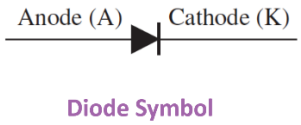
الكلية	**كلية الهندسة**
القسم	**قسم الهندسة الكهربائية**
المادة باللغة الانجليزية	Fundamentals of Electronics I
المادة باللغة العربية	**أسس الإلكترونيك ١**
المرحلة الدراسية	**الثانية**
اسم التدريسي	**حامد ردام حسين**
عنوان المحاضرة باللغة الانجليزية	SEMICONDUCTOR DIODES
عنوان المحاضرة باللغة العربية	**ثنائيات أشباه الموصلات**
رقم المحاضرة	4
المصادر والمراجع	Electronic Devices and Circuit Theory 11thEdition by Robert L. Boylestad, Louis Nashelsky
	Electronic Devices 9th Edition by Thomas L. Floyd

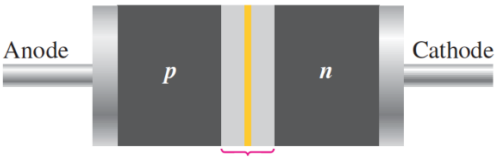
Lecture 3: Diode Characteristics

- ## The Diode

- The diode is made from a small piece of semiconductor material, usually silicon (Si). In which half is doped as a p region and the other half is doped as an n region with a pn junction and depletion region in between.
- The diode is a p-n junction diode. It is a two-terminal device that conducts current only in one direction.
- The P region is called the anode and is connected to a conductive terminal. The n region is called the cathode and is connected to a second conductive terminal.



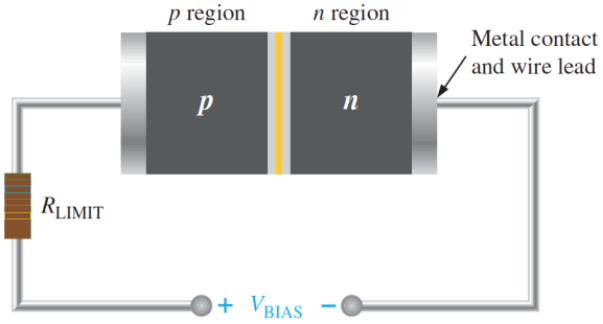
Diode Symbol



Depletion region

1. Diode Forward-Bias condition ($V_{BIAS} > 0$ V)

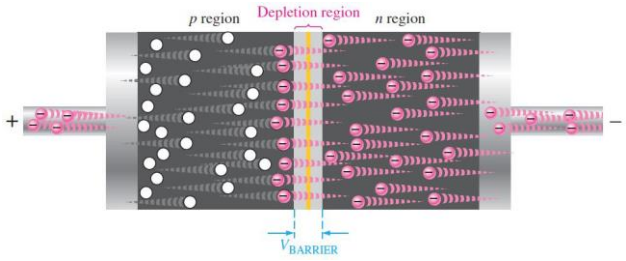
- **Forward bias** is the condition that allows current through the *pn* junction.
- **Notice** that the negative side of V_{BIAS} is connected to the *n* region of the diode and the positive side is connected to the *p* region.
- V_{BIAS}, must be **greater** than the **barrier potential**.



What happens when a diode is forward-biased?

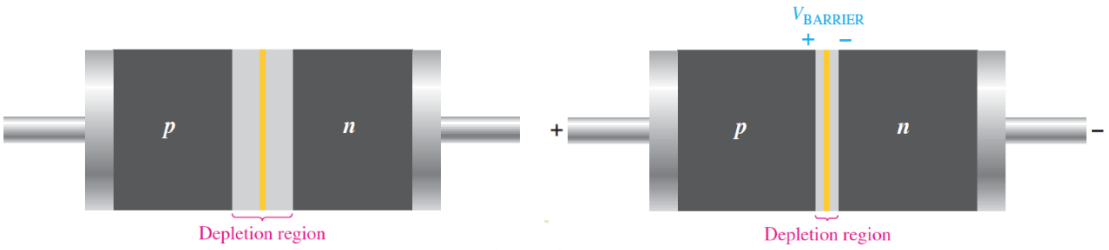
- The bias-voltage source imparts sufficient energy to the free electrons to overcome the barrier potential of the depletion region and move on through into the *p* region.
- Once in the *p* region, these conduction electrons have lost enough energy to immediately combine with holes in the valence band.
- The positive side of the bias-voltage source attracts the valence electrons toward the left end of the *p* region.

