Lec (02)

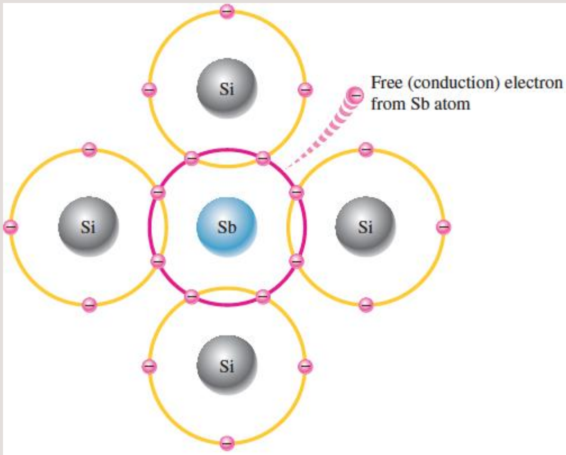
Doping (Adding Impurities)

- Semiconductive materials do not conduct current well and are of limited value in their intrinsic state.
- Intrinsic silicon (or germanium) must be modified by increasing the number of free electrons or holes to increase its conductivity and make it useful in electronic devices.
- This is done by adding impurities to the intrinsic material.
- This process, called **doping**, increases the number of current carriers (electrons or holes).

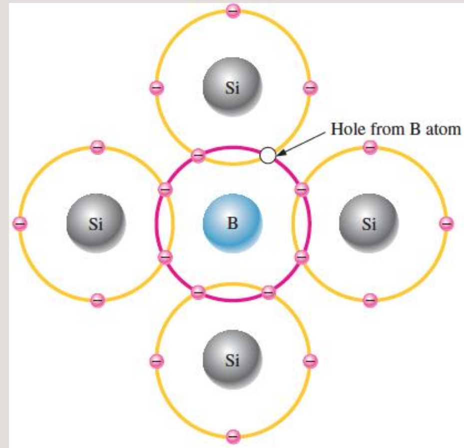
Doping (Adding Impurities)

- By adding certain impurities to pure (intrinsic) silicon, more holes or more electrons can be produced within the crystal.
- To increase the number of conduction band electrons, pentavalent impurities are added, forming an n-type semiconductor. These are elements to the right of Si on the Periodic Table.
- To increase the number of holes, trivalent impurities are added, forming a p-type semiconductor. These are elements to the left of Si on the Periodic Table.

III	IV	V
B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb



Pentavalent impurity atom in a silicon crystal structure. The extra electron from the antimony (Sb) atom becomes a free electron.



Trivalent impurity atom in a silicon crystal structure. A boron (B) impurity atom is shown in the center.

N-Type Semiconductor

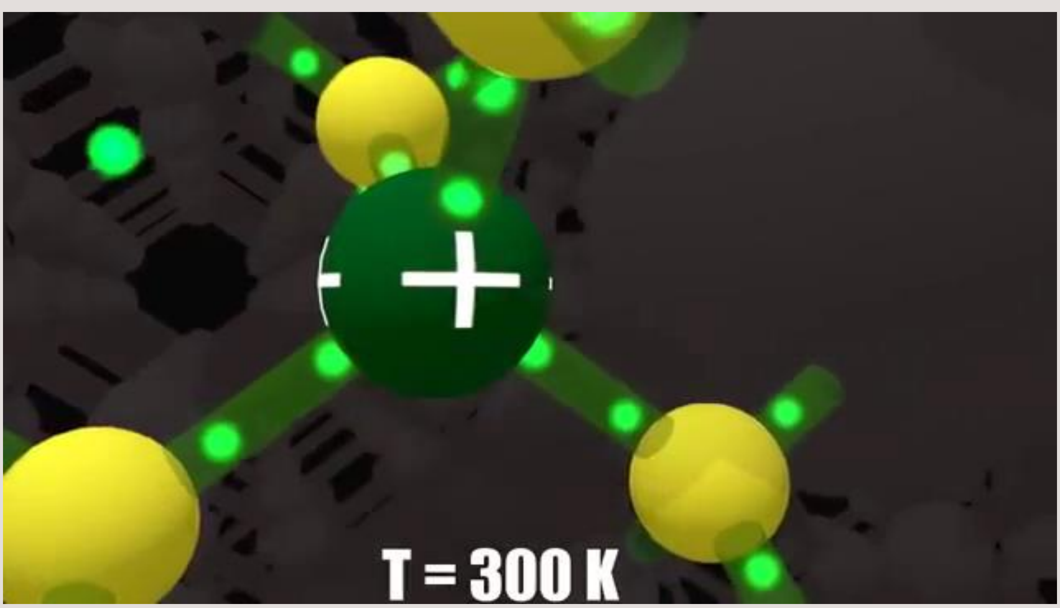
- Since most of the current carriers are electrons, silicon (or germanium) doped with pentavalent atoms is an *n*-type semiconductor (the *n* stands for the negative charge on an electron).
- The **electrons** are called the **majority carriers** in *n*-type material.
- There are also a few holes that are created when electron-hole pairs are thermally generated.
- **Holes** in an *n*-type material are called **minority carriers.**

