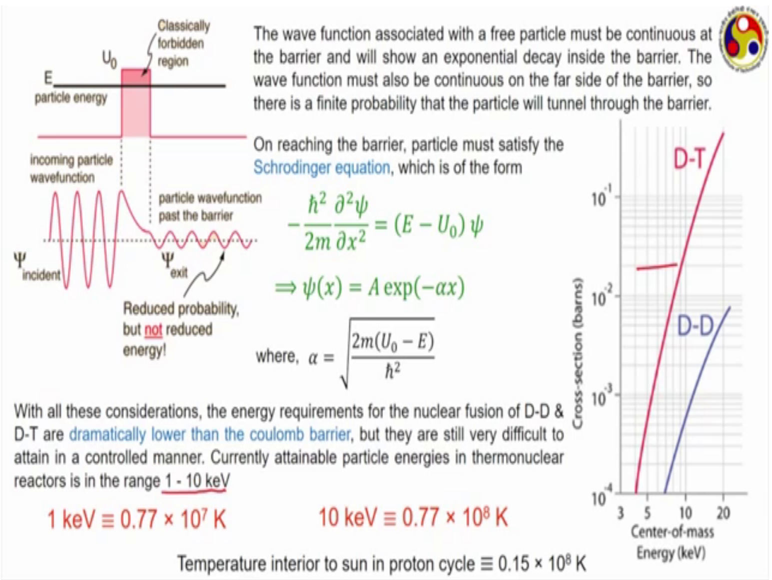

We get 1 keV to correspond to something like 0.77 into 10 to the power 7 Kelvin which is still more than 1 million Kelvin means you are talking about 7.7 million in temperature and 10 keV even one order higher 0.77 it is 10 to the power 8 Kelvin or 77 million Kelvin. Just to put that in the perspective the temperature in the interior of the sun is something like 0.15 into 10 to the power 8 Kelvin.

So, that is just something like 4 to 5 keV talking about. So, we are in order to facilitate despite all these corrections and advantages that we are getting because of the tunnelling effect etcetera; still the temperature range requirement that we are talking about that is extremely high and that can be higher than the temperature that we may have inside the sun even to get a 10 keV of energy level.

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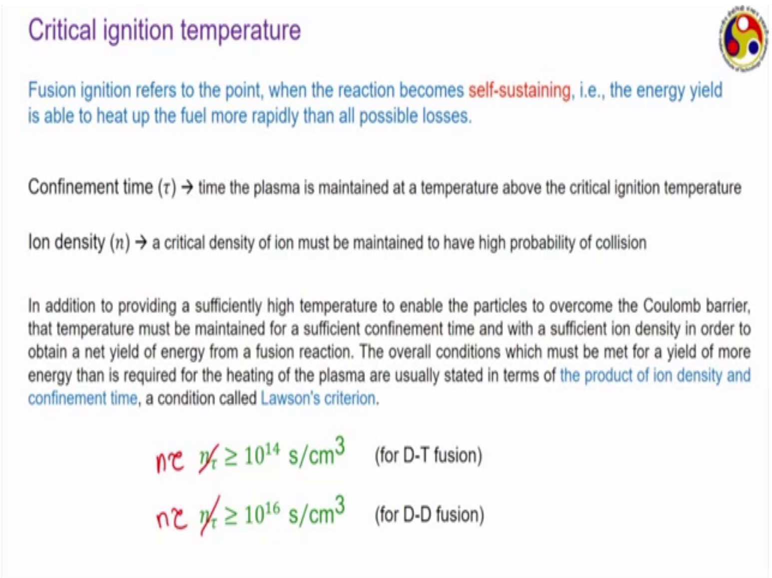

So, the temperature requirement is the biggest issue that we can have in order to facilitate the fusion reaction. We somehow have to produce that level of temperature and another issue is that whenever we reach that level of temperature all material turns to plasma.

So, handling the plasma is another very big issue ah, but temperature alone is a not the only one rather that is something called the critical ignition temperature which refers to fusion ignition which refers to the ignition the temperature requirement of the point where the reaction becomes self sustaining. That is we somehow have to initiate the reaction once and also provide some desired level of conditions.

But once the reaction starts, the amount of energy that will be coming out of the reaction that should be sufficient to continue the reaction itself; it is something like the that chain reaction. Means to initiate the fusion process we have to strike an uranium 235 isotope with a neutron, but once the fission happens then it will emit a fu neutrons.

And if you can provide proper condition then at least one of those neutrons will be able to induce fission for another U 235 that we are sustaining a chain. The same applies here the if we can provide the conditions properly then we can reach a condition where the energy yield from the fusion is sufficient to sustain the reaction and hence no further external energy source will be required.