- The valence electrons move from one hole to the next toward the left.
- As the electrons flow out of the *p* region, they leave holes behind in the *p* region.



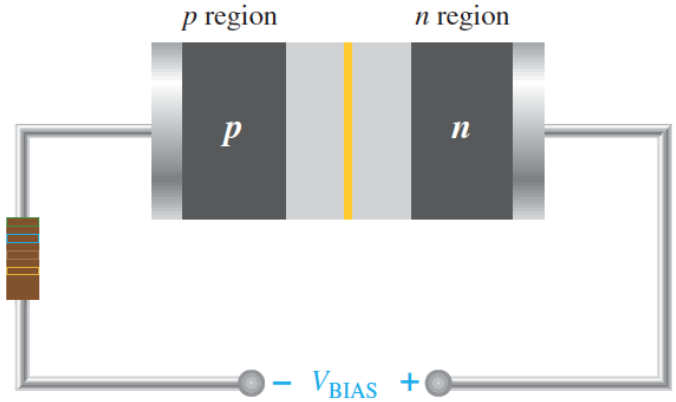
The Effect of Forward Bias on the Depletion Region

- Under the electrons flow into the depletion region, the number of positive ions is reduced.
- As more holes effectively flow into the depletion region, the number of negative ions is reduced.
- This reduction in positive and negative ions during forward bias causes the **depletion region** to **narrow**.



2. Diode Reverse-Bias condition ($V_{BIAS} \leq 0\ V$)

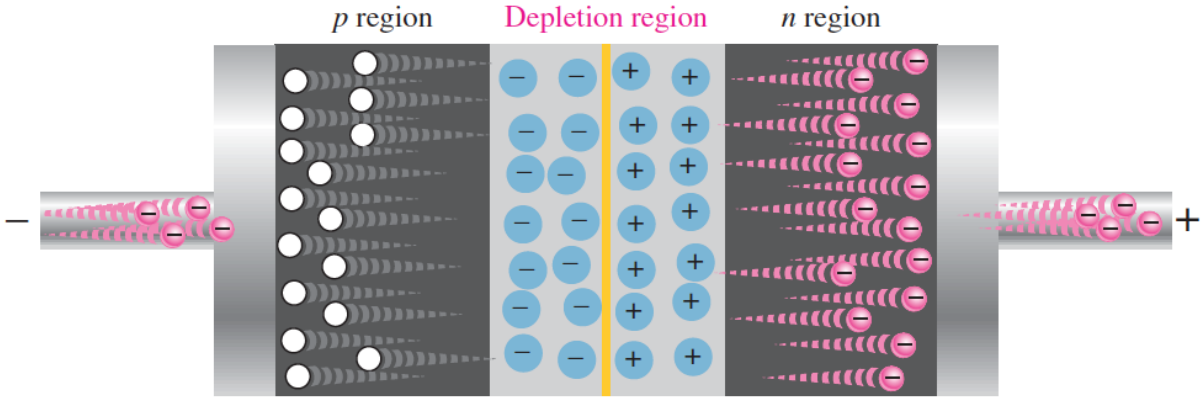
- **Reverse bias** is the condition that essentially prevents current through the diode.
- Notice that the positive side of V_{BIAS} is connected to the *n* region of the diode and the negative side is connected to the *p* region.



- Note that the **depletion region** is shown much **wider** than in forward bias or equilibrium.

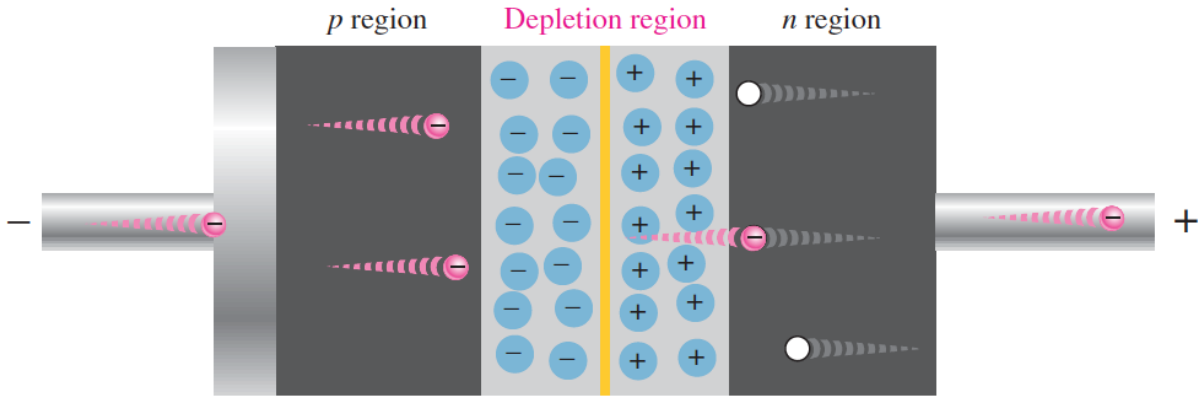
What happens when a diode is Reverse-biased?