Because the pentavalent atom gives up an electron, it is often called a ***donor atom***.

P-Type Semiconductor

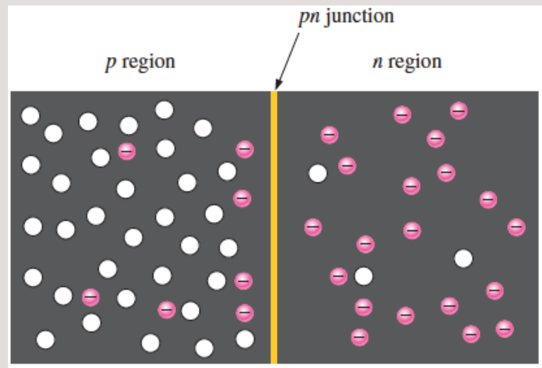
- Since most of the current carriers are holes, silicon (or germanium) doped with trivalent atoms is called a *p*-type semiconductor.
- The **holes** are the **majority carriers** in *p*-type material.
- There are also a few conduction-band electrons that are created when electron-hole pairs are thermally generated.
- Conduction-band **electrons** in *p*-type material are the **minority carriers**.

Because the trivalent atom can take an electron, it is often referred to as an ***acceptor atom***.



The PN Junction

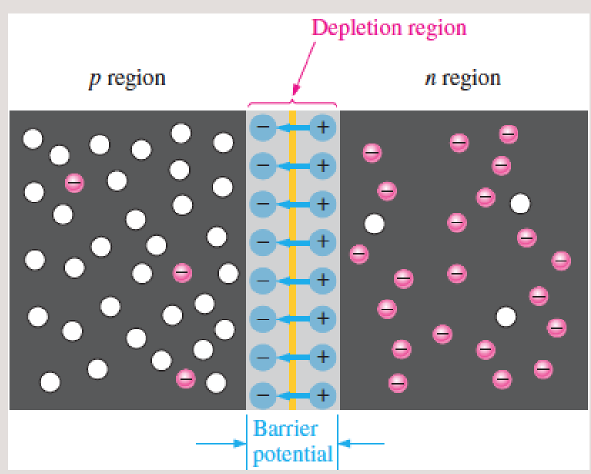
- When you take a block of silicon and dope part of it with a trivalent impurity and the other part with a pentavalent impurity, a boundary called the ***pn* junction** is formed between the resulting *p*-type and *n*-type portions.
- **The *PN* junction is the basis for diodes, transistors, solar cells, and other devices.**

