Non-conventional Energy Resources
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Lecture – 29
Battery Basics

Hello. In this class we are going to look at batteries basically, they are devices that are very ubiquitous they are all over the place, and at any given point in time you know all of us seem to be using batteries.

So, in this class we will look at some of the basic concepts associated with batteries, the signs of the batteries and how it functions and so on. In fact, I don't know if you realize that, but in any given you know social setting, that you may be in chances are there are more batteries than there are people, you will typically find this to be true. Because, at any point in time most of us seem to be carrying our mobile phone with us, we also typically have a wristwatch of some kind that we are wearing. So, right there, there are two batteries. So, already you know if you see 10 people there are 20 batteries there.

So, that's the extent to which this technology is now you know common place in our life; we don't even realize it, we don't realize that we are carrying batteries in on top of it if you have a laptop or a computer that has a battery, and if you have a calculator your calculate scientific calculator whatever you are carrying has a battery. So, all lots of things have batteries which we don't even realize that, it is having a battery and over and above this we carry you know a power bank or something to extend the range of our mobile phones. So, that's only a battery more or less.

So, this kind of situation exists. So, therefore, it is a technology that is interesting to look at. In the context of non conventional sources of energy, batteries play a very critical role very important role, because a lot of those technologies you know we spoke about solar energy, we spoke about wind energy, we spoke a lot of detail about how those technologies function. But, one common aspect with all of those technologies is that they don't produce power in a consistent way throughout the day and throughout the year.

So, there is significant impact of the time of the day on the you know power being produced, the conditions at the time of day determining the power being produced. If it is solar technology, it could be just you know a passing cloud could make a difference rain could make a difference or you know completely cloudy day could make a difference and of course, there is a big huge difference between day and night so that difference is there.

If it is wind technology again you know you may have a gust of wind, you may have steady wind flowing, you may have fast wind going, so again as the day progresses you may have different conditions for power generation. And then also there are seasonal variations. So, all of these impact those two major technologies that are being pursued and actively around the world.

So, you also always need to have some energy storage process or you know technology to go along with these non conventional sources of energy, to really utilize that non conventional source of energy. And that is the context in which we will study let's say batteries and later we will look at fuel cells. Both of these are when they don't; I mean fuel cell is not storing energy, but they give you the flexibility of you know distributing the power that you generate across the day.

So, you generate power. So, you may at times be generating more power than you need. So, you need a way in which you can, but your utility. So, your utility pattern has a different profile, it doesn't necessarily match with the profile of the power that you are generating.

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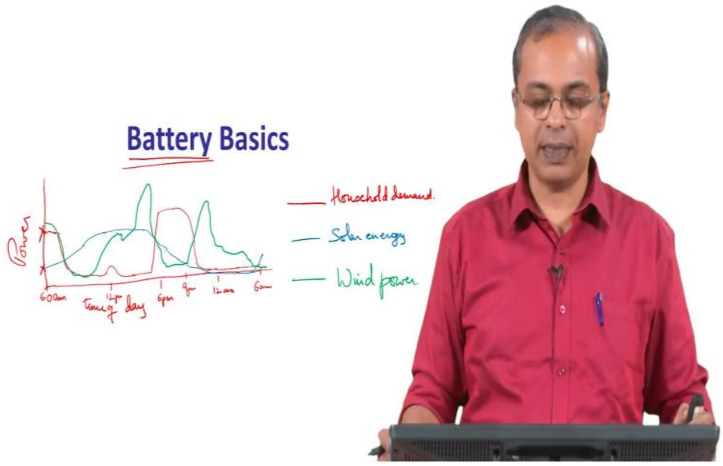

So, for example, let’s say if if I mark time of the day right and this is say power and let’s say how are we utilizing it. So, let me say this is 6 am ok. So, this is 12 noon this is 6 pm. So, this is 12 pm and this is a little further down am. So, if you do this you will find that usually in most houses if they are you know let’s assume that on average everybody is up around 6 o clock. So, your power you say this kind of high.

So, this stays high because a lot of things are on, you know your kitchen is on, you are a fan is on maybe grinder is on may things might be on. So, this is kind of high everybody is getting ready to go to school or office and then everybody leaves for school office whatever and then suddenly there is a huge drop in power consumption.

So, it will stay low kind of stay low maybe at lunchtime it goes up a little bit then stays low then comes back, then again sometime in the evening everybody comes home. So, everybody comes home and then you are back you know you are entertaining yourself watching TV or you know cooking something else heating some food up a lot of things you do so, your power consumption goes up and then stays up. So, let’s say this is about. So, this is around here. So, half your mark would be 9 pm.

So, little past 9 pm again everybody goes off to bed and then it power decreases. So, you just have some basic fan running and then it stays low and that is how you get 12 12 am, and then if you continue this till 6 am which is the 24 hour mark. So, it will sort of stay low relatively speaking some basic thing will be going on maybe a few fans may be running etcetera all your lights will be off now even if you were running AC, you won’t be running it in several rooms you will be done anything, but.

So, so you can see this is the profile of power requirement as the day progresses in most households this is kind of likely to be the case and 6 am again as I said this is start climbing back up to where you saw out here right. So, this is what you have now if you look at the power generation ok. So, let’s say it is solar panel. So, if it is solar panel, then you will have some fairly let’s say from 6 am the power goes up then by 12 pm I am just drawing some schematic.

So, let’s say this is this is how the power stays and then this continues of you have bright sunlight till about 6 pm then it starts dropping in intensity by 9 pm you have nothing and then it drops to 0 and then stays 0 then by 6 am it starts climbing back up when the sunlight starts coming ok.

So, they are not very accurately done. So, this is solar energy and this is your household demand; and let’s say this is wind power. So, wind power it even doesn’t even have a particular pattern I mean through the day and through the night you may have all sorts of you know variation and power. So, just to give you some I mean I am just drawing a schematic which has no you know no basis, I am just except that to show you that it is kind of random.

So, you may have actually fairly good wind power being generated and then it might just drop down and then it may just go up and will go up even higher it might do this. So, some random thing it might do and then it will do something like that. So so, there is no you cannot very accurately predict what wind power is going to do. So, this is how the wind power is going.

So, you can clearly see that if you look at what your house ultimately let’s say you are only powering your house right. So, let’s say you have set up a small plant either a windmill or a solar panel plant, which powers your house and say neighboring some 4 or 5 houses are being powered by this. So, the demand for the house is essentially whatever is the red curve that you see here. And clearly the red curve does not match either the green curve or the blue curve.

So, it just totally does not match I mean there is no comparison they are totally off. So, therefore, you need something to balance this out right. So, when you need power if you are just directly connected to it, then you need power at 6 am the solar energy is just barely started producing power you are asking like three times the power. So, you are this is what it is generating this is what you are asking. So, solar energy is not going to do it for you.

So, at some other point in time it is delivering much much higher power and you are demanding much lower power. So, then what is it going to do with that excess power; so all that is getting wasted. So, therefore, you need something in the middle that you know keeps collecting up this energy that is being generated, and then makes it available to you when you need it based on your usage pattern so that you don’t feel any difference. In the house you are just going to come and switch on lights and switch on fans and tube lights and do not know led lights watch your TV etcetera.

You don't want that to be disrupted based on what the solar panel is seeing out there right. So, that therefore, it is in this context that the batteries make a big difference. So, an energy storage device like a battery makes a huge difference because it helps you manage the supply variation with the demand variation it evens it out for you ok. So, that is why we are and batteries and we will look today at the basic ideas associated with how batteries function, what are the important parts etcetera.

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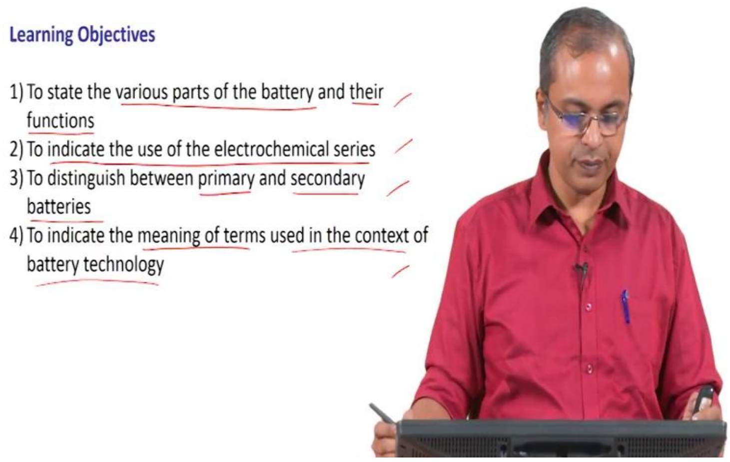

So, our learning objectives for this class are to state the various parts of the battery and their functions. So, to look at that what are the parts of the battery critical important parts of the battery and what are the functions, to indicate the use of the electrochemical series. So, what is that electrochemical series I am sure you have heard about it? So, as a part of our you know complete package of the understanding of batteries, we will briefly visit this electrochemical series and at least highlight the important aspects associated with it and to distinguish between primary batteries and secondary batteries.

So, these are two kinds of batteries that are commonly there and we will distinguish between them. And also in the context of this discussion we also look at the meaning of some terms used in the context of battery technology. In fact, in the few classes that we will deal with this technology, some more terms should be there I am not introducing all the terms here because I don't want them to be known completely in isolation, when you listen to the term in the context of its usage you will better understand what it is that we are referring to.

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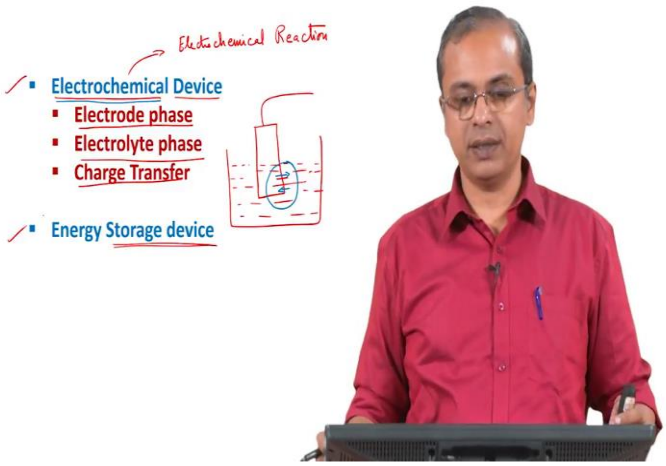

So, these are our learning objectives parts and functions of the battery use of the electrochemical series distinguishing between primary and secondary batteries and some of the terms that are used in this context. So, this is what we are going to look at. So, what is a battery? A battery first of all is an electrochemical device it's an electrochemical device. So, what do we mean by an electrochemical device? So, an electrochemical device of course, I mean a very I mean suggests as suggested by the name supports an electrochemical reaction.

So, it supports an electrochemical reaction. So, for that the parts and whatever the process that is involved is that there is something called an electrode phase, there is an electrolyte phase. So, there are two things in the electrode in the electrochemical device or in a battery one is referred to as the electrode and the other is called the electrolyte and the phase simply refers to the fact that, it is an and you know physically distinct, mechanically separable, chemically homogeneous part of the system. So, that is basically what we are looking at and across that I mean it is a region in that system where the properties are uniformly constant.

So, so if you take a piece of metal that would be a phase, inside that also you may have multiple phases, but generally let's say we have got a pure metal billet we have not got w are not got an alloy we have got a pure metal then you have a and it is all in one crystal structure then it is one phase.

Then you have a liquid that is another phase you can take another piece of metal that's a different phase. So, that is how you would look at it. So, there is an electrode phase normally we think of it as a solid, and there is an electrolyte phase normally we think of it as liquid, but these can change, but this is the normal you know perception that we have. And importantly the reaction should occur in a manner that there is a transfer of charge between the electrode phase and the electrolyte phase. So, when that happens, so let me say that this is an electrode and it is sitting in contact with an electrolyte ok.

So, and then it goes off to some external circuit some wire is that let's say. So, now, when this electrode is in contact with this electrolyte, you should have a transfer of charge. So, let me just change the color here. So, you should have a transfer of charge this way or this way, some charge should come from the electrolyte to the electrode or from the electrode to the electrolyte some one of the two should happen.

If you if you have this happening as part of the reaction, then this transfer of charge between the electrode phase and the electrolyte phase is what creates this situation that this reaction gets referred to as the as the as an electrochemical reaction. So, an electrochemical reaction and that that is a transfer of charge between the electrode phase and the electrode electrolyte phase. So,. So, that's the point and the battery device itself that we use is an energy storage device.

So, I will highlight this aspect a little more a couple of slides down the through this class little later in this class, but that's just something that you need to keep in mind. So, a battery is an electrochemical device, and it also happens to be an electrochemical storage device. So, these are two characteristics of a battery that it is a electrochemical device. So, that is there are the reactions occurring there are of electrochemical reactions and it happens to be an energy storage device.

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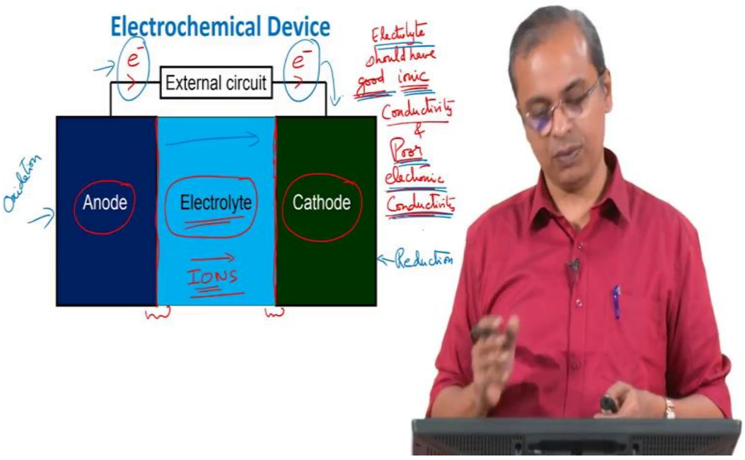

So, what are the major parts? As I mentioned there should be an electrode and an electrolyte, but for the battery to be complete you actually need two electrodes and an electrolyte ok. So, one electrode we refer to as the anode, and the other electrode we refer to as the cathode and in the middle there is the electrolyte.

So that is what we have. So, the electrochemical reaction, there are actually two electrochemical reactions that are happening, there is one reaction that is happening in this region between the anode and the electrolyte, there is another electrochemical reaction that is happening between the cathode and the electrolyte.

So, in each interface the cathode electrolyte interface which is this region here this border between these two. So, this region here in this border as well as in this border, let’s assume these are electrodes are plain electrodes, flat electrodes, flat metallics electrodes or whatever. So, in these two borders there is a reaction that is occurring. So, there is an electrochemical reaction that is occurring between the cathode and the electrolyte, there is a different electrode electrochemical reaction that is happening between the anode and the electrolyte and these two reactions are allowed to interact with each other using two different pathways.

One is the electrolyte that is one pathway, and the other is the external circuit that is the other pathway okay. So, that is the other pathway. So, the external circuit could be anything, I mean you could you could have you know maybe you have a bulb there or a fan there or whatever or you just have some measuring device that measures what is going on, but basically this is what is. So, there are two pathways through which these two reactions are interacting with each other, one is the external circuit one is the electrolyte. And the way the system works is that through the electrolytes there is movement of ions okay movement of ions. So, ions are moving through the electrolyte, and in the external circuit you have movement of electrons.

So, that is what we have at the external circuit there are electrons moving in the electrolyte there is ions moving. And so, if you look in terms of property what property is being expected of these various parts especially with respect to the electrolyte. The major property that is required is that the ions should be able to move quickly ok.

So, the electrolyte should have good ionic conductivity and that simply implies that the ions can move quickly from one side to the other side, whichever side they are moving they may be moving from cathode to anode or anode to cathode depending on the reaction, but whichever way they are moving they should be able to move quickly. If they move slowly that is slowing down the overall reaction and that impacts the current coming out of this reaction ok. So, this has to have good ionic connectivity. Importantly it should have poor electronic conductivity.

So, you should have good ionic conductivity and poor electronic conductivity why should it have poor electronic conductivity? This is only for the electrolyte that I am talking about. So, this is for the electrolyte ok. So, for the electrolyte it should have a good ionic conductivity and poor electronic conductivity. So, why should it have poor electronic conductivity? It needs to have poor electronic conductivity because we don't we want these electrons to go through the external circuit only then it does some work for you right. So, if you have a bulb which is sitting in the external circuit, that bulb is select up that led or whatever that you have put an external circuit is say lit up only of electrons pass through it.

Now, if you on the other hand if you gave some you know some internal path for the electrons to pass, then the electrons will not come to the led they will actually go in within the cell itself and that is a waste of the reaction. So, this reaction on the anode and the reaction the cathode are generating these electrons, these electrons you want in the external circuit only then something happens and so, if you accidentally provide an internal path for the electrons to go, then you have lost those electrons or if you know 10 20 percent of the electrons go that way or 50 percent of the electrons go that way half the current that you have generated has been wasted.

And therefore, the electrolyte should have this twin property of having good ionic conductivity, and poor electronic conductivity this combination is very important. It should actually be an from the perspective of electron movement it should be an insulator, it should not be a conductor of electrons ok. So, that forces the electrons to go through the external circuit and that is how we end up using the battery.

So, that is the idea here.

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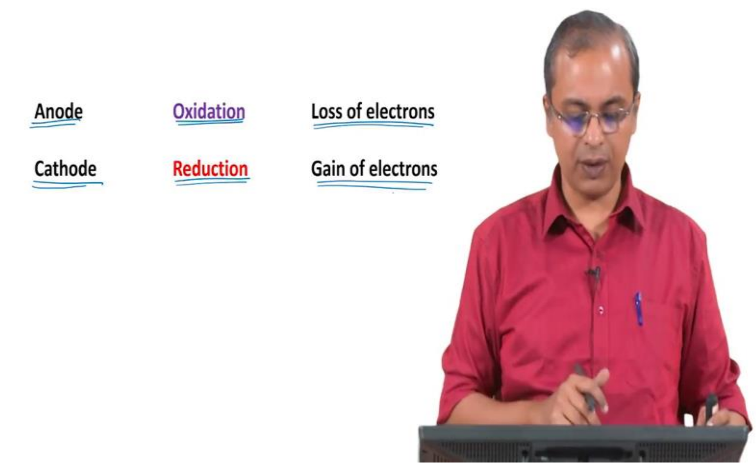

Now, we mentioned these terms anode and cathode and as I said you know maybe many of this at different differing level is levels of detail, you may have even seen it in high school days and some part of your college days I would still like to highlight some specific points associated with it because I think often people have confusion on these points and therefore, I will highlight some points and then that makes our discussion more complete and cogent. So, we will do that.

So, we use these terms anode and cathode. Now lot of people then associate it with you know some something like you know negative electrode, positive electrode they get lot of these terms are used and sometimes it is confusing. Now the way you should you need to understand it is that, there is only one strong definition of what is an anode and what is a cathode and then once you understand that definition everything else is related to that definition.

So, the definition is that anode is the electrode, where oxidation is occurring ok. So, anode is the electrode where oxidation is occurring and oxidation means loss of electrons anode is the electrode where oxidation is occurring if oxidation occurs there is a loss of electrons. Cathode is the electrode where the opposite is happening which is reduction and reduction means gain of electrons. So, what is gaining electrons? Some species is gaining electrons some species is gaining electrons, what is losing electrons? Some other species is losing electrons ok.

So, that is the way you have to think about it; so anode oxidation, cathode reduction that is really the main definition. So, you can look at any electrochemical circuit, and try to understand where oxidation is happening where reduction is happening. Wherever oxidation is happening that is the anode wherever reduction is happening that is the cathode. You can even have electrochemical cells, where on the same metal one region of the metal is undergoing oxidation; another region of the same metal is undergoing reduction.

So, that location where the anode oxidation is happening, that location is called the anode the other location where reduction is happening is called the cathode. And so, you may even have like 10 such locations; you may have 10 locations where reduction is happening 10 other locations where or say 7 locations where oxidation is happening, but at a higher rate than those seven locations are anodes these 10 locations are cathodes. So, that’s the way you should remember it. So, now, if you look at this definition anode oxidation loss of electrons and you go back to this figure. So, at the anode we have oxidation occurring at this anode and then there is a loss of electrons. So, what is happening? Those electrons are the ones that are coming out into your external circuit.

So, whatever material is there in the anode is undergoing that oxidation, and because of that oxidation electrons have been released and they are not in a position to go through the electrolyte because the electrolyte does not have electronic conductivity, and they are forced to go through the external circuit. So, that is why in in when you are using the battery, when you are actually using the battery the location from which the electrons are coming out is a anode ok. And as you continue using the battery the cathode is the place where reduction is happening there. There's a gain of electrons; the only place where it can gain electrons from is the external circuit because that is where the electrons are coming. So, that is how these electrons are going in here. So, reduction is happening here and this is where oxidation is happening ok.

So, oxidation is happening at the anode, reduction is happening at the cathode. So, now, we understand a terminology. So, anytime you are confused you try to figure out where the oxidation is happening, where the reduction is happening I will touch upon this once more in another context and then I think it will become really clear to you. So, at that point we; so you don't have to just memorize that you know zinc is the anode you know say silver is the cathode, you don't have to memorize like that in that cell you figure out where the oxidation and reduction is happening.

So, importantly you have to understand that those circumstances can change, we can make the what one electrode is when one electrode is undergoing oxidation, you can create other circumstances where that same electrode now undergoes reduction ok. So, during the time that it was undergoing oxidation it was behaving like an anode, during the time that it is undergoing reduction it is behaving like a cathode.

So, that's the point you have to remember that is why this definition is important. Because the exact same metal in the exact same solution can be forced to do one reaction in preference to the other reaction. When it is forced to do one reaction in preference to the other reaction based on the reaction that is happening you decide whether its anode or cathode ok. So, that's the point.

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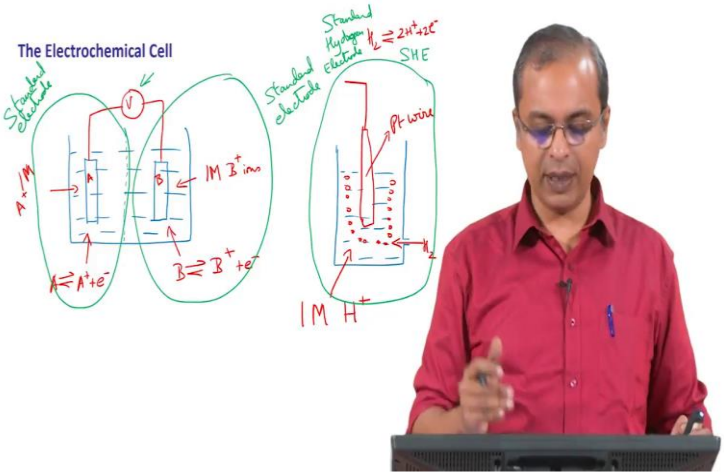

So, now, the electrochemical cell what we do as we saw here is that you have this anode and cathode and so, you can have a whole bunch of anodes and cathodes. So, you want to create a situation where you understand what will happen when you take one anode, and put it in or one material and connect it to another material with some electrolyte in the middle, you want to understand what will happen right.

So, to do that we have to try and create some standard versions of these combinations, and once you understand how the standard versions behave you can you know couple two standard versions, and then from that you will know what those that combination will do and then from there you can create a non standard version of the same combination. So, that is the process by which the people understand what a battery does right.

So, you have to first come up with a standard version for an electrode and an electrolyte, and like that you will have several such standard versions then you pair up them pair them up. So, then you have one electrode one electrolyte, and then the electrolyte and this is a second electrode. So, that becomes complete pair again they are still under some standard conditions. So, they there is a some behavior associated with that. And then you may use them in non standard conditions, but how it will behave in non standard condition is something that you learn from how it behaves in the standard condition. So, this is how you do. So, what we basically do is that the electrochemical cell will typically consists of two electrodes. So, let me just put some some kind of a beaker here and there is some electrolyte here, and some membrane which which may be a slight separator which doesn't allow complete mixing of the two electrolytes because you may have a slightly different electrolyte on one side and different electrolyte on the other side.

You put one metal in here and another metal here okay and the let's say this is metal A and this is metal B ok. So, A and B you have. So, what we will have is you will have the possibility of this reaction here, that is A going to A plus plus e minus and similarly here you will have the possibility of the reaction B going to B plus plus e minus and these could happen reversibly. Let's assume that they are happening reversibly. So, in other words it can do both ways ok. So, this is likely happening and then let's connects this in an external circuit and here we will put a voltmeter and we will connect it up this way ok. So, what we are doing is we will also say that the electrolyte that is here contains one molar concentration of B plus ions and the electrolyte here contains one molar concentration of A plus ions.

So, this combination that you have here of a metal a metal A sitting in contact with a solution that has one molar concentration of its ions under one atmosphere pressure and you know let 25 degree centigrade, this combination is referred to as a standard electrode. So, this is a standard electrode similarly here also you have a standard electrode.

When you combine two standard electrodes like this and that is why you have this membrane in the middle because you have A plus ions on the left side and B plus ions on the right side and so, you don't want a massive mixing of them you want to maintain the standard condition that is how it is done this way then you measure a voltage this voltage is the voltage between two standard electrodes okay and this is consistent with the voltage difference, that you will measure between these two electrodes using the standard electrochemical series which we are going to see in just a moment ok.

So, you have various possibilities for metal A, you have various possibilities for metal B you can keep on taking different-different combinations and you can measure these voltages, and typically this voltage is the difference in voltage between these two electrodes. So, now, you have wide range of different voltages. So, it gets confusing.

So, you will have all sorts of different combinations of different pairs of materials you can take, and you will have I mean infinite possibilities you may have of these potentials. So, what we do instead is we try to standardize one part of the cell and then compare all electrodes with respect to that standard part. So, what is that standard part? It is simply an electrode which contains a beaker. So, let me just change that here. So, you will now have some let's say some beaker of this sort with one small opening the side, in which we will put actually the electrolyte here will be one molar of h plus ions ok.

One molar of it is an acidic electrolyte. So, some acid is there, but with one molar concentration, and in this you bubble hydrogen gas H_2 gas is bubbled. So, that bubbles up ok. So, at one atmosphere pressure you are bubbling this gas and it is bubbling up and in this you dip a piece of platinum; platinum wire and from this you can connect it to some external circuit.

So, if you do this then you create this reaction of H_2 going to 2 H plus plus 2 e minus that is the reaction that is occurring in this electrode, this is referred to as the standard hydrogen electrode this setup that you see here is the standard hydrogen electrode or SHE for short it will be called SHE standard hydrogen electrode SHE.

So, this now becomes a standard. So, in the pair that you are seeing on the left hand side of your screen, in that pair you can always remove let's say B instead of b you put this electrode SHE instead of B you make put SHE then you will get the standard potential for A. So, A versus this A a part of this 10 this standard electrode with the A as the metal, if you combine it with SHE you will get its standard electrochemical potential; similarly you combine B separately with SHE you will get its standard electrochemical potential.

So, like this you can get in instead of simply coupling A with B you couple A with SHE you couple B with SHE you couple C with SHE like this you get potentials always with respect to SHE and then once you get there are potentials with respect to SHE you can get the potential of A versus B by simply adding those potentials or subtracting those potentials based on the way in which your reaction is being written. So, if it is written always as a reduction potential you subtract those potentials.

So, so by making these combinations of A versus standard I mean this half of the cell versus the standard hydrogen electrode B half of the cell versus standard hydrogen electrode etcetera by doing this and noting down those potentials we create this standard electrode poten standard electrochemical series ok.

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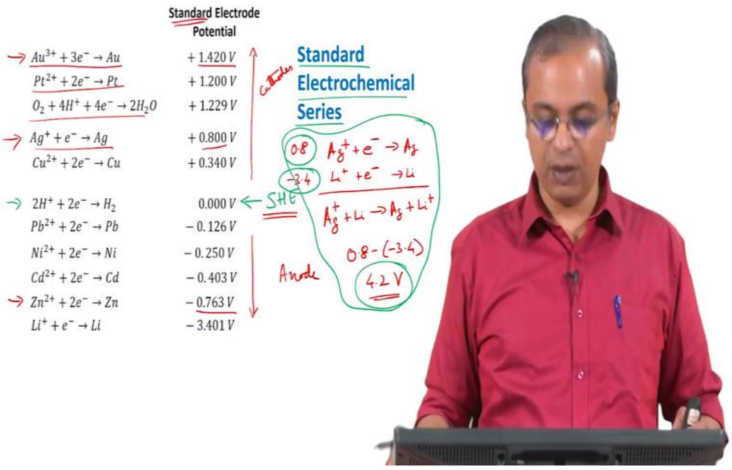

And in this case that SHE is sitting here.

The SHE potential is arbitrarily set as 0. So, this is an arbitrary choice it is set at 0 and with respect to that we note down all the potentials. So, you combined gold with silver, I am I am sorry gold with hydrogen and you got that potential, you can combine you know silver with hydrogen you will get this potential of point plus 0.8 volts, and then similarly you can combine say zinc with that hydrogen electrode then you will get minus 0.7 6 3 volts.

So, like this you can you know combine different electrodes and get those respective potentials. So, now, if you wanted to combine silver with zinc you simply do 0.8 minus 0.763 and you will get a cell potential of 1.563. So, that is the cell potential of these 2. So, that is how you use this standard electrochemical series by looking at all of these potentials as independent potentials, and then subtracting them.

Point to note the hydrogen electrode has been arbitrarily set at 0. So, there is no specific reason why we should be using that as 0 it’s just arbitrarily set it to 0 and with respect to the hydrogen electrode whatever is above it is considered to be more what shall I say more noble or more you know stable kind of electrodes and these are more active ok. So, more active; so if you based on how you couple them more or less whatever is more active means they will tend to get oxidized more easily. So, you tend to these the species that are below hydrogen are that are towards the lower part of the standard electrochemical series are all going to try and behave like anodes, and those that are noble which are on top of the electrochemical series are trying to most likely going to behave as cathodes.

So, any pair you take any pair you take in this electro standard electrochemical series, you look and see which one is above which one is below on this electro chemical series. The more positive one behaves as a cathode, the more negative one behaves as the anode in this electrochemical series. Please also note these are all written as reduction reactions okay they are written in the reduction reaction. So, in that mode this is the potential if you reverse the reaction the potential will get become negative. So, whenever you do. So, that is why I got 0.8. So, what I have basically done is, I have written Ag plus plus e minus will give you Ag and then let's say I will let me combine it with let's say lithium for example, lithium. So, lithium plus plus e minus gives you lithium.

So, if I subtract these two. So, this potential is 0.8. So, this is 0.8 and this is minus 3.4, right. So, if I subtract these two then I will have Ag plus plus Li gives you Ag plus Li plus. If I subtract these two reactions and then the potential is simply 0.8 minus of minus 3.4. And therefore, you will get what is it 4.2 volts and that's because the second reaction now happens in reverse and that's that's basically.

So, because one has to get oxidized one has to get reduced and whatever is above has a tendency to get reduce. So, this is how we get the standard potential for this cell. So, any combination we get we try to find out the standard potential is required. So, every battery will have some something in the anode something at the cathode and you can you know under standard conditions you can figure out what's the difference in potential.

Now, this is I must also point out that we keep referring to the standard condition. So, you have to always, please remember that this is only under standard conditions ok. So, and the standard condition is this metal sitting in one molar concentration of its ions. So, that is the standard condition, but you can actually do this under non standard conditions also. In fact, therefore, that is why when you make a battery and you measure its open circuit voltage that may not necessarily match what you will see in these from the standard electrochemical series.

And the specific reason why that is the case is that the two materials that you have selected there may not be sitting in their standard conditions. So, if you change the condition then you can use this standard condition as a starting point and figure out what its potential will be in the non standard condition, and then that is the potential you will use for doing this kind of calculation that we just did here ok.

So,. So, the calculation that I just did here assume standard conditions, it assumes that the two electrodes are sitting in standard conditions. If they are not sitting in standard condition under the non standard condition you should find out what would this potential have been and what would this potential have been out of the non standard conditions, but the process would be the same.

You get those two potentials under the non standard condition and you do the subtraction, you will get some answer. And in fact, if you go to non standard conditions you can even create a situation where what material is showing up as an anode in the showing up as being more active in the standard electrochemical series, will now become more noble. And therefore, you may even get a potential that is negative if it show shows you a potential that if that is negative, it simply means that the reverse reaction is the spontaneous reaction.

The way this is set up, the positive potential shows you the direction in which the reaction is spontaneous. So, right now if you do this combination silver will keep getting reduced lithium will keep getting oxidized, that’s the spontaneous direction of the reaction and that is why we got a potential that is positive ok. So, that’s how we you see standard electrochemical series ok.

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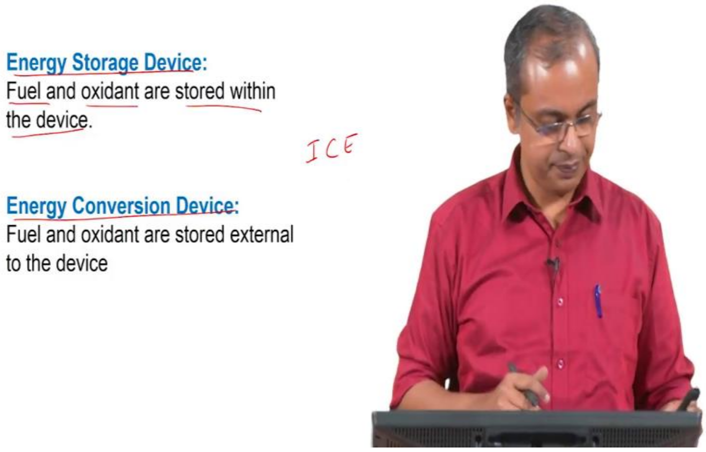

So, in the context of batteries a few specific terms, I told you earlier that we have the batteries and is an energy storage device and so, what is the significance of it? It means that the fuel and the oxidant are stored within the now within the device. So, the significance of this is that the size of the battery is some indication of how much chemical is there in the battery and therefore, how much how long it can operate.

So, for example, you go to the shop and you buy some you know same brand battery, you can buy you know what we call the pen torch battery or you can buy the triple A battery which is even thinner than that or you can buy D cell or C cell which are bigger batteries. So, for the same brand same kind of chemistry that is there, the thinner battery will last lesser time the thicker battery will last longer time if you use it to power the same device.

So, let’s say you connect the thinner battery to power led, that led let us say will run for 10 days if you connect it to a thicker battery which is twice that the volume let us I am assuming if its twice that volume instead of 10 days it will now run for 20 days. So, the size of the battery decides how long it can operate in energy other kind of device which is the energy conversion device, the chemicals are stored outside of the device they are not stored in the device.

So, later when we look at fuel cells that would be an energy conversion device and the you know the chemical being stored outside or being stored in the inside may not seem like much of a difference, but operationally it's a big difference because it means that the size of the device does not decide how long it will last. So, even with a small device you can have it running for a indefinite period of time, because you are just supplying the chemicals from outside and that's why those devices are interesting and are more flexible. And in fact, a device that you are used to very commonly which you have not thought of in this in the context of this terminology is the internal combustion engine.

So, your internal combustion engine or ICE internal combustion engine which is what is the engine that is there and say your moped or your motorcycle or car whatever no. So, there the patrol is sitting in the petrol tank. So, the size of the engine if you say I have a 1.2 liter engine, that does not tell you how long that engine will run that how long the engine will run or how long the car will run which depends on the size of a petrol tank how much petrol you have got in the petrol tank.

So, you fill your petrol and it will lasts for the duration of that petrol tank, and as it gets close to empty you simply refill the petrol and you can keep going. So, that is the convenience of an energy conversion device you simply have to tank up change the tank and keep going whereas, in an energy storage device like a battery you have to do recharging because that chemicals have to be now you know corrected in some form or in other words reversed in some form within that device and that takes time.

So, that is the difference ok.

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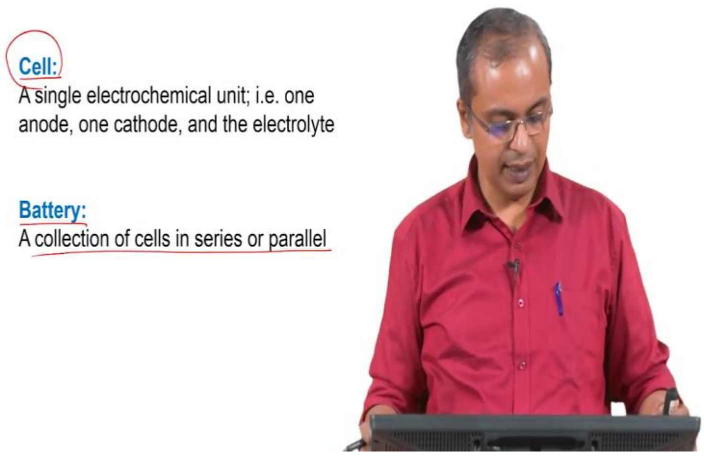

Also in this context we have this idea of a cell and a battery. So, this is something we should at least be aware of I mean we may still use it in commonplace terminology and that's how I even used it earlier part of this class, but strictly speaking what we refer to as a battery and we say you know we tell somebody in our house saying a go to the shop and buy some battery, and come right that actually at that point we are asking them to go and buy.

A cell we are not asking them to go buy a battery a battery is actually a collection of cells in series or parallel. So, if you take your let's say television remote and you open it right. So, inside that you will have two batteries right actually what you have are two cells, and there they may be sometimes pointing in the same direction in which means that there are two cells sitting in parallel or you may have them inverted, one pointed in this way and the other pointed the other way in which case they are in series.

So, two cells there are sitting in either series or parallel based on how the remote has been designed, then that combination is called a battery. So, you similarly even a remote control toy, in the toy you will have some few cells in your remote you will have a few cells, you will find in some case it is sitting in series some case it is sitting in parallel this combination is called a battery. Strictly speaking that is the terminology that is used and each one of them individually is called a cell. So, that's how the terminologies is used, but we of course, in common usage we tend to simply call it a battery. So, at least we should be aware of this definition we may not use it very strictly, but if you ever run into the word cell and you run into the word battery you should know the difference. So, this is the idea ok.

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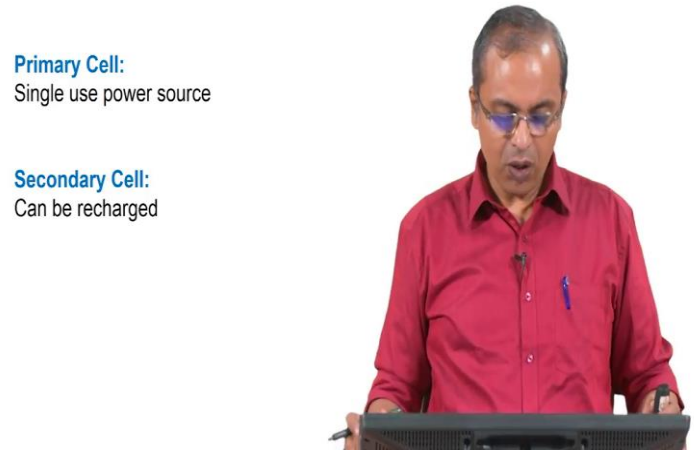

Also in this context we have something called a primary cell and something called a secondary cell, these are the terms that are used in a more technical sense primary cell versus secondary cell.

A primary cell is basically a single use power source. So, these are the kinds of cells that cannot be recharged in other words the chemicals that have been used in that the chemistry that is being used in that cell is such that it is not reversible it is not reversible chemistry. So, once the reaction is complete, you cannot simply flow current in the opposite direction and get those reactions to go back to their previous condition the reactants to go back to their previous condition or to make the products go back to being the reactants.

So, that is not possible with that. So, we have lot of those you know cells that we buy in the shop which are single use cells. So, you use it in your remote, once it is done you throw it away you go buy a new cell right. So, we don't necessarily keep recharging that. So, that kind of a cell is referred to as a primary cell that is the correct technical term for it.

Similarly the opposite is true for what is a secondary cell, these are the cells that we in common usage refer to as rechargeable batteries. That we say rechargeable battery you know that term that we use is the term that is being used for this technically indicated item as a secondary cell.

We what has been indicated technically as a secondary cell that is what we are referring to as a rechargeable battery. So, these are cells which where if you reverse the direction of current you will have the opposite reactions happening or the reactions will happen in opposite direction, and you will get back the original reactants that you started with and that's a secondary cell. And therefore this, and so you should keep that also in mind that not every cell is reversible so you that is why you know you see those warnings in those you know rechargeable units saying you cannot just put any cell that you want in that, only that specific cell you have to put in there and recharge because there will also something associated with the voltage first of all some cells cannot be reversed.

So, if you send force current through them, they may just explode or something bad may happen. So, you don't want that happening, only some cells can be recharged, only they can be they should be recharged and even there you should only put it in a specific recharger and not just you cannot take different brands and just throw them into different rechargers, because the recharging unit is designed to work correctly with this chemistry work correctly with that voltage associated with that chemistry and so, you should not arbitrarily mix them. So, this is the difference.

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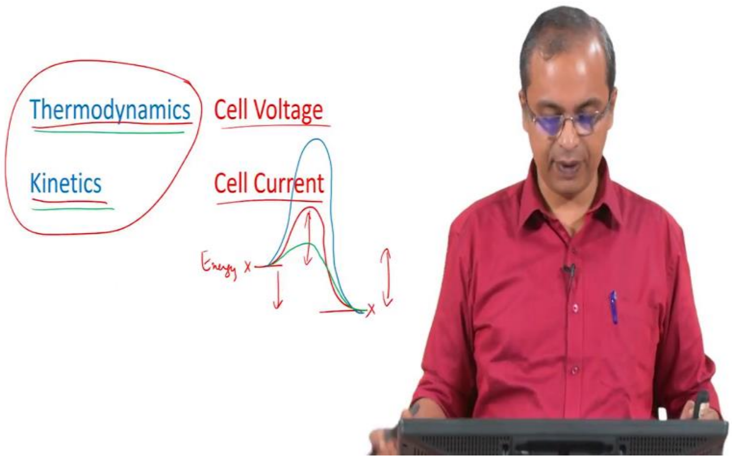

So, now there are there's another aspect of this battery technology that we should be aware of the voltage that we measured. The standard electrochemical potentials that we measure, the you know potential of that combination that power that you then you know subtract one potential from the other and you get the voltage of the cell etcetera right that is the thermodynamics of the cell that refers to the thermodynamics of the cell.

So, that is the theoretical condition which represents the driving force for the cell to operate. It represents the possibility of the reaction to occur the you know the drive for the reaction to occur etcetera. When we draw current from the cell that represents the rate at which the reaction is happening that is called. So, so the thermodynamics gives a cell voltage ok.

So, thermodynamics which represents the ability of that reaction to happen gives us the cell voltage when and so, that ability is something that we measure in typically measure in open circuit conditions. So, we are. So, you just you know put a voltmeter across your cell and you measure a voltage that cell voltage represents the thermodynamics of that system and represents the ability of that cell to perform.

On the other hand when you draw current from it that represents the kinetics of the system, that represents how fast that reaction will happen okay and that is the cell current. So, cell current is the kinetics cell voltage is the thermodynamics. So, these are two very important parameters we often do not realize it, but these are the two that decide many things in our in our in nature.

In nature many things are decided with thermodynamics and kinetics, so for example, if you take a piece of wood right you take a piece of wood and you light a fire, the wood burns. So, another why does that happen? Because the wood has a tendency to burn it what is happening when you wood burns, wood burns and then all the carbon in the wood becomes carbon dioxide right. So, and the fact that it is burning or continuing to burn means the carbon prefers to become carbon dioxide.

So, carbon dioxide is the more stable condition. So, if you allow carbon to react with oxygen, it will react with oxygen and form carbon dioxide ok. So, this ability of carbon to react with oxygen and form carbon dioxide and this you know tendency of carbon, this tendency of carbon to react with oxygen and form carbon dioxide is represented by its thermodynamics that tendency is captured by thermodynamics.

So, that is why you get delta g for that reaction, the delta g for that reaction would be negative; that means, it is spontaneously it it has a direction in which it will tend to go the C will react with O_2 and form CO_2 ok. So, it a that is there is a driving force for that reaction ok. So, it is trying to happen, but it is also important to understand that when I keep a piece of wood in air I just keep it on the table or even the table the table itself is wood why does it not immediately burn?.

Now there is a tendency that you know you understand that carbon dioxide you would it would rather be carbon dioxide than carbon why does it just not burn you just keep it there it doesn't just spontaneously burn and disappear into carbon dioxide it does not because you have a driving I mean you have an activation energy barrier, there is an activation energy barrier. So, that is how. So, you will have the reactant and some level, you will have the product at this level and. So, this is the energy difference this is the energy, and therefore, since you have this drop in energy when you go from C_2 to O_2 a two.

From C to CO_2 that is a desired state of affairs, but to go to this distance you have to actually go past a activation energy barrier and it is this activation energy barrier that is what makes the world stable the way we see it. So, that is why know their clothes we wear things that we use etcetera are not just spontaneously catching fire and you know getting oxidized, even though the oxide will be the more stable con state in which it it will be there. So, there is an activation energy barrier, which prevents a reaction from happening even though thermodynamically the reaction is trying to happen. So, in the context of things we have to understand the kinetics the rate at which the reaction is happening is an important aspect and so, in the and that rate is often affected by the activation energy barrier.

So, the activation energy barrier decides you know how easy or difficult is it is for the same reaction to occur you make the activation energy barrier smaller the reaction will happen faster okay and that's what the catalyst does. Whenever you use a catalyst that is what it is doing is it is reducing the activation energy barrier; therefore, making it easier for the reaction to happen, but the ability of the reaction to happen is the same. So, this point here and this point here are not changed, only the barrier has changed. So, you may have a smaller barrier or a larger barrier and that. So, if you want. So for example corrosion: corrosion is something is an undesirable reaction. So, we do things to increase the barrier for corrosion.

So, we are increasing the activation energy barrier for the corrosion on the other hand. So, if you are talking of a corrosion reaction, you are basically trying to do this we are trying to increase the barrier. If you are on the other hand you are talking of some you know battery kind of situation, where you want the reaction to occur fast you are trying to do this than to reduce the activation energy barrier. So, that is what you are trying to do with respect to the activation energy way. So, this is the point. So, there is thermodynamics and there is kinetics, and it's a combination of these two that you see eventually as the performance of your cell in terms of voltage and current respectively.

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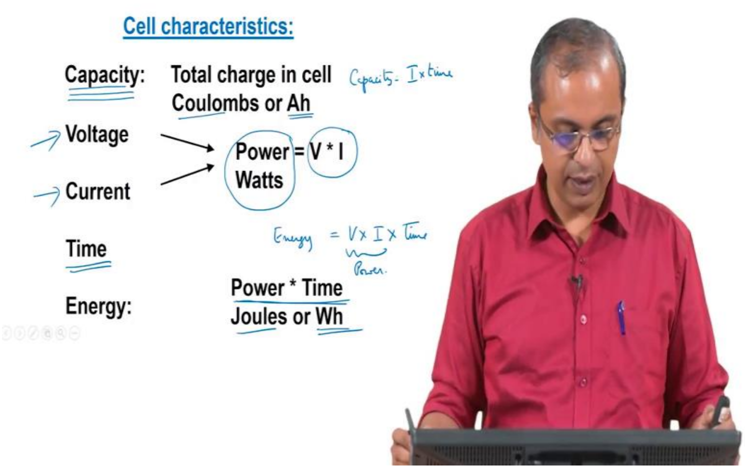

And the cell characteristics are captured by a few different terms, we typically only look at voltage. So, we typically keep referring to the voltage in the in the cell. So, this is the point that we keep referring to that's the open circuit voltage, the current is what we draw from the cell, the rate at which the reaction is occurring the rate at which those electrons are being drawn and so, the combination of that those two gives you the power in watts. So, that is simply V into I. So, that is the characteristic of the cell. The capacity of the cell is a term that we use which represents the total charge that is available in the cell, and that charge is in typically in coulombs or ampere hours.

So, that is basically whatever current you are drawing times the duration for which you draw the current. So, that is where if you have the same you know chemistry and you have a smaller battery and you have a larger battery, the capacity of the larger battery is more than the capacity of the smaller battery. So, if you even if you draw the same current, that let's say it is twice the size the duration for which it will last is twice as long.

So, even if you are drawing the same current if one battery lasts one hour, the thinner battery lasts one hour the thicker battery is twice its size let's say the thicker battery will last two hours. So, for the same purpose, so if you are lighting some product I mean some place and you want light to be on for two hours you should use the thicker battery, and you don't want to change the battery right. So, the time comes in there. So, the time is associated with this process in this manner and that's how we get it and the energy that is available is power into time.

So, current into time gives you the capacity, power into time gives you the energy that is available and that is in joules or watt hours ok. So, this is how we get the different parameters that we use to understand what is possible. So, the power the energy that is available also includes you know the fact that it has it is not just the current that is coming out, but current is coming out at some voltage that is why you have.

So, you have V into I into time this is energy and of which this is power right, so V into I into time. So, the energy equals V into I into time, the capacity equals I into time ok. So, that is the capacity how long will it last this is; what is the total energy that is available. So, this is the. So, this is amperes and that is hour. So, ampere hour you will get this is watts and that is hour, so watt hours you will get. So, this is the different parameters here ok.

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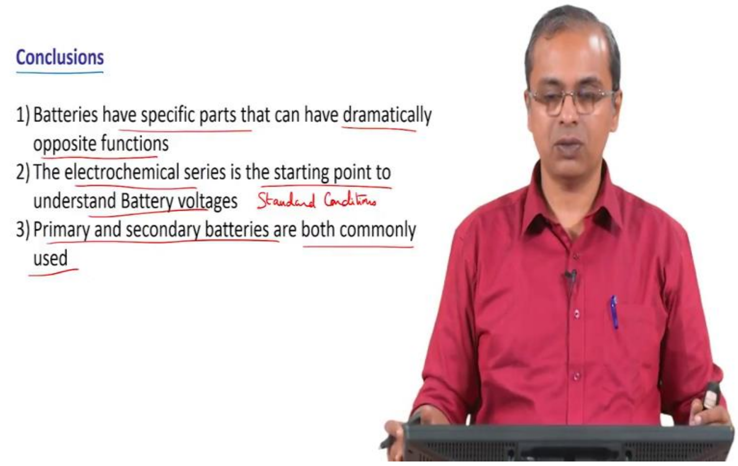

So, in conclusion, we have just now briefly looked at all the basic ideas associated with a with a battery. So, our main conclusions here are the batteries have specific parts that can have dramatically opposite functions, and that is what I meant what I mean here is the of idea that you have an electrode phase and you have an electrolyte phase and what we are demanding of the electrolyte phase in terms of conductivity is the opposite of what we are demanding from the electrode in terms of conductivity. Electrode should have good electronic conductivity, electrolyte should have good ionic conductivity and they should be in opposition to each other, but as a reaction they will all assist each other. So, that's the point.

The electrochemical series is the starting point to understand battery voltages, but as I pointed out the electrochemical series is under standard conditions. So, this is standard conditions always please remember that these are standard conditions, but that is the correct place for you to start because otherwise its confusing you mean there is just no end to all the conditions you can set these various materials to. So, we set some standard conditions and that is this standard electrochemical series which is the place where we look at the standard electrode potentials which means the electrodes are set under some standard conditions.

Any non standard condition can be derived from starting from the standard condition and that is why this way it is a nice the process, and there you subtract one electrode from the other electrode you will get the open circuit potential and then you can decide which way the reaction is happening. And that potential itself may change so, you have from the standard electrochemical series you have one that is above which is noble, one that is below that is active. So, if you take the difference then you will find that this is the open circuit potential and this is the. So, what is above is the one that will undergo reduction, what is below is the one that will undergo oxidation.

So, this lower electrode is your anode the upper electrode is your cathode. But if you go to non standard conditions this potential can go low or high this potential can also go high or low. So, supposing this where to go high and that were to go low because you have gone to non standard conditions, then what originally. So, now, we can see that their relative positions have reversed. So, what originally served as the cathode will served as the cathode will now become the anode what originally served as the anode can become the cathode.

So, you can see that all these things are possible with respect to the you know electrochemical combinations that are possible. And I also told you that there are primary and secondary batteries that are and these are all very commonly available and commonly used, primary batteries are single use batteries secondary batteries are rechargeable batteries.

So, that's our basics that I felt are you know relevant for the discussion on batteries, we will look at some battery systems and how batteries performs and so on and these you know phenomena will all be relevant in that context. So, that's the discussion and main conclusions for today's class.

Thank you.

KEYWORDS:

Batteries; Energy Storage Device; Primary Batteries; Secondary Batteries; Electrochemical Series; Electrochemical Device; Electrode; Electrolyte; Anode; Cathode; Cathode Electrolyte Interface; Anode Electrolyte Interface; Ionic movement; Electronic movement; Oxidation; Reduction; Standard Electrode; Standard Hydrogen Electrode(SHE); Cell; Cell Voltage; Cell Current; Activation Energy Barrier; Catalyst; Corrosion; Capacity; Energy

LECTURE:

Basic concepts associated with batteries, their sign conventions and how they function are described. This lecture concentrates on the various parts of the battery and their functions. The difference between Primary and Secondary batteries is also clarified. The principle of electrochemical series are spoken in detail to relate to the concept of Batteries.