- **In the *n* region,** as the electrons flow toward the positive side of the voltage source, additional **positive** ions are created. This results in a **widening** of the depletion region and a depletion of majority carriers.
- **In the *p* region,** electrons from the negative side of the voltage source move from hole to hole toward the depletion region where they create additional **negative** ions. This results in a **widening** of the depletion region and a depletion of majority carriers.
- As more of the *n* and *p* regions become depleted of majority carriers, the electric field between the positive and negative ions increases in strength until the potential across the depletion region equals the bias voltage, V_{BIAS}. **At this point**, the transition current essentially stops.



3. Reverse Current

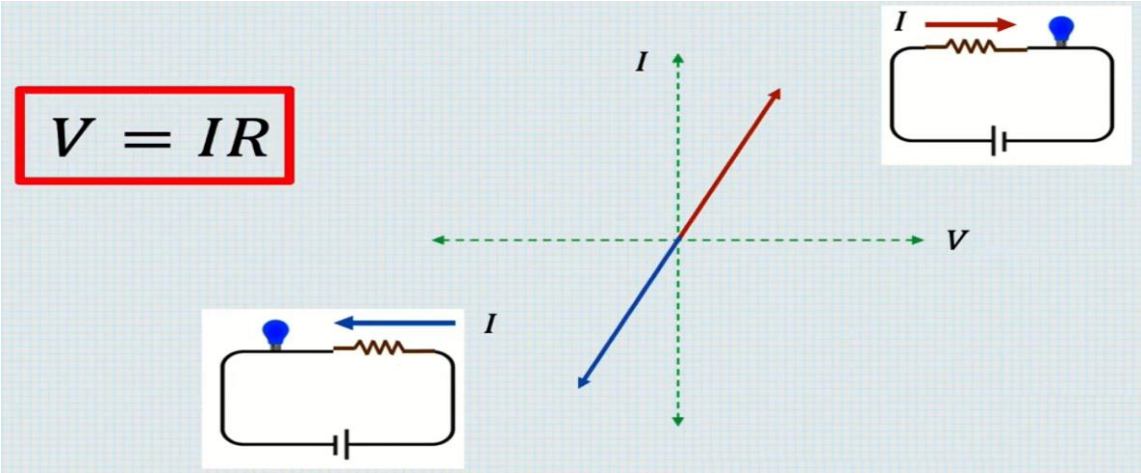
- There is an extremely **small current** that exists in reverse bias after the transition current dies out is caused by the minority carriers in the *n* and *p* regions that are produced by thermally generated electron-hole pairs.
- The conduction band in the *p* region is at a **higher energy level** than the conduction band in the *n* region. Therefore, the minority electrons easily pass through the depletion because they require no additional energy.



4. Reverse Breakdown

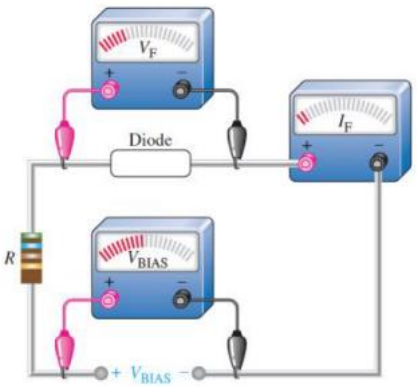
- If the external reverse-bias voltage is **increased** to a value called the ***breakdown voltage,*** the reverse current will drastically increase.
- The high reverse-bias voltage imparts energy to the free minority electrons so that as they speed through the *p* region, they collide with atoms with enough energy to knock valence electrons out of orbit and into the conduction band.
- The newly created conduction electrons are also high in energy and repeat the process.
- The multiplication of conduction electrons is known as the **avalanche effect,**