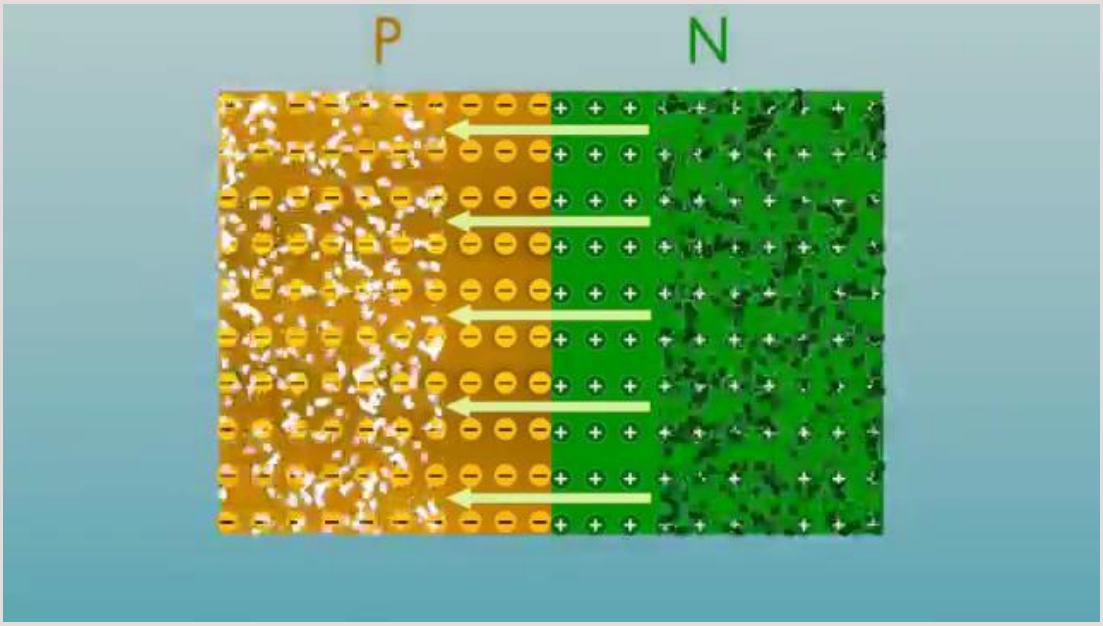


The basic silicon structure at the **instant** of junction formation showing only the majority and minority carriers.

Formation of the Depletion Region

At the **instant** of the *pn* junction formation, the free electrons near the junction in the *n* region begin to **diffuse** across the junction into the *p* region where they **combine** with holes near the junction.

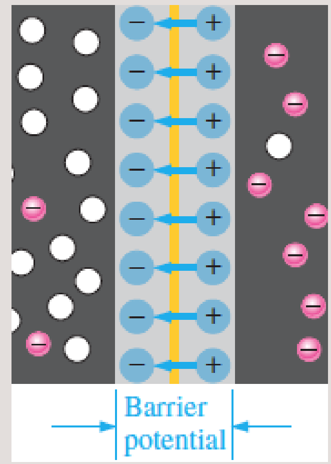




- **Before** the *pn* junction is formed, there are as many electrons as protons in the *n*-type material, making the **material neutral** in terms of net charge. The same is true for the *p*-type material.
- **After** the *pn* junction is formed, the ***n* region loses free electrons** as they diffuse across the junction.
- This creates a layer of **positive charges** (pentavalent ions) near the junction.
- As the electrons move across the junction, the *p* region loses holes as the electrons and holes combine.
- This creates a layer of **negative charges** (trivalent ions) near the junction.
- These two layers of positive and negative charges form the **depletion region.**
- **In the end equilibrium is established and there is no further diffusion of electrons across the junction.**

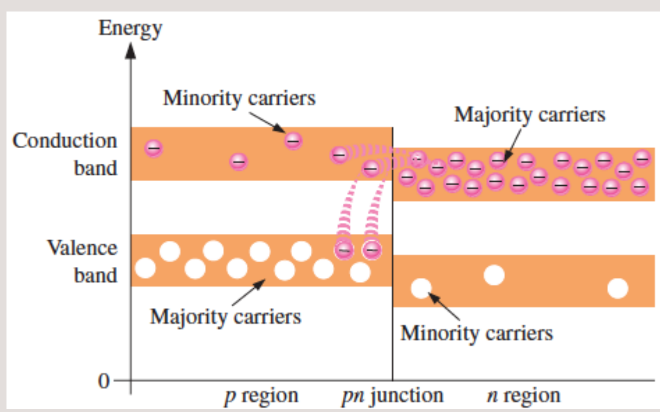
Barrier Potential

- An ***electric field*** *is established in* the depletion region.
- This electric field is a barrier to the free electrons in the *n* region, and energy must be expended to move an electron through the electric field.
- This potential difference is called the **barrier potential** and is expressed in volts. (0.7 V for silicon and 0.3 V for germanium at 25°C).



Energy Diagrams

The valence and conduction bands in the *n* region are at lower energy levels than those in the *p* region, but there is a significant amount of overlapping.