But temperature satisfactory in the temperature alone is not sufficient rather we have to consider a few other factors also you know. So, that we can overcome all possible losses one is the confinement time the plasma must be maintained at that temperature above the critical ignition temperature.

For a certain period of time then only it can reach that self sustaining period if we are able to achieve this critical temperature only for a very short instance just for a pulse then it may not be sufficient to have a self sustaining thing other is the ion density a critical density of ion must also be maintained to have this high probability of collision.

So temperature confinement time and this ion density all together leads to this condition of critical ignition temperature or self sustainment. In order to provide a sufficiently high temperature to enable the particles to overcome the coulomb barrier therefore, we have to provide a high temperature a sufficient confinement time and also a sufficient ion density.

So, that we have a net yield of energy from the fusion reaction a part of that is sufficient to continue the reaction and rest can be utilized for the downstream application purposes. And that condition generally is given by a product of ion density and the confinement time condition often referred as a Lawson’s criteria.

And this is the condition for a D-T fusion the product actually this should not be written like this; should be n into tau the n into tau this product should be at least 10 to the power 4 second per centimetre cube and for D-D reaction again it is just n into tau ah; it should be greater than 10 to the power 16 s power centimetre cube.

So, this Lawson's criteria is something which we have to provide that is we must provide sufficient iron density and also we must provide sufficient amount of confinement time. So, that the ions are exposed to a sufficiently high temperature over a long period of time. And hence it reaches a situation where the energy in this sufficient to self sustained the reaction.

So, a critical initial temperature it is quite it is just analogous to the critical temperature that we the sorry; it is quite analogous to the criticality condition that we get in case of fusion reaction.

There we must ensure the criticality that is the reactivity should be equal to 0 or multiplication factor should be equal to 1. So, that we can sustain chain reaction just same here this, but here condition is given in terms of this product of n and tau and also in terms of temperature.

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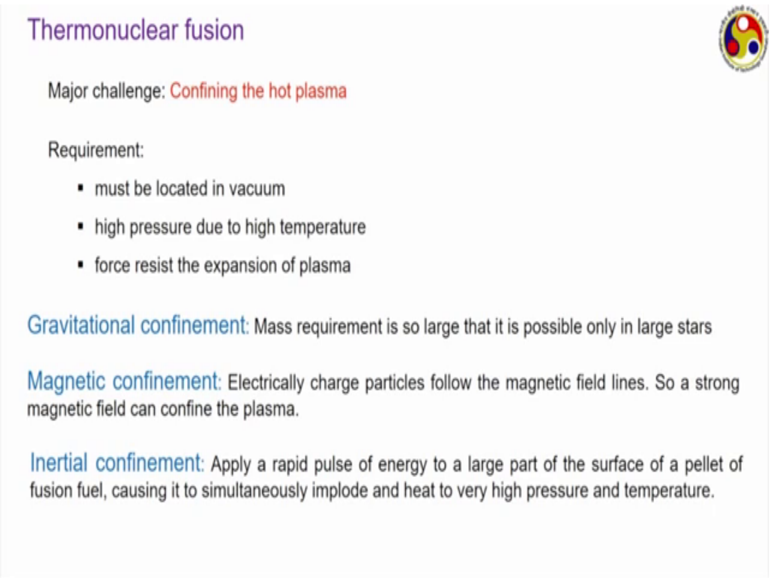

Finally, we come to thermonuclear fusion actually there are quite a few ways that the fusion has been conceptualized, but I repeat at the moment there is no commercial fusion reaction reactor which we can depend on rather there are quite a few research reactors which are giving newer inputs about the fusion reaction and the possibility of having fusion as a commercial source of operation.

May be we are going to have commercial fusion reaction in near future, but at the moment we are depending mostly on the research reactors. And also I could have putting lots of more data at this point data from quite a few research reactors or whatever research outcomes that we have, but this being more a fundamental course.

So, I thought about this giving an introduction to the thermonuclear fusion the thermonuclear fusion reactors. And if you are interested about the topic you can explore further. So, the biggest challenge in a thermonuclear fusion is confining the hot plasma once you can attain that critical ignition period, we know that the fusion reaction is possible. But before we can reach that level all the particles because of that high temperature that reaches the plasma level and handling hot plasma is extremely difficult.

So the requirements; firstly, the plasma should not come in contact with any kind of walls; so, it must be located in a vacuum. Secondly, as the temperature is high pressure also will be high. So, we have to handle extreme conditions of high pressure and high temperature and also the plasma because of this energy interaction we will try to expand.

And therefore, we must provide some kind of force to release this expansion that force can be of different kinds, it can be gravitational force, it can be magnetic force or it can be an inertial force. And accordingly we can have different kinds of confinement structures. Gravitational confinement that is the amount of mass that is required to have a gravitational confinement is not possible at the earth rather it is possible only at very large stars.

The thermal nuclear fusion is generally the mechanism that stars are stars go through means at the initial level of their birth; they had only hydrogen isotope or only proton.

And because of the nucleosynthesis they are continuously going on forming heavier isotopes like from proton to deuterium from deuterium to helium to even heavier things like lithium or carbon or oxygen and some of the stars are even reached very high mass number level something in the range of irons and as you know iron and nickel are the isotopes which are having the highest level of binding energy per nucleon.

So, they gets stabled as more or less there which actually also leads to a loss of the energy that the stars are able to emit. And hence in a way that indicates the starting of the depth of those stars, but coming back to this point gravitational confinement is more relevant to those stars, but not for not for technical point of view; what we commonly find is a magnetic confinement.

Electrically charged particles follow magnetic field lines; so, a strong magnetic field is provided to confine the plasma here I have strong refers to extremely strong. Actually the problem of handling a plasma or the issue of handling a plasma leads to all possible extreme conditions.

Extremely high temperature, extremely high pressure and also extremely high magnetic field all these three together leads to a real tough technical problem which we hope will be solved in near future. And the final one is the inertial confinement it apply a rapid pulse of energy to a large part of the surface of a pellet of the fusion fuel causing it to simultaneously implode and heat to a very high pressure and temperature levels.

This is something that researchers have started to work on and may get may show a proper good demonstration in near future and may give and or if it is at a level to give a good demonstration then it can also be thought as a future option. But presently all these are still under research ah; the knowledge base is still quite limited while we know completely about how fusion happens, what are the things that we need to control fusion, but we are yet to reach that level of technical advancement so, that we can actually control that reaction.

And also the fusion reaction like fission reaction can be controlled or uncontrolled it is again quite similar to that critical subcritical or supercritical like we in case of fission reaction. A controlled reaction is where the rate of reaction can be controlled to a fixed level, but an uncontrolled one is where the rate of reaction keeps on increasing rapidly. And I had to utter the term, but the example of an uncontrolled reaction is a hydrogen bomb that is an example of a fusion reaction, but an uncontrolled one. So, that takes us towards the end of this particular module.

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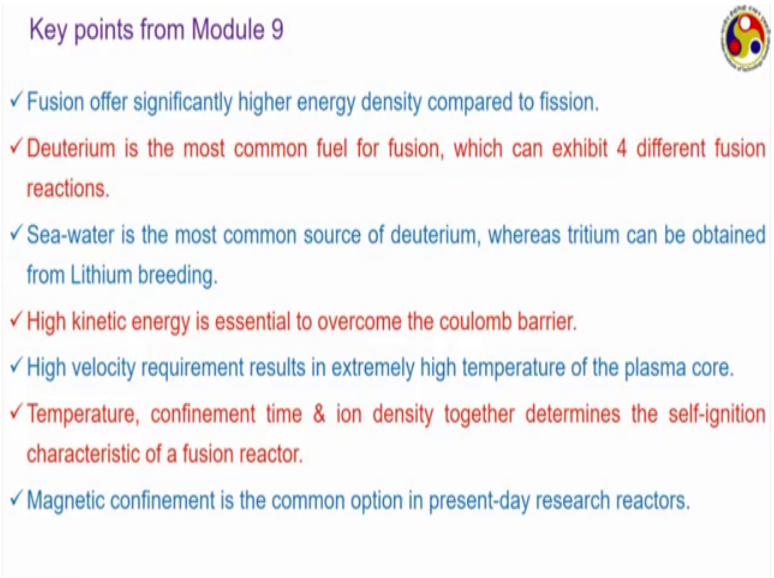

Again I repeat I am not added any technical data or and any information or analysis which is too tough this is a primary level course and so, I am keeping information only to the basic concepts.

But to summarize the topics that we have discussed we have seen that fusion offers significantly higher energy density compared to fission and deuterium is the most common fuel which can go through 4 different kinds of fusion reactions. The D-T reaction on deuterium tritium reaction is the most preferred one because it shows a small coulomb barrier and also it gives a reasonably high amount of energy. Sea water is the most common source of heavy water whereas, tritium can be obtained from a lithium breeding and that in order to overcome the coulomb barrier very high kinetic energy is required which essentializes extremely high temperature level.

And because of the temperature level all the material gets converted to plasma making it very very difficult to handle that. Temperature, confinement time and iron density together determines the self ignition characteristic of a fusion reactor. And finally, very briefly we have mentioned the magnetic confinement is the common option in present day research reactors.

So, that takes us to the end of our module number 9; I would wait for your questions if you have any queries please keep on writing to me I will try my best to answer to you.

So, I am signing off from module number 9 in the next week we are shall be discussing about the effect of radioactivity on biological substances.

Thank you.