5. V-I Characteristic for Resistor

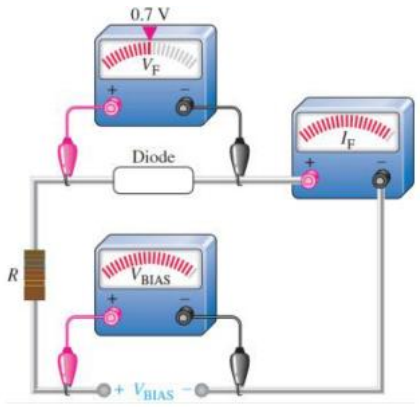


6. V-I Characteristic for Diode (Forward-Bias)

- When a forward-bias voltage is applied across a diode, there is current. This current is called the ***forward current*** (I_F).



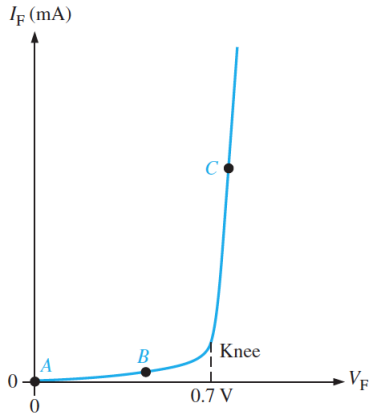
Small forward-bias voltage ($V_F < 0.7$ V), very small forward current.



Forward voltage reaches and remains nearly constant at approximately 0.7 V. Forward current continues to increase as the bias voltage is increased.

Graphing the V-I Curve

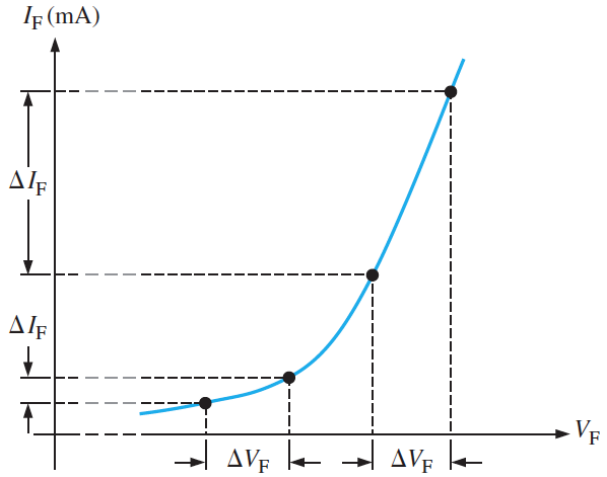
- The diode forward voltage (V_F) increases to the right along the horizontal axis, and the forward current (I_F) increases upward along the vertical axis.
- **Point *A*** corresponds to a zero-bias condition.
- **Point *B*** where the forward voltage is less than the barrier potential of 0.7V.
- **Point *C*** where the forward voltage *approximately* equals the barrier potential.
- As the external bias voltage and forward current continue to increase above the knee, the forward voltage will increase slightly above 0.7V.



V-I characteristic curve for forward bias

7. *Dynamic Resistance*

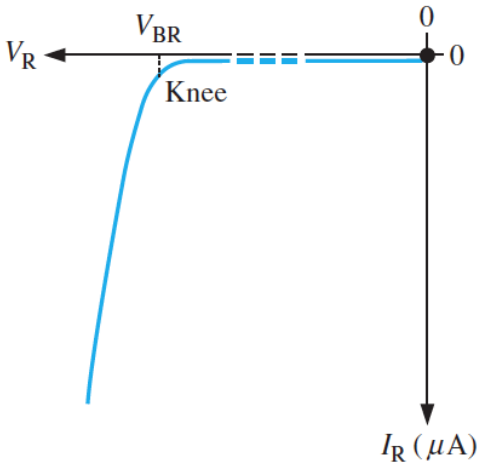
- The resistance of the forward-biased diode is **not constant** over the entire curve. It is called *dynamic* or *ac resistance r'*d.
- **Below the knee** of the curve the resistance is **greatest** because the current increases very little for a given change in voltage ($r'_d = \Delta V_F/\Delta I_F$).
- The resistance begins to **decrease** in the region of the knee of the curve and becomes smallest above the knee where there is a large change in current for a given change in voltage.



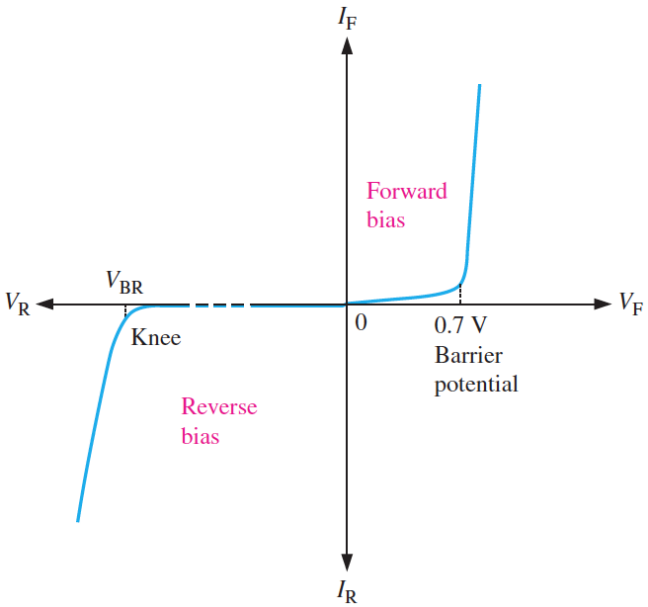
Expanded view of a portion of the previous curve

8. V-I Characteristic for Reverse Bias

- When a reverse-bias voltage is applied across a diode, there is only an extremely small **reverse current (I_R)** through the *pn* junction.
- **At 0V** across the diode, no reverse current.
- As you gradually **increase V_R**, there is a very small reverse current and the voltage across the diode increases.
- When the applied bias voltage is increased to a value where (V_R) reaches the breakdown value (V_{BR}), the **I_R begins to increase rapidly**.
- As you continue to increase the V_R, the current continues to increase very rapidly, but the voltage across the diode increases very little above V_{BR}.



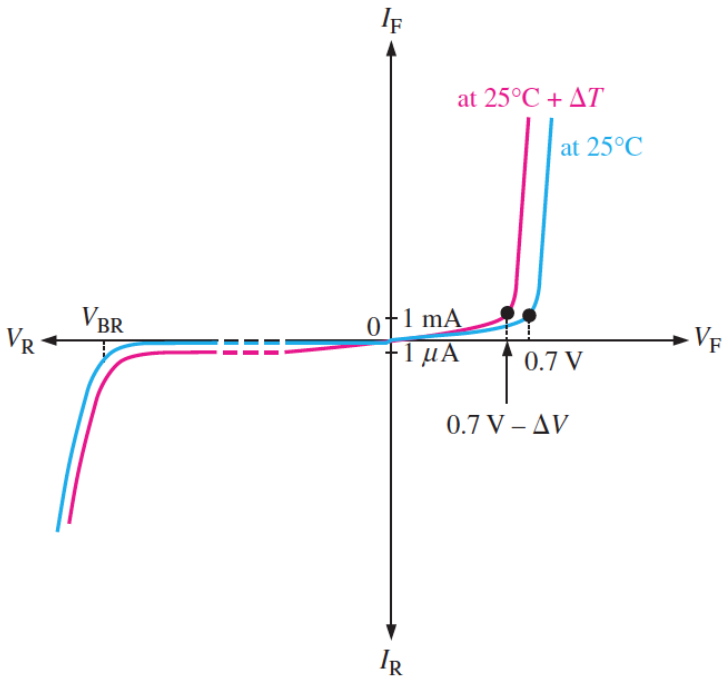
The Complete V-I Characteristic Curve:



9. Temperature Effects

- **For a forward-biased diode**, as temperature is increased, the forward current increases. Also, the forward voltage decreases.
- **The barrier potential decreases by 2 mV for each degree increase in temperature.**
- **For a reverse-biased diode**, as temperature is increased, the reverse current increases.

Note: the reverse current below breakdown remains extremely small and can usually be neglected.



10. Review Questions

1) Compare the depletion regions in forward bias and reverse bias.
2) When does reverse breakdown occur in a diode?
3) Discuss the significance of the knee of the characteristic curve in forward bias.
4) On what part of the curve is a forward-biased diode normally operated?
5) Which is greater, the breakdown voltage or the barrier potential?
6) What happens to the barrier potential when the temperature increases?