

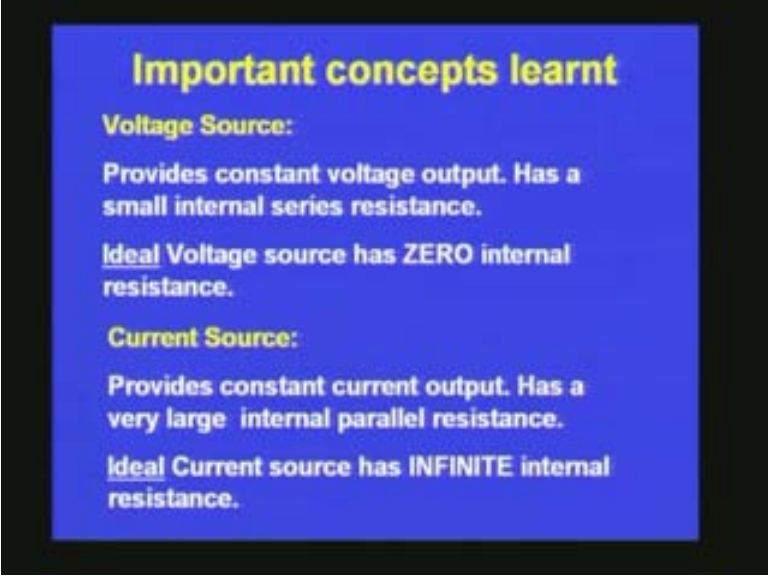
**BASIC ELECTRONICS
PROF. T.S. NATARAJAN
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**LECTURE-6
SEMI CONDUCTOR DIODES**

Hello everybody! In the series of lectures on basic electronics, learning by doing we will go on to the next lecture. In the previous lectures we were discussing about Thevenin's and Norton's theorem. We also saw some illustrative problems and we solved using Thevenin's theorem and Norton's theorem and then finally we also performed an experiment of the same problem which we discussed by using actual voltmeter and voltage sources. Before we go further let us recapitulate the concepts that we have learnt so far over the past few lectures.

First we talked about the voltage source.

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Important concepts learnt

Voltage Source:
Provides constant voltage output. Has a small internal series resistance.
Ideal Voltage source has ZERO internal resistance.

Current Source:
Provides constant current output. Has a very large internal parallel resistance.
Ideal Current source has INFINITE internal resistance.

Voltage source provides a constant voltage output and it has got a very small internal series resistance. An ideal voltage source has zero internal resistance. We should remember all these concepts. Then about current source; it provides a constant current output and it has got a very large internal resistance connected in parallel. Ideal current source has infinite internal resistance. We also saw what resistors are. Resistors oppose the flow of current and are measured in units of ohms and the value of the resistances and the wattage are the two important parameters while getting resistors. Resistors can be combined, connected in series and when you connect the resistors in series the total resistance is the sum of the all the resistors.

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Important concepts learnt

Resistor: Oppose the flow of current, and is measured in units of Ohm.

Resistors connected in Series add, and series resistors divide voltage.

Resistors when connected in Parallel, the effective resistance is smaller than the smallest and parallel resistors divide current.

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$R_{\text{eff}} = \frac{R_1 R_2}{R_1 + R_2}$$

So you have to add the resistors and we also saw series resistors divide voltage. We can also connect resistors in parallel and when you connect in parallel the effective resistance is always smaller than the smallest in the group and also parallel resistors divide current. Just as series resistors divide voltage, parallel resistors divide current. I have given the expression also for the effective resistance. R_{eff} is $R_1 R_2$ divided by $R_1 + R_2$ when you have two resistors R_1 and R_2 connected in parallel. Similarly we also saw about capacitors. They help to store electrical charges or electrical energy. Farad, microfarad are the units of capacitances. Capacitors can also be connected in series.

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Important concepts learnt

Capacitors: Help to store charges or electrical energy. Farad, microfarad, etc., are the units of capacitance.

Capacitors when connected in Series divide voltage and has same charge. The resultant capacitance is smaller than the smallest.

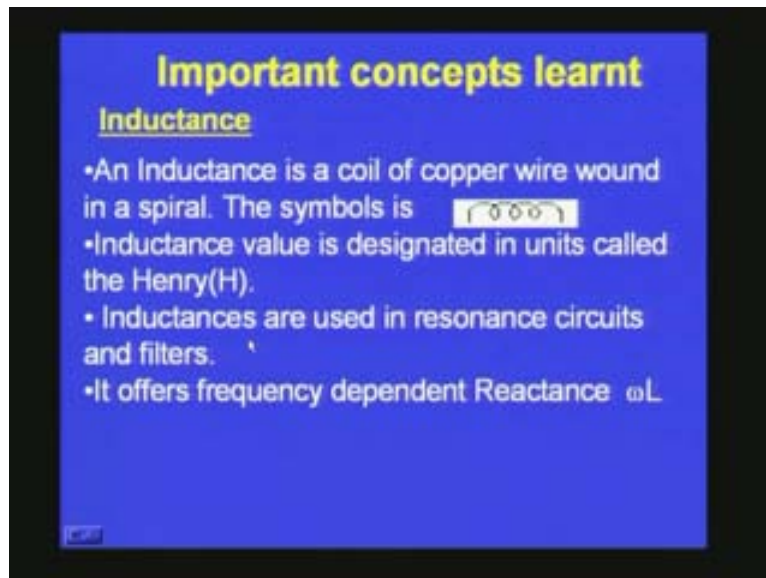
Capacitors when connected in Parallel, have same voltage and divide charges. The resultant capacitor is sum of the individual capacitances.

$$\frac{1}{C_{\text{eff}}} = \frac{1}{C_1} + \frac{1}{C_2}$$
$$C_{\text{eff}} = \frac{C_1 C_2}{C_1 + C_2}$$

They divide voltage when I connect them in series and they have the same charge. The resultant capacitance is smaller than the smallest. When you connect them in series they behave something very similar to resistors connected in parallel. Capacitors, when connected in parallel they add. The total capacitance will be the sum of the individual capacitance and they have the same voltage when you connect them in parallel. But they divide charges among themselves proportional to the value of the capacitance.

Inductances are basically coil of wire, good conducting wire and they are usually designated in units called the Henry. Millihenry, microhenry and Henry.

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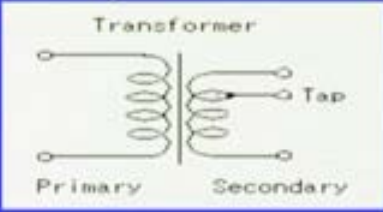
Inductances are used in resonance circuits and filters. They offer frequency dependent reactance equal to ωL . ω is the frequency of the AC, L is the self inductance of the coil. One application of the inductance is in transformers where you have a primary and a secondary, two coils separated independently. When you apply an AC voltage in the primary there is a corresponding induced voltage in the secondary and the proportional voltage induced will depend upon the number of turns of coils in the primary and in the secondary, the ratio of the turns in the primary and the secondary. This is due to what is known as the mutual inductance between the two coils and that mutual inductance is also measured in Henry.

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Important concepts learnt

TRANSFORMER

- The change in current of one coil affects the current and voltage in the second coil and this phenomenon is called Mutual inductance .
- Mutual inductance (inductance) is measured in units of the Henry.



Next we saw some laws. First important law is ohms law; very fundamental in electrical and electronics. At constant temperature the current in a circuit is proportional to the voltage applied across its terminals.

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Important concepts learnt

Ohm's Law:

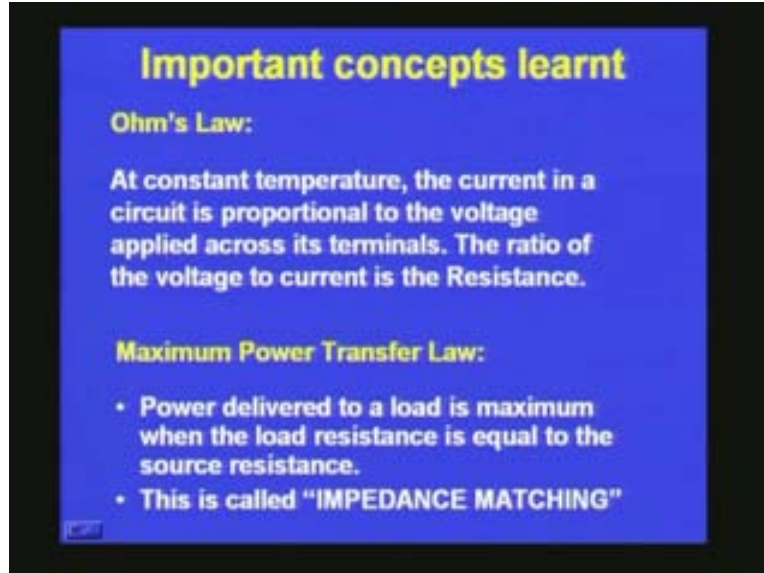
At constant temperature, the current in a circuit is proportional to the voltage applied across its terminals. The ratio of the voltage to current is the Resistance.

Maximum Power Transfer Law:

- Power delivered to a load is maximum when the load resistance is equal to the source resistance.
- This is called "IMPEDANCE MATCHING"

This is the statement of the Ohms law. The ratio of the voltage to current is called resistance. This gives us ways of obtaining any one of the quantity when you know the other two quantities. For example voltage is equal to I into R , current into resistance and resistance is voltage divided by current and current is voltage divided by resistance, etc. So you can use these for different applications. Then we also saw some other useful theorems like maximum power transfer law. The maximum power is delivered to the load from a given circuit only when the two impedances match.

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The source resistance and the load resistance are equal. Then only you have maximum transfer of the power from the source to the load and this is why it is called impedance match. You should have matching impedance for maximum power transfer. Then we saw another law which is superposition law or theorem where if you have in a network more than one source, voltage source or current sources then how do we calculate the effective voltage across any of the resistors in the circuit. For this we make use of the superposition theorem because these ohms law is basically a linear law and therefore when you have linear relationship then you can use the superposition theorem. What we do here is we try to remove all the other sources and have only source at a time and try to find out the effect of one source on the given resistor. What is the voltage developed due to the one source? Like this you calculate for each of the sources separately as if they alone are in the circuit and then try do add them to together. That is what we mean by superposition. So when you do that we have to remember important things like if it is a voltage source you want to remove then you must remove it and replace it with a short. If it is a current source which you are removing from the circuit for simplicity then you should remove the current source and leave it open. So voltage source should be shorted current sources should be open before you go for a superposition theorem consideration. So this is something which we should remember.

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Important concepts learnt

Superposition Law:

When we have networks with more than one voltage source or current source, the voltage across any component in the network is obtained by algebraically adding the contributions due to each of the sources existing independently with the other sources absent.

Here, since we consider only one source at a time, the other **voltage sources** must be replaced with a **short** while other **current sources** must be replaced with an **open circuit**.

Then we also saw the Thevenin's theorem and the Norton's theorem which are very important in network analysis. Any complicated circuit can be equivalently given as one voltage source which is called the Thevenin's equivalent source and one internal resistance which is the Thevenin's resistance.

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Important concepts learnt

Thevenin's Theorem:

Any complicated network can be effectively replaced by a single Thevenin's voltage source and a Thevenin's series resistance by using this theorem.

Norton's Theorem:

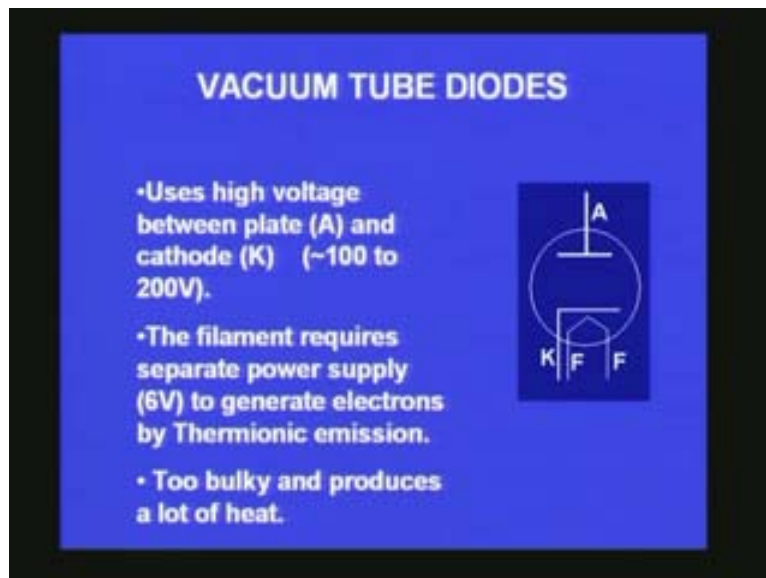
Any complicated network can be effectively replaced by a single Norton's current source and a Norton's shunt resistance by using this theorem.

So you can replace a very complicated circuit with one source and one resistance in series. That could be a voltage source and if it is a current source then it becomes Norton's theorem. You can have current source and one Norton's resistance in parallel. You can effectively replace any given circuit and we also saw the equivalence of the Norton's theorem and the Thevenin's theorem. The Thevenin's resistance is equal to Norton's resistance and Thevenin's voltage source is the Norton's current source into the

Thevenin's resistance or the Norton's resistance. So these are very, very useful for rest of the discussion on the different application circuits.

We will move onto some of the devices which are very, very important in electronics. The first device that we have is the diode, semiconductor diode. Originally the diode was in the form of a vacuum tube.

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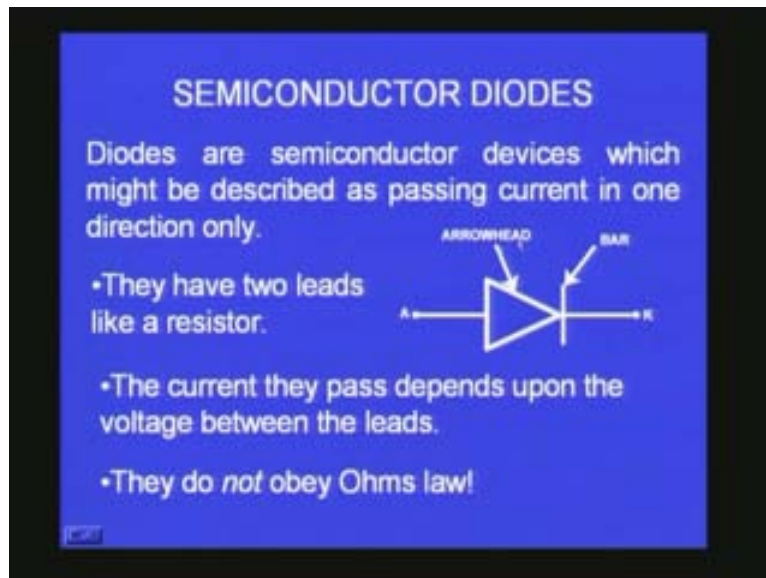
I have shown on the screen. You have a vacuum tube which is shown by circle. You have a plate, you have a cathode and the cathode is heated by a filament FF that is shown in the figure and when you pass the current through the filament that is getting heated up and the heat is passed onto the cathode and when the cathode gets hot then it starts emitting electrons. This is called thermionic emission and these electrons will have to be collected by the plate. Therefore in the external circuit you will maintain the plate positive and the cathode negative. Then you would find electrons will flow from the negative cathode to the positive plate and thereby there will be a current flow.

If on the other hand I maintain the plate A negative and the cathode positive you would find the electrons which are emitted by the cathode can never reach the anode because they will again be attracted back to K because electrons are negatively charge and K is positive. Therefore you find there will not be any current flow if I maintain the anode A as negative and K as positive. Only when I maintain A as anode, as positive and K cathode as negative I will get a current flow and therefore this is a device which conducts only in one direction. Current can flow only in one direction. Such a device is called a diode. Actually the name diode comes from this two electrode device. Two electrodes we call diode. But the problem with a vacuum tube diode is that you have to apply a very large voltage of about hundred to two hundred volts for operation. Apart from that for heating the filament, for generating the electrons you have to connect a low voltage power supply, usually an AC voltage power supply for six volts for the filament and

therefore you should have two power supplies for the operation of a diode and also because it involves vacuum tubes i.e., vacuum is in there, you would find that the device itself will be very large.

It is very bulky and it produces lot of heat. With all these problems you have to look for alternatives and the alternative came from the solid state device which is the semiconductor diode. The diodes, now-a-days normally mean only semiconductor diode and the semiconductor diodes are basically a device, a device which conducts in only one direction. It does not conduct in the other direction.

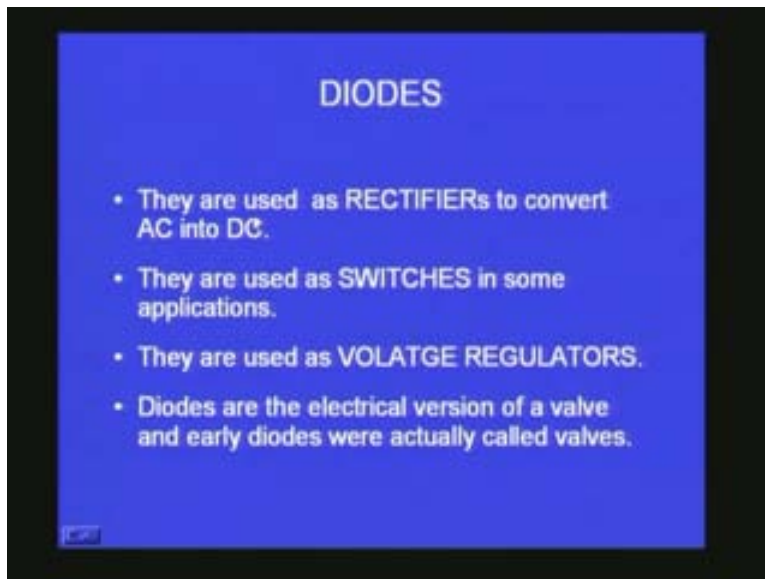
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If you see on the screen, you see there is a diode symbol shown which is having an arrow and there is a bar here and the direction of the arrow shows the direction of easy flow of current. So current will flow from the A to K and when I try to pass the current from K to A by changing the polarity you would find the current will not be passed. Therefore the AK direction offers low resistance to current and the KA direction offers high resistance and therefore a diode is a device which offers low resistance in one direction and high resistance in the other direction.

So this is what basically a diode is and how much current it conducts will depend upon the voltage you apply across the diode. They do not obey ohms law. That means the current is not directly proportional to the voltage you apply. It depends on the voltage. If you change the voltage, current can suddenly start increasing enormously. So these are the very important points with reference to diodes and the diodes are used as rectifiers. They are very important in electronics. They are used as rectifiers to convert alternating current into DC.

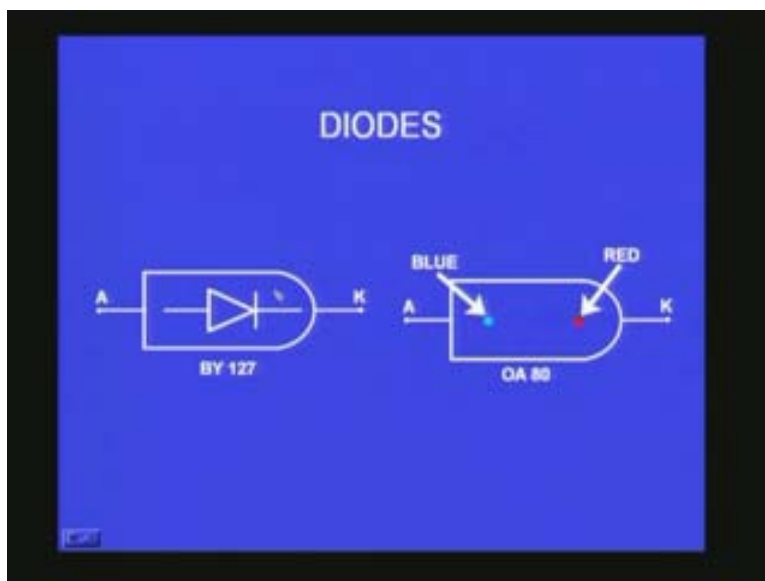
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Therefore such devices are found almost in every electronic equipment that we can think of. They are also used as switches in some applications, digital and other applications. They are also used as voltage regulators. To maintain a constant DC voltage we can make use of semiconductor diodes and I already mentioned to you that diodes are electrical solid state version of the earlier valves, the two electrode vacuum tube devices.

I have shown the symbol of the diode.

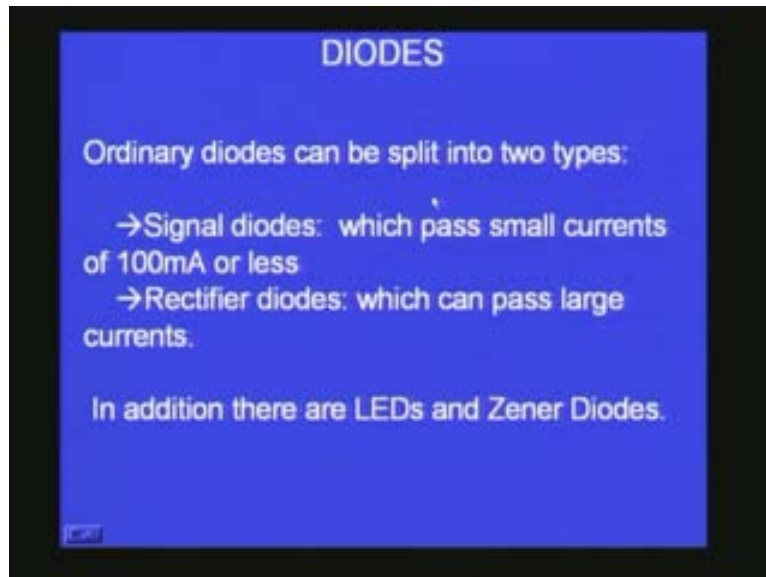
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This is a very popular diode BY 127. Physical dimension will be some thing like that and they will show an arrow on the body of the thing painted. That shows the direction of

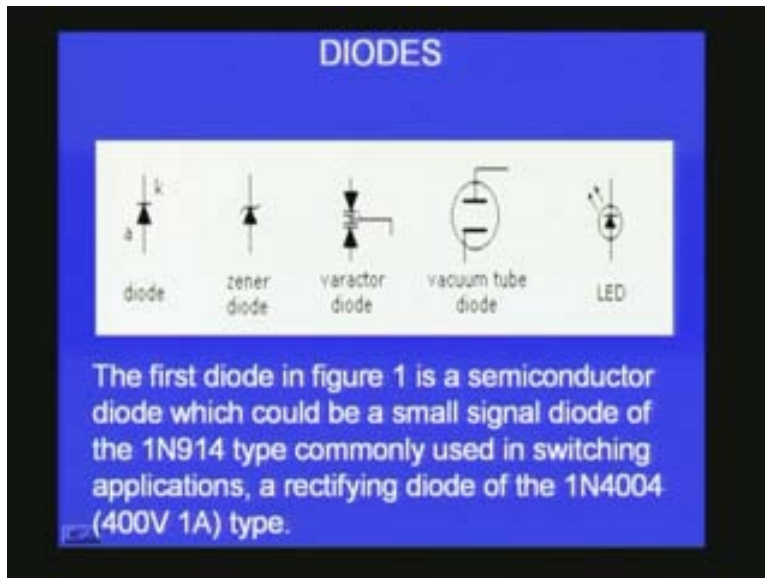
easy current flow or low resistance. It can also be shown by a dot, blue and red dot as you can see in the case of OA 8G diode, pin point contact diode and that is shown by a red and a blue dot. The red dot shows the cathode and the blue dot shows the anode terminal. The ordinary diodes that we normally make use of are of two types.

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One is the signal diodes which are used for passing very low currents or less than 100 milliamperes. Then there are rectifier diodes which I already mentioned to you. They are used for building large power supplies and therefore they can pass large current several amperes also. In addition there are other different types of diodes like LEDs which you would have already known. Light emitting diodes the diodes which will emit light and Zener diodes which are basically voltage regulating diodes. All these are different types of diodes I have shown on the screen. There is a normal diode. The first one is the normal diode the second one is a circuit symbol for a Zener diode or the voltage regulator diode and the next one is a varactor diode which is actually a capacitor, variable capacitor. It is used for variable capacitance application. This has almost replaced all the normal gang capacitors which were in use in those days and they are very efficient.

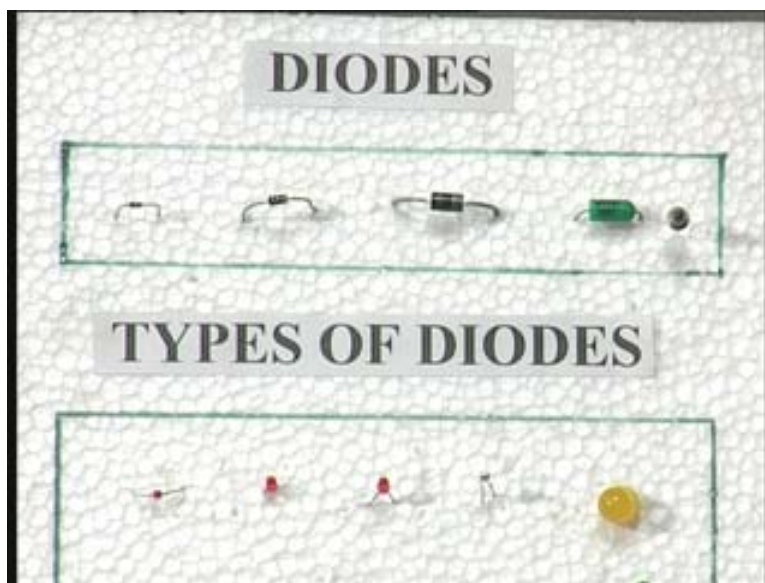
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Depending upon the voltage applied their capacitance value will change. We will see more details of these varactor later on. This is the vacuum tube diode which has got two electrodes, one plate and one cathode and finally you have the light emitting diode which is actually a diode which emits light of different colors.

I will show you some of the diodes that I have brought here for you. You can see there are number of diodes here. All of them are semiconductor diodes. They are meant for either rectification or for signal control.

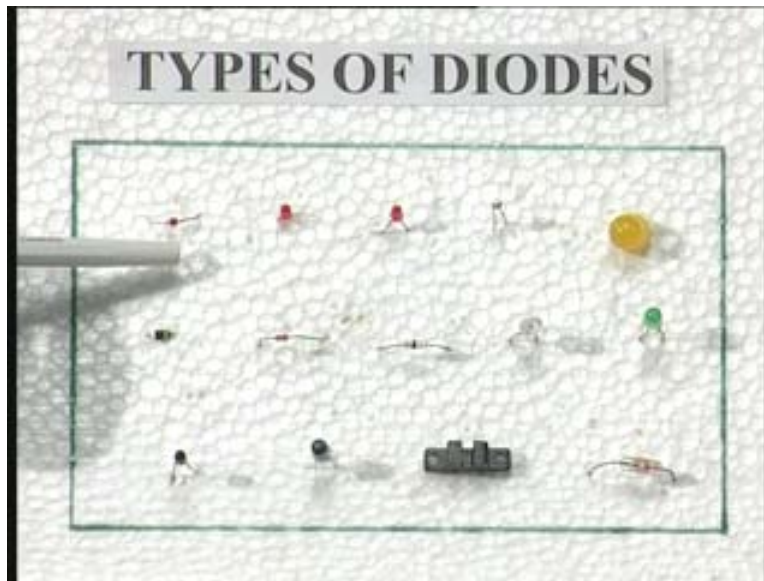
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So you have one diode here which is the smallest diode 4148. This is a general rectifier diode. This is also a rectifier diode. This can handle slightly larger current. This is like

the BY 127 which I already mentioned to you. You can see this is a diode which will take very large currents. You could also see diodes which are very big like a nut and bolt which will carry hundreds of amperes. So there are different types of diodes which are used here and there are also different varieties of diodes. I already mentioned to you about the light emitting diode.

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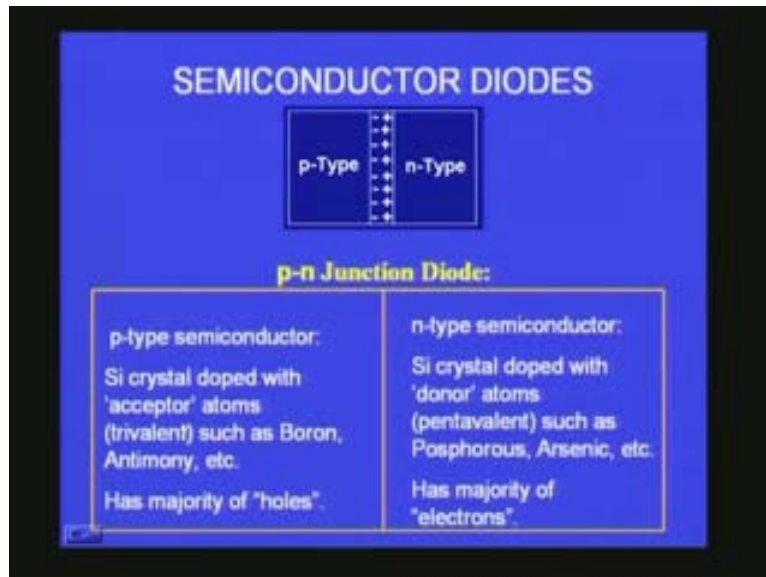


You can see the light emitting diode. All of them are light emitting diodes. They are of different dimensions. This is very small. This is about 3mm and this is also 3mm of a different color and this is a 10mm LED. This is a 5mm LED. This is also a 5mm LED. This is another diode the point contact diode. This is a Zener diode. This is a varactor diode. This is very small. This is varactor diode which is used for capacitance variation. This is again another diode. This is a photo diode. This is a optocoupler, opto isolator. You have a LED here and you have a photo diode here, both and if any things is coming in between these two, there is a small slot, if anything comes in between that, that can be detected using this. We will perhaps see little more about this later on. This is also point contact diode. So you have large number of different types of diodes which are used for different types of applications.

Let us move on to study about semiconductor diodes. The semiconductor diode I am sure many of you are familiar. I am not going into the details of the design of the semiconductor diode because it is more like a lab course. So I am going to assume certain knowledge from your side. For example the semiconductors you know are materials which have conductivity which is not as good as copper or any good conductor and it is also not bad as bad as a pure insulator. So at absolute zero, semiconductors are insulators; at other normal temperatures semiconductors have got reasonable conductivity and germanium and silicon are examples of semiconductors and you can have different types of material introduced into the semiconductors to make theme more conductive and this

is called doping. By doping an acceptor atom or trivalent atoms such as boron, etc., you can make the semiconductor P type.

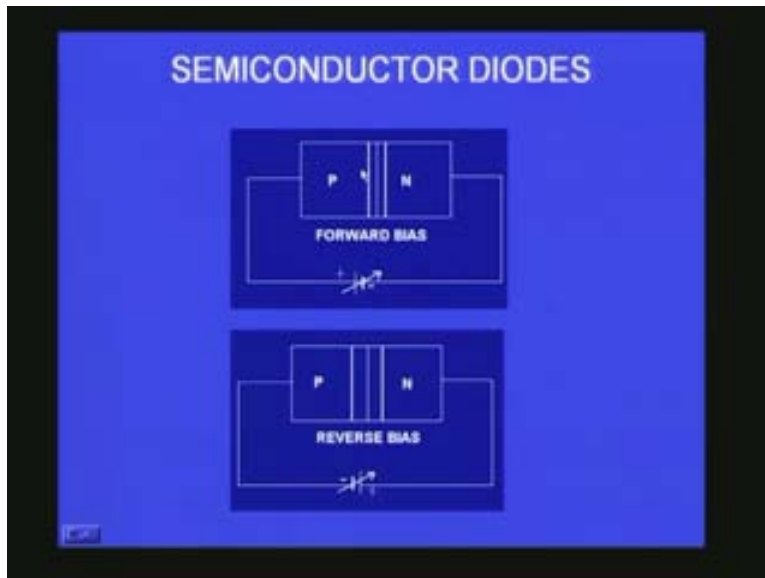
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It will have majority of holes. In the same semiconductor, you can introduce donor atoms like the pentavalent atoms such as phosphorus, arsenic, etc and then you will have majority of electrons in them. Therefore they become n-type semiconductor. So you can have two different types of doped semiconductors. One is the p-type semiconductor the other is the n-type semiconductor. The p-type and the n-type when you combine them together like I have shown on the picture, you would find some of the charges, electrons will be falling into the holes very close to the junctions where these two devices comes together and in that area you could find there will be a depletion region. All the charges will be removed from this region and there will be a very small potential developed at the junction and this potential will make sure that no more electrons from this side or holes from this side will diffuse to the other side. This is the condition when you do not apply any voltage. A normal p-n junction diode will have two types of material p-type and n-type brought together and it will form a very fine depletion layer in between.

Now what will happen if I apply a voltage? You can see on the screen I have the p-n junction diode. As you have seen previously it is connected to a battery with the p side connected to the plus of the battery and the n side connected to the negative of the battery and then you would find this becomes forward biased. That means the holes here will be repelled by the positive electrode here and the electrons will be repelled by the negative electrode from here and so they will be able to overcome the potential barrier near the centre at the depletion region and they will be able to cross over and therefore they will record a current.

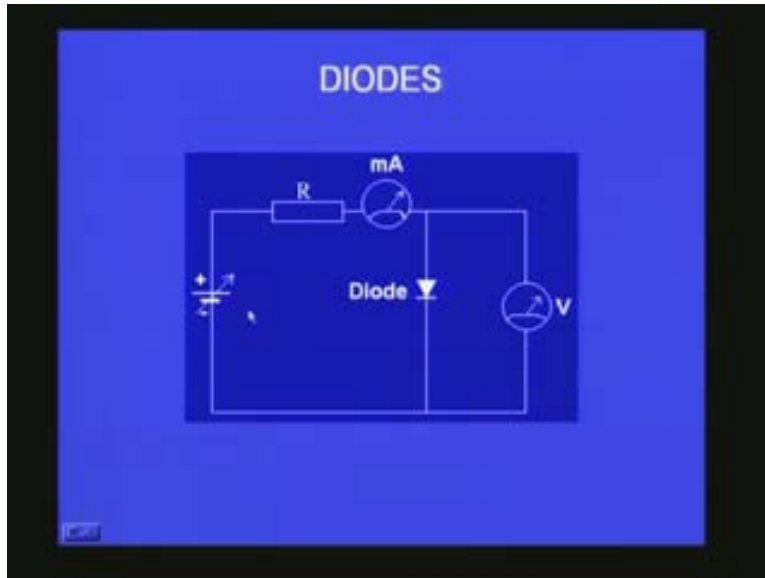
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This forward bias conduction will correspond to a low resistance path for the electrons and holes and therefore this is a low resistance configuration. On the other hand in the next picture you can see I have reversed the polarity of the battery. The p side is connected to the negative and the n side is connected to the positive. Then you would find the holes will be attracted towards the negative terminal on this side and therefore the electrons and the holes will move away from depletion region. Therefore the width of the depletion region will increase. In the other case in the forward bias the width of the depletion layer will decrease when I apply a voltage compared to the no voltage condition. So here depletion lower layer increases in width because electrons and holes move away from the junction and therefore you would find this will become high resistance region and therefore in this configuration the diode will show high resistance. So there are two configurations, the forward bias when it is low resistance path; reverse bias when it is high resistance path.

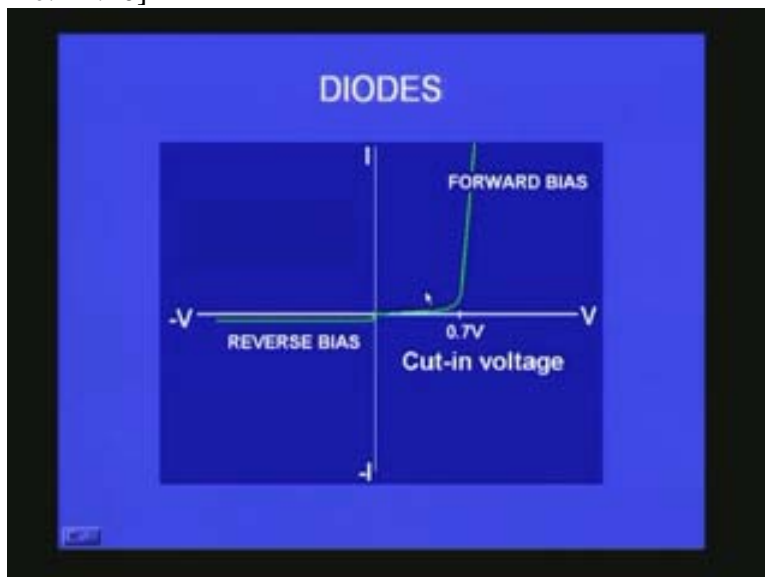
The characteristics of diode can be obtained by using a simple circuit like this where I have put the diode and across the diode I have put a voltmeter and I have put a milliammeter to measure the current flowing through the diode. This resistance is a protective resistance put in series.

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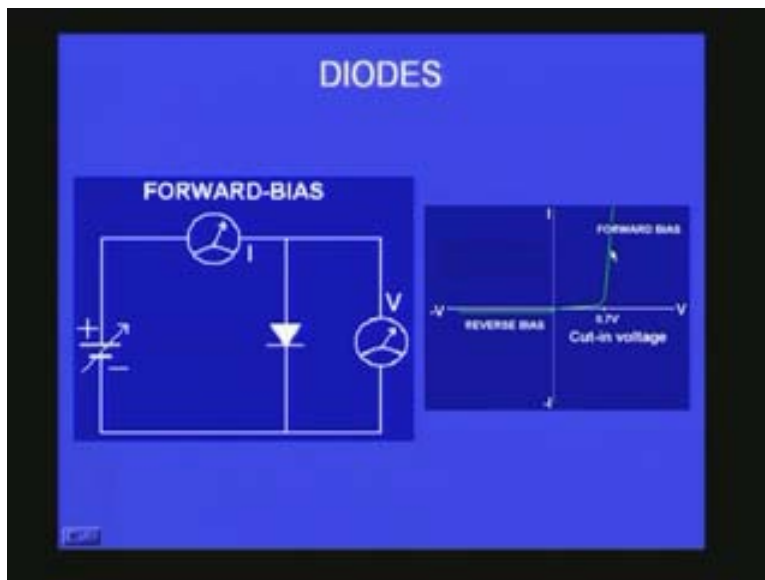
If I keep varying the voltage what will happen to the current with reference to voltage? This is what we call IV characteristics of the diode. Because we are talking of the diode passing current easily in one direction and not passing current easily in the other direction we may have to reverse the direction of the voltage also while doing the experiment. I have shown you the characteristics that would be obtained when we do such an experiment. You would find this side is the positive side and this side is the negative side of the voltage. This side is the positive current and bottom is the negative current. So when we increase the voltage on the positive side you find the current is very slow to increase at the beginning and then at around 0.7V or so the current starts increasing enormously. So this 0.7 which is characteristic of silicon is called the cut in voltage beyond which current will be very, very large; below which current will be very, very small.

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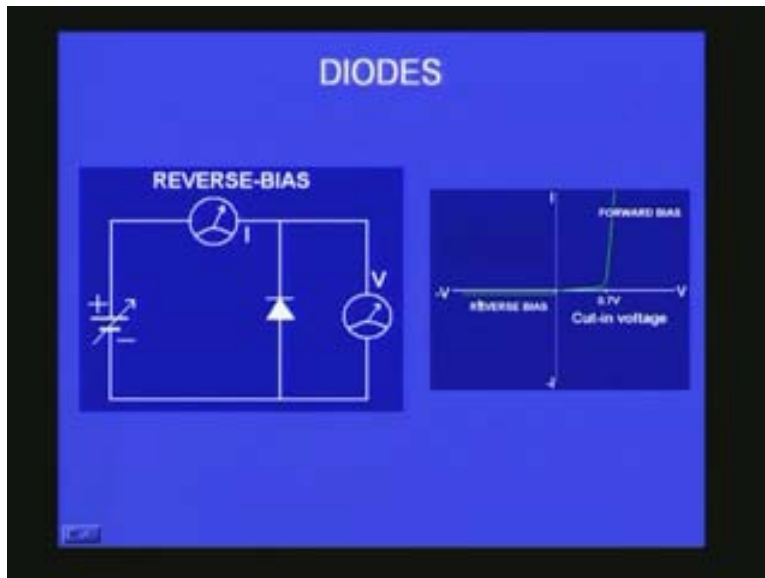
This is the characteristics of the forward bias diode. The same voltage for the case of germanium diode will be a just around 0.1 to 0.2. So it will start rising even when the voltage is 0.1 or 0.2 across the diode. But when you now reverse the voltage and apply negative voltages you would find the current is very, very small of the order of micro amperes or even less and they will be constant for a given temperature. If you increase the temperature, this current can increase but otherwise it will be very, very small. If you use the same milliammeter on the reverse side you could never even see any reflection on the meter because the current will be much less than the milliammeter that you want to measure and therefore this is the IV characteristics of a diode on the forward and reverse bias. I have also shown separately the two circuits and two graphs.

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This is the forward bias where you can see plus is connected to the positive end of the arrow and negative is connected here and you have the I and V and this part of the graph will be obtained by using this circuit and next when you have the reverse arrangement, reverse bias then this is the graph that you would obtain.

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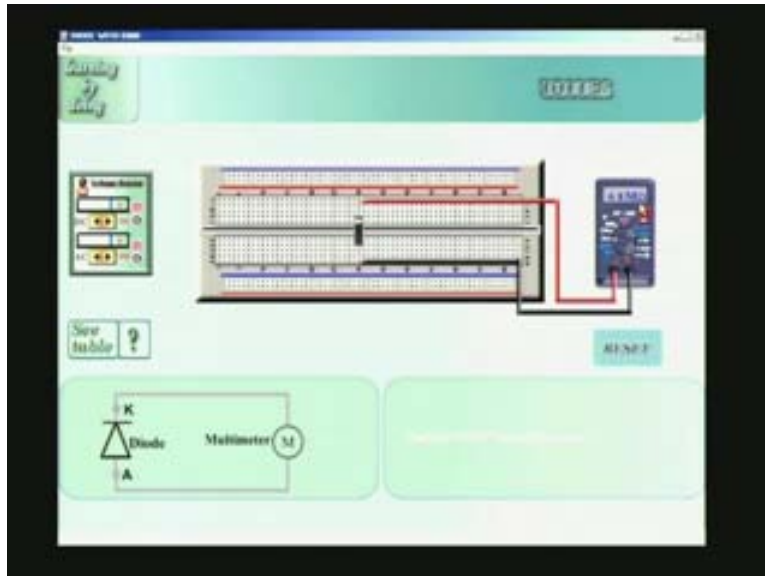


A constant but small current will be flowing which will be temperature dependent and which will be very, very small of the order of few micro amperes.

How do we test whether the diode is working well or not? The simple way is to use a multimeter. We know the diode shows low resistance in one side and high resistance on the other direction and therefore I can just put the multimeter in resistance mode and just connect the two terminals to the ends of the multimeter in the ohms range. When I connect in a particular direction the resistance will be small of the order of the few kilo ohms and when you interchange the terminals and measure the resistance, the resistance will be very large. We will later on see that experiment also.

We will actually see a simulation of the experiment now. On the screen you have a breadboard and you have a diode. It is now in the forward bias direction and I have connected the multimeter and let us now switch on the multimeter to measure the resistance range. It in resistance range and you can see the reading is 2.3 kilo ohms. So the diode in this connection, which is the forward bias connection; red connected to the positive end of the diode, black connected to the negative end of the digital multimeter. The resistance is 2.3 kilo ohms which is a small value. Now I switch off and then try to change the orientation of the diode by clicking on the diode. When I click on the diode, the diode becomes reverse biased. You can see the negative terminal has moved to the top side compared to the previous one and therefore now I have reversed the diode. Now let us switch on the multimeter and measure the resistance and the resistance measured is 6.8 megohm.

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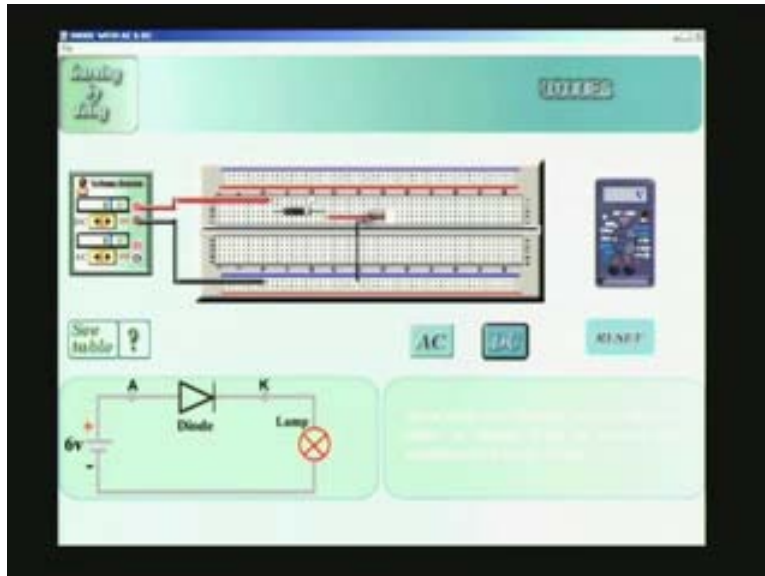


In the forward bias it was around 2-3 kilo ohms and in the reverse bias it is 6-7 megohms and therefore there are two different resistances corresponding to the forward and reverse bias directions.

Let us move on to the next slide. I already mentioned to you that we do have apart from silicon diode, germanium diode and cut in voltage for the germanium diode is about 0.2V approximately and they also can be used. But they are not very useful because they are not as good as silicon diode with reference to temperature behavior. The temperature is one of the important parameter which can alter the performance of semiconductor devices and in that germanium diodes are more prone to variation due to temperature compared to silicon diode and therefore people generally prefer silicon diode in their applications and even while soldering one has to take care that they do not heat the diode too much because it will degrade the performance of the diode.

Let us try again simulation experiment with the diode, with an AC and a DC. I will click on the DC. You have a diode and you have a lamp here and they are now connected to a voltage source. The positive end is connected to the positive of the battery voltage source and negative end is connected to the lamp and then the circuit is completed. Let us switch on the voltage source and then when I apply 6V which is the voltage corresponding to the lamp you would find the lamp glows. Because the lamp glows we understand diode is offering low resistance. That is why all the current is able to flow through the lamp and therefore the lamp is glowing. If I switch off, the lamp is off. When I again switch on the LED the lamp glows. So this shows when I connect the diode in the forward bias direction the current flows through the circuit.

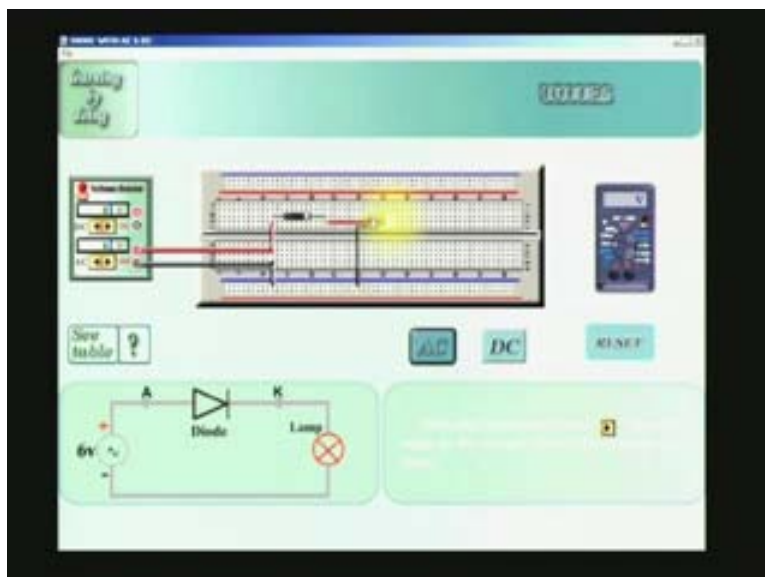
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I click on the diode; immediately it becomes reverse biased. The diode is changed in direction and now I will again switch on the power supply and apply the same 6V. Now you find that the lamp is not glowing. The lamp is not glowing because the diode is reverse bias and in the reverse bias direction the diode offers large resistance. Therefore there is no current flowing through the lamp and the lamp does not glow. This is a very simple experiment to show that the diode conducts in only one direction.

Let us try the same experiment with AC. I have an AC source here and now that is connected to the diode and the lamp in series. If I now switch on the AC source and connect 6V you find the lamp glows.

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Because AC means alternating it has got both positive and negative terminal which will keep changing with reference to time and so you would find one half of the applied voltage will be passed through the diode when it is positive with reference to the diode and therefore the lamp glows. But if you are very observant you could find the intensity of lamp now is nearly half the previous one. If I switch off and interchange the diode as before, I have changed the direction of the diode now. I again switched on the power supply and apply the AC volts. You find now also it glows. So when I apply AC for both orientations of the diode the lamp glows but with less intensity. This is understandable as I already explained to you because AC means alternating the positive and negative terminal will be alternating and therefore for one half of the period, the diode will be conducting which ever orientation the diode is connected in the circuit. This is a very simple circuit to show the basic behavior of a semiconductor diode.

The other type of diode I already mentioned to you is light emitting diode. The diode which emits light when you apply a voltage when it is forward biased. This is very useful in generating displays as lamps to indicate for example whether a particular device is on or off; the power supply or a multimeter or a television. So this is used for different applications in display and I have shown a very simple circuit here.

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The slide is titled "DIODES" and contains the following text:

- The LED requires about 10mA for a bright glow and has about 1.7V across its terminals.
- Hence when we connect a 5V power supply (V_{cc}) to it we must include a resistor in series to drop the excess 3.3V [(5-1.7)V].
- Hence the value of series resistor is

$$R = 3.3V/10mA = 330 \text{ Ohms.}$$

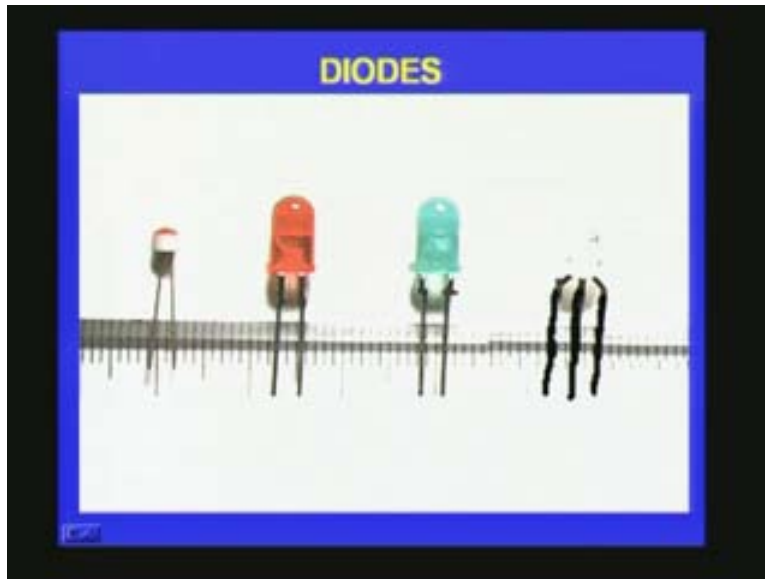
The circuit diagram on the right shows a power supply labeled V_{cc} connected to a resistor labeled R , which is in series with an LED. The LED is represented by a triangle pointing to the right with a vertical line and a small arrow pointing away from it. The bottom terminal of the LED is connected to ground.

You have got a V_{CC} ; you have got a resistor connected in series with the diode. This diode is the light emitting diode. By choosing proper material, the diode can be made to emit different colors. It can be red, it can be blue, it can be green or it can be yellow. LED normally requires about 10 milliampere of current passing through them to generate reasonable glow and they approximately have about 1.7V across the terminals here, about 2V. Hence when we connect a 5V power supply in general then we must make sure that the excess voltage 5-1.3 which is 3.3V is dropped in some resistor which is connected in series. Therefore now we can find out what should be the value of resistance, R , to be connected in series with the LED so that the 10 milliampere current will be maintained

across the LED. So all that you have to do is $3.3V/10$ milliamperes, which gives 330 ohms. Therefore whenever you use 5V to energize a LED you use a 330 ohms resistor in series. That will be good enough to maintain a constant current of about 10 milliamperes across the LED and the LED will glow brightly. If you connect it the other way that is V_{CC} to the other side and ground then you would find the LED will not glow because LED as I mentioned to you already is also basically a diode.

I have shown in the picture the different types of LEDs.

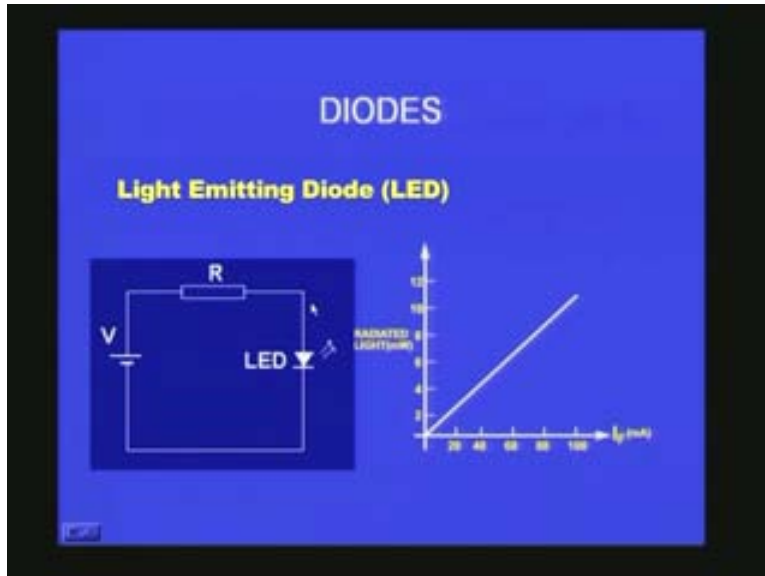
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You can see the red, the blue and the green. You also have these days multicolor LEDs. That is you can have in the same encapsulation two LEDs mounted side by side so that if I connect in one orientation one LED will be forward biased and a corresponding color, say red, will be glowing and when I reverse the voltage then the other LED will be forward biased and which will give a different color, for example may be green. This is useful also in different applications to indicate a very specific condition of the circuit or in which directions the current is flowing, etc.

When I plot a graph with reference to current verses the radiated light for an LED, you find the graph is almost linear. That means light intensity increases linearly with the current. If I increase the current the brightness of the light also will increase. But we should make sure that we don't pass too large a current otherwise the LED will be burnt out. Also one important point with reference to LED is they are very sensitive to reverse voltages. If you exceed reverse voltages by more than 3 or 4V there is no possibility that the LED will still survive such a treatment.

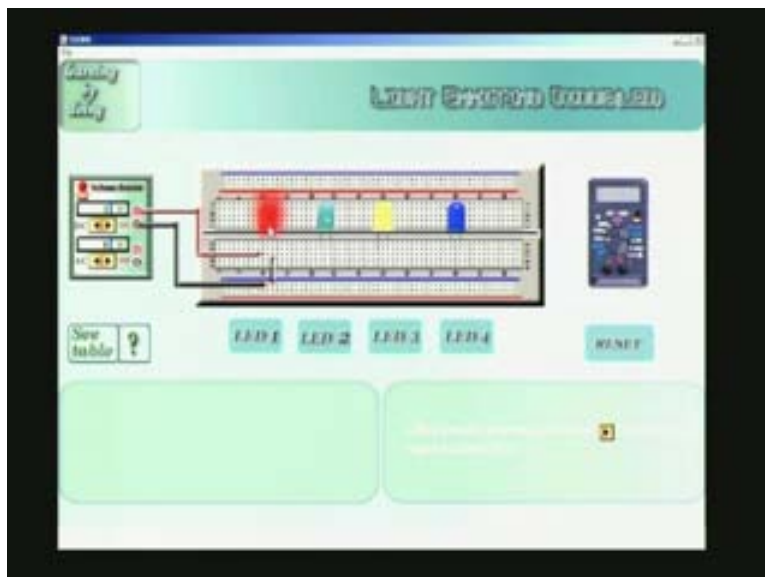
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So one has to be very careful when one applies reverse voltage to the LED; it should be very less.

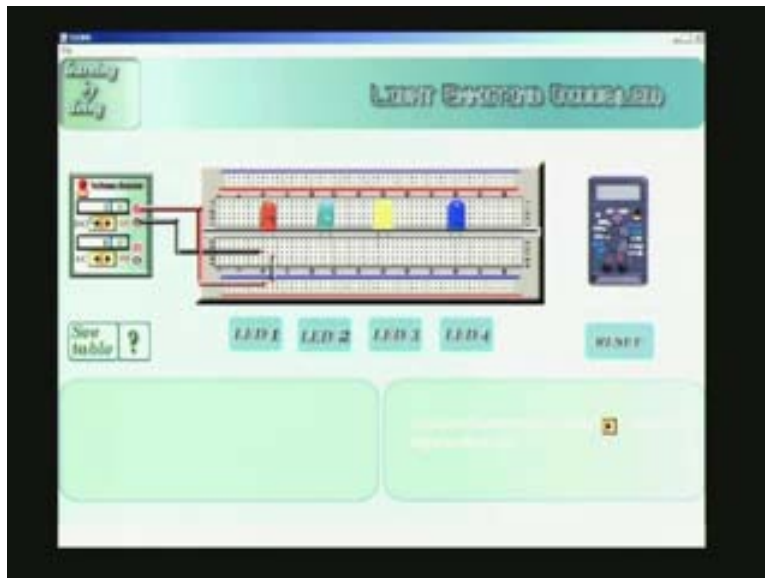
Let me go on to show you a demonstration, simulation of different LEDs; a very simple simulation. I choose for example red LED. Immediately the wiring is done. With reference to the voltage source it is connected to the LED. Positive connected to the positive end; negative connected to the negative end of the LED. I switch on and then I switch on the power supply. I apply about 3V standard, fixed voltage, you find the LED is glowing.

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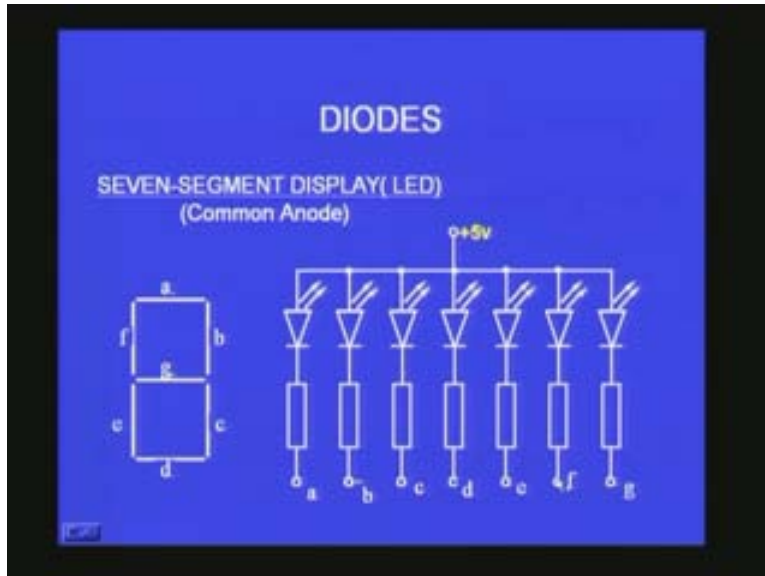
It is not glowing when I remove the voltage. I will switch off and reverse the LED and see whether it is a diode or not. When I now click here instead of reversing the diode I have reversed the polarity at the power supply. I have interchanged the plus and minus terminals. So plus terminal is now connected to the negative of the diode and the positive is connected to the ground. Now if I switch on the power supply and apply the voltage you find the LED is not glowing.

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Therefore you can see the LED is also a light emitting diode. Basically it is a diode. Therefore it will conduct in only one direction and due to that there will be a glow only in one direction. Now I will switch off. We can choose any other LED. For example I will choose LED 3 which is a yellow LED and if I switch on you can see the glow is yellow and again if I interchange you would find that it will not glow. When I switch on the power supply, apply the voltage you find the LED is not glowing. So LED is also diode and it can be used for different lamp indication purposes in different circuits. Light emitting diodes are also used very widely in display devices by a very ingenious technique. The technique we use is to arrange the LEDs in the form of figure eight. You can see on this side, left side of the picture you have seven segments a, b, c, d, etc. There are seven segments. All these seven segments are individual LEDs. This is one LED in the form of a bar; b c and everything is a LED. They come into two different configurations. One is called common anode. That means all the anodes of all the seven LEDs are connected together and that can be connected to the plus of the power supply and all the negative terminals you have to connect to the series resistor and connect it to power supply ground.

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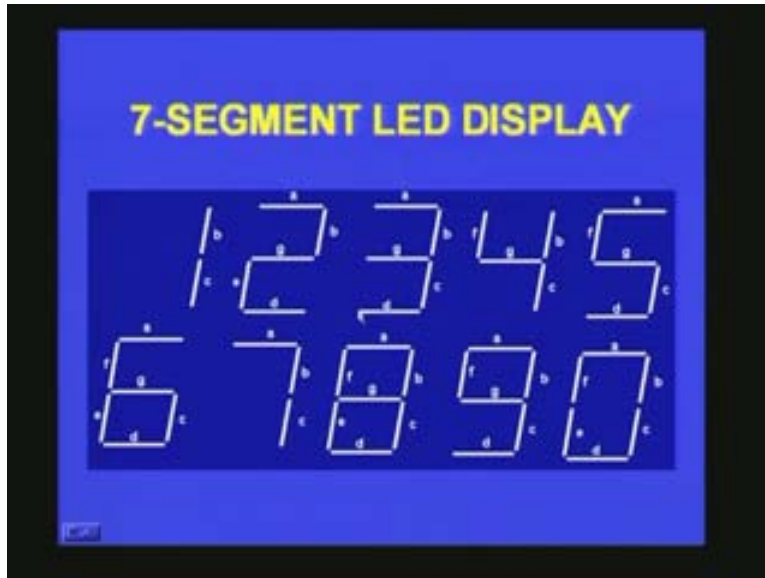


Then you would find all the LEDs will glow. I have shown the LEDs in this way by the symbols. But these are actually the segments a, b, c, d, e, f.

You also have another variety of seven segment LED display which is common cathode. In this instead of the anodes being connected together the cathodes will be connected together and they will be maintained to cathode and all the anodes can be individually switched to get the different segments glowing. The idea behind the seven segments is that by selectively glowing any of the combinations of the segments you can generate all the number that you want from zero to nine. For example if want zero I will make the 'g' LED not to glow and all the other LEDs will glow. Then you could find number zero on the screen. If you want number eight then I will make all the seven segments glow. Then it will become figure eight. If I want number one I will make only b and c to glow; rest of the segment will not glow. So like this by selectively making the LED's glow you can generate different numbers. I have shown it in the next screen.

For example b and c will give me one; a, b, g, e, d will be give me number two; number three, four, five is not good enough perhaps. But still you can recognize it as number four, five, six, seven, eight, nine and zero. All the numbers can be displayed using one single seven segment LED.

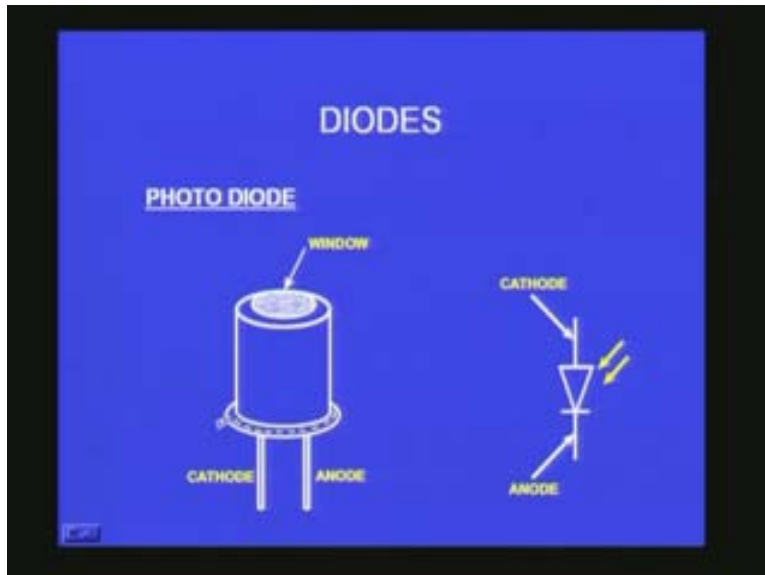
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You can put them in an array side by side and make the display come with two digit or three digit numbers you want.

Another variety of the diode is a photo diode which I did not mention so far.

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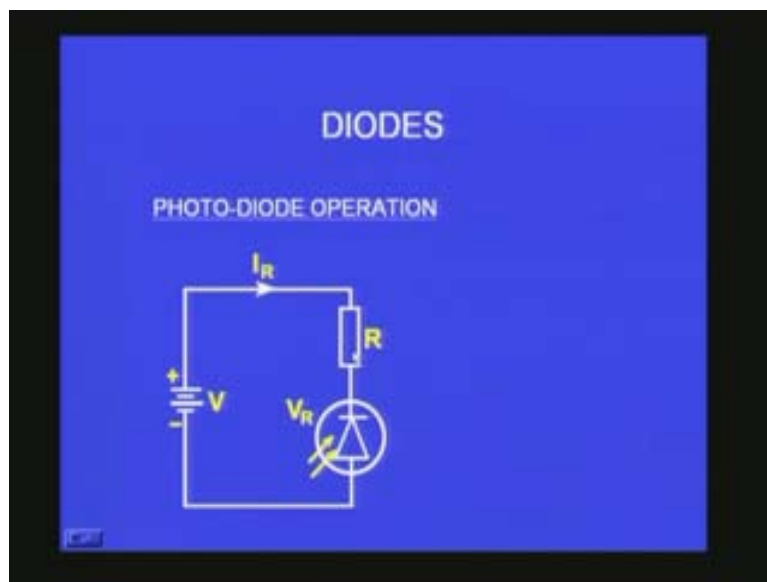


A photo diode is the opposite of light emitting diode. In the light emitting diode light is emitted; in the photo diode light is received and there is a corresponding change in the diode due to the light incident on that. Remember we discussed about different types of resistors. We talked about light dependent resistors, a cadmium sulfide crystal, where when you shine light the resistance becomes less and when you cut off light the resistance becomes large. Similarly this is a diode in which when you shine light current

is generated; when you do not shine light the current is zero and therefore it is in the off condition or open condition.

Circuit symbol for the photo diode is same diode symbol with arrows pointing towards. For a LED we put the arrows coming out to show that light is coming out of the LED. In this case light has to be received by the diode and therefore the arrows are shown towards the diode. This is an encapsulation of the diode. It is like a simple transistor with the top open and with the small lens put there so that light can go in and then reach the semiconductor which is maintained here, the p-n junction. Normally photo diodes are operated in reverse bias.

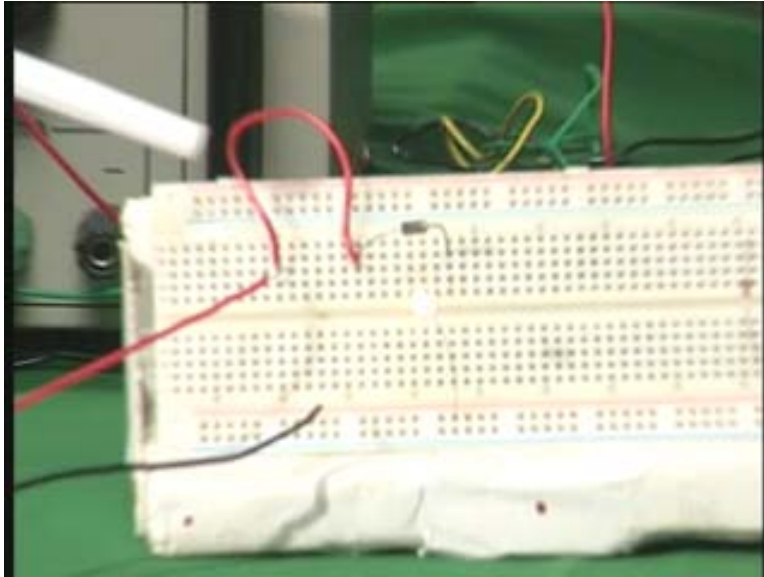
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With the series resistors you connect the voltage source in a very simple scheme like that and if you now measure the voltage across the diode you would find it will be very large when there is no light falling on it. When you shine light the resistance will drop down because there will be a current flowing through the diode and because of this the resistance will decrease. Photo diodes are useful in optical detectors; plenty of applications for photo diodes.

Let me move on to show you some actual experiment about this diode. Whatever I so far discussed I will show you. Here on the breadboard I have one diode. You can see the negative end on this side. This is a normal 1N 4002 type of a diode, rectifying diode and there is a very small lamp, 6V lamp which is also connected in series and now I want to connect this voltage source. I have connected the voltage source with the positive connected to the diode end and the negative is connected to the lamp and then the negative of the battery is coming back. Let me set the voltage to around 6V. When I apply 6V you find the lamp is glowing. I hope you can see the lamp glowing.

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When I connect the plus to the plus end of the diode and the circuit is completed you find the diode is forward biased so it conducts and therefore the lamp is glowing and you can see that. I will quickly remove the diode change the orientation put it back without changing the voltage and let us see whether the lamp is still glowing. I removed the diode; I change it over and connect it to the same point. Now you find that lamp is not glowing. I can change the power supply here again back so that it will again be forward biased. Then the lamp should glow. Let us see. Now you can see the lamp is glowing because I have interchanged the diode as well as the connection to the power supply. Therefore again it is forward biased and therefore the lamp is glowing. So you can see a diode will conduct only when forward biased. That is what we have seen.

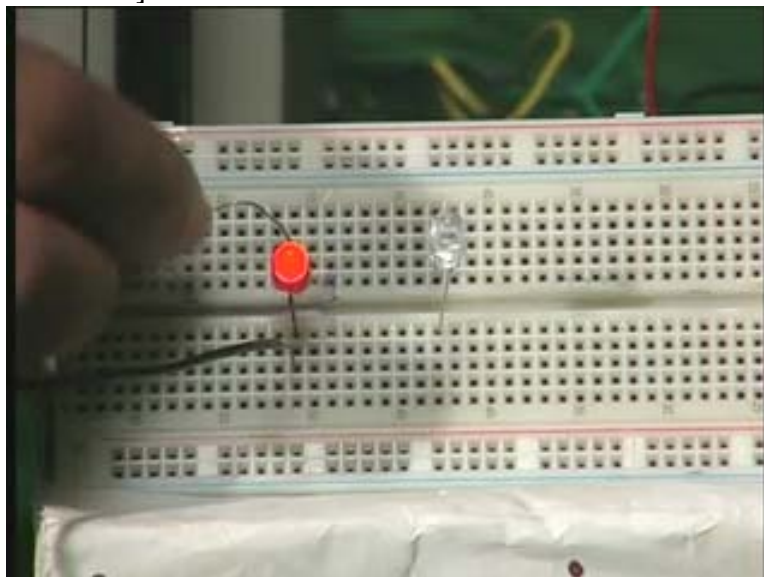
We have also said how a diode can be tested using a multimeter. I have got a diode here. I am going to test whether it is working or not using a multimeter. I connect the multimeter in the resistance mode. Now it is in the resistance mode. I take the two leads and connect one across the diode and let us see what the resistance is.

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So it is high resistance. Now let us interchange and see what the resistance is. Now you see it is around 980 K ohms. In one configuration it is about 970K ohms or so in the other configuration it is showing very high resistance. The blinking corresponds to very high resistance; it is much larger than 40megohms and therefore a diode can be tested by just using a multimeter in the ohms range and if you have low resistance for one orientation and high resistance for another orientation then the diode is in good condition. Otherwise the diode has to be discarded. Let us move on to the next experiment which will involve the light emitting diodes. I will set the voltage to a lower value because I already mentioned to you that a LED has to be powered with a very small voltage of the order of 1.7. So I will keep around 2V. I will connect this power supply across the two LEDs that I have here. Let me see whether LED is glowing or not. Now I have connected immediately you see the LED is glowing.

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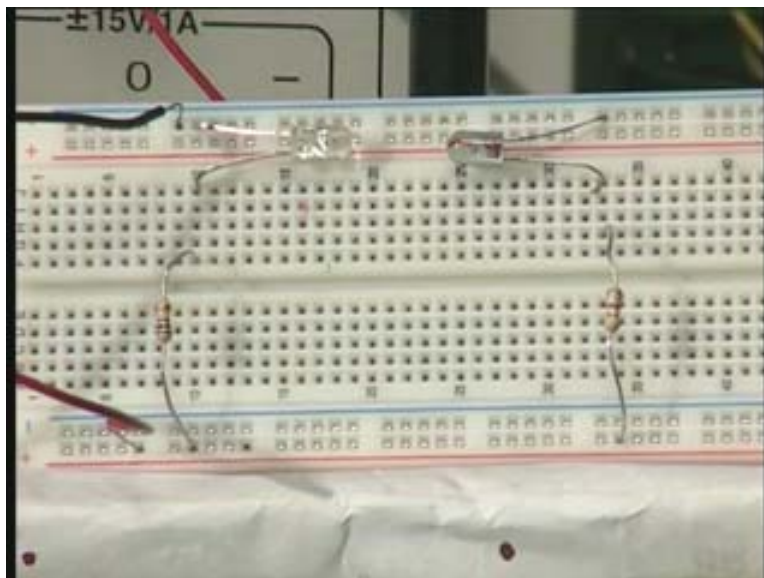


If I remove, it goes off; if I connect it is coming on. If I interchange black I put at the top and red I put at the bottom you find the LED is not glowing. Therefore the LED is glowing for only one direction and that is the forward bias direction. Let us test the other LED. I hope you can see the LED; the glow is there but it may not be enough. I can increase; so it is now glowing. When I remove it is not glowing. When I include because it is transparent perhaps the color is not very well seen but you can see that LED is glowing. So when I interchange this also will not glow. When I put the black on the top and connect the bottom to the plus you would find the LED is not glowing. Therefore these are basically diodes but light emitting diodes.

I also have a seven segment LED connected here. Let us connect 5V, the positive of the battery and set the battery voltage to 5V. If I touch the different pins, you can see the different segments will glow. This is one of the segments; this is the second segment; this is a dot; this is the third segment. I hope you are able to see. Similarly on this side you can see the other segments. There are different pins. By connecting them to different pins you can see the different segments can be made to glow. There are circuits which can be used to directly make them come with numbers zero to nine. This is also a very useful device.

Let me move on to the next experiment which makes use of a photo diode. Here I have a photo diode. I again apply about 5V. This is a LED. This is a photo diode. This photo diode is connected in series with a large resistance. It is about 4.7K by the color code. This is about 100 ohms. I have connected 100 ohms in series with the LED and applied about 5V here. Therefore a large current will flow through the LED and this light will be falling on the photo diode and therefore you find the resistance of the photo diode will decrease. When I measure the voltage across the diode or the resistor, it should change depending upon the light falling on it.

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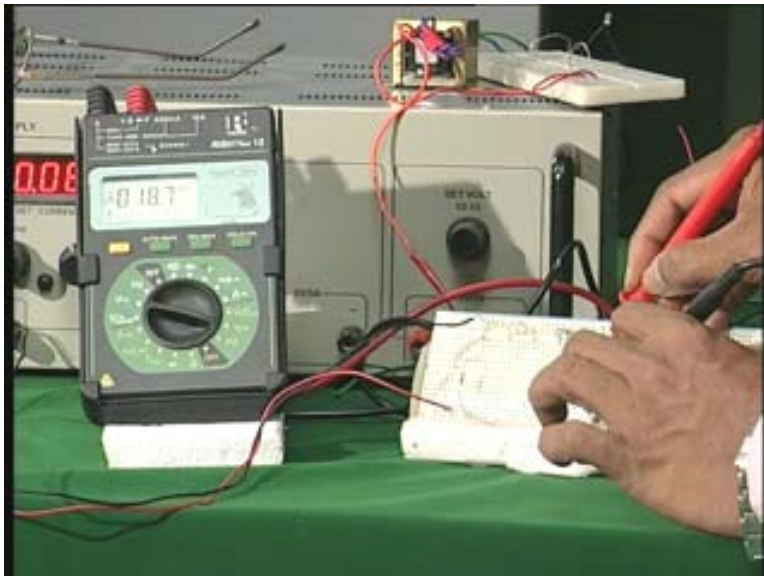
Let me use the multimeter to measure voltage. I have connected to positive voltage, DC voltage. Now I will connect the voltmeter across the resistor and see what is the voltage? It is around 26 millivolts. I put something in between here and then measure the voltage. If I hide now you find there is zero millivolts.

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The display shows zero millivolts. If I remove it and connect it here you find I get 18.7 millivolts.

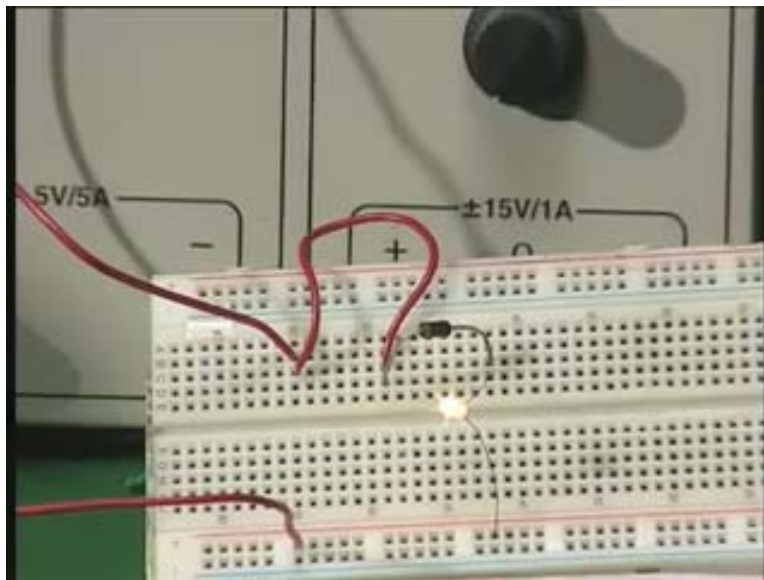
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The light that is coming out here need not be visible light. Actually this is an infra red light emitting diode. This diode emits light not in the visible range but in the infra red range and that is why even if there is enormous light around still this is behaving properly with some 18 millivolts and zero millivolts because this is more sensitive to infra red region. So this is the photo diode that I just talked to you.

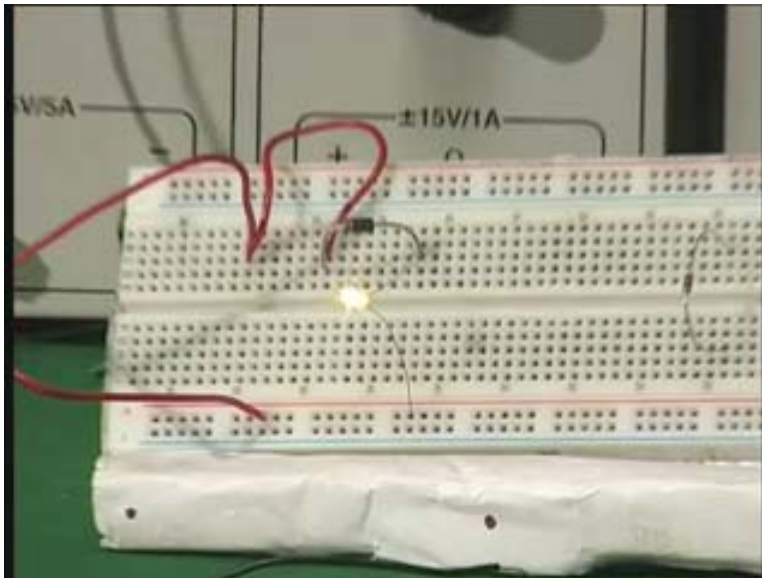
I have shown the diode only with DC. I have a transformer which gives around 9V or 6V. I am going to connect the transformers across the diode and the lamp circuit which we already saw. Now what happens? This is a transformer which provides 6V and the AC and therefore the LED is glowing now.

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Now I interchange the two terminals. I remove the bottom one and put it on the top and the top one to the bottom still the lamp is glowing because this is alternating current.

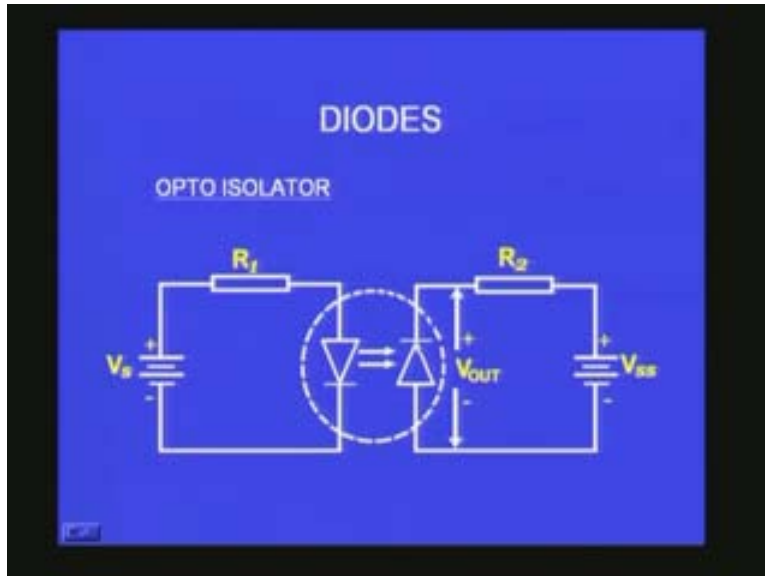
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You can also see that the intensity is slightly less than what you obtained when you obtained pure DC from here. Therefore you can see a diode will pass AC because there are two halves; one on the positive going side and other one on the negative side. The diode will at least pass one of them depending upon which orientation it is in the circuit. So you find the diode passes AC but it blocks DC; unidirectional. After passing through the diode the current will become unidirectional. After passing through the diode the AC becomes a DC. That is why diodes are used for building rectifier circuits to convert AC into DC. We have seen the following demonstrations: how a diode can be tested with multimeter? how diode behaves with DC and with AC? how the LEDs are made to glow by using simple 3V supply and how display devices exploits the seven segment arrangement of the LED and finally we also saw the application of a simple working of a photo diode where we used an infra red light emitting diode and infra red sensitive photo diode. When the two are arranged in series facing each other you would find when I apply the voltage the infra red beams are received by the photo diode and therefore its resistance is very low. When I cut that by using some object in between the resistance becomes very large and therefore the voltage become less across that. This we have already seen.

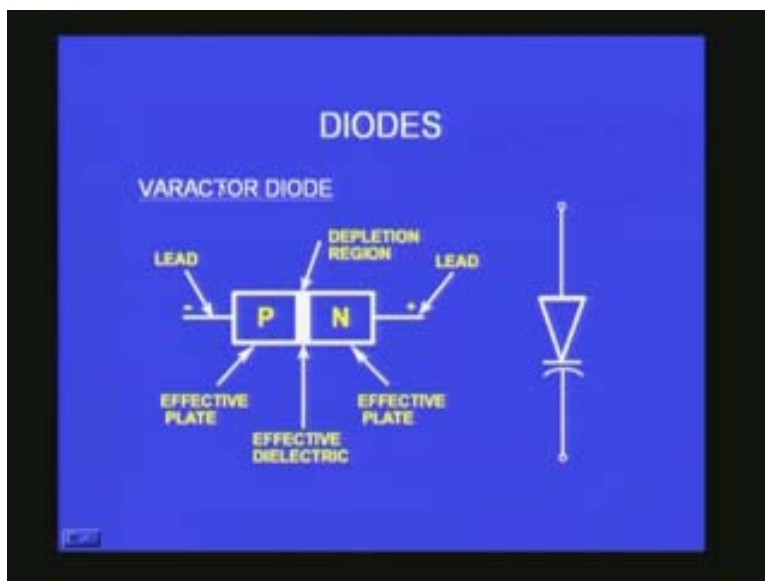
Another application of the photo diode is what is known as opto isolator. In different circuits some time we find we have to isolate two different parts of the circuit. There should be no electrical connection at all. In such a situation we can make use of the combination of a photo diode and a LED. That is what is shown here. You have a voltage source, you have a resistor and you have a LED. On the other circuit we have the voltage source, resistor and a photo diode.

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When I change the voltage here the LED intensity varies and therefore the photo diode receives different intensity and its resistance can vary and that can be detected. You find a connection between two circuits. Whatever that I do here will also be felt on the other side of the circuit. But the link is not direct but only through the light beam that is passed between the LED and the photo diode. So they are perfectly isolated with reference to electrical connection but through light beam they are inter connected and therefore this is called opto isolator. They have been isolated with optical beam and the other diode that I already mentioned to you is very important; the Varactor diode.

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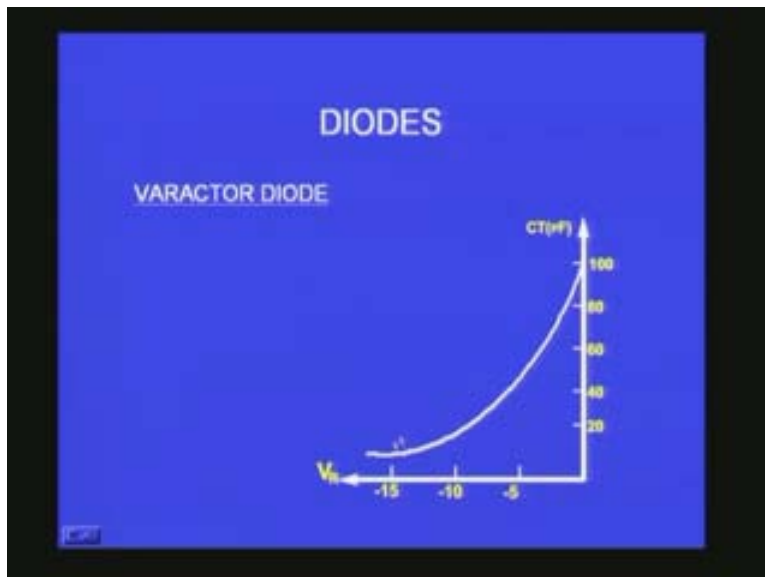


The principal of the varactor diode is that when I reverse bias a junction diode the depletion layer increases. When I forward bias a junction diode the depletion layer

decreases. That give us idea that when I change the reverse voltage you would find I can change the depletion width. The p type is a good conducting part, the n side of the semiconductor is good conducting part and in between you have a depletion layer. So it is like a capacitor with one conductor here, another conductor here separated by a dielectric insulator and this is a simple diode capacitor. When I change the reverse voltage on the diode the depletion width changes. When the depletion width changes in a parallel plate capacitor, the distance between the plates change and the capacitance will change. Therefore the capacitance of the Varactor diode depends on the applied voltage and therefore you can use it as variable capacitor. That is the application of a Varactor diode. The circuit symbol is shown here with a capacitor at the end along with the diode to show that the diode behaves like a variable capacitor.

The response of the variable capacitance with reference to the voltage is shown in this graph.

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As you increase the negative voltage capacitance drops because the width increases. This has got very wide applications in all communication equipment. In this lecture we have seen different types of diodes; what is the basic behavior of the diodes? Light emitting diode, photo diode, Varactor diode and how diode can be used for display devices in the form of seven segment LED display. In the next lecture we will see other applications of diodes like rectification and wave shaping. Thank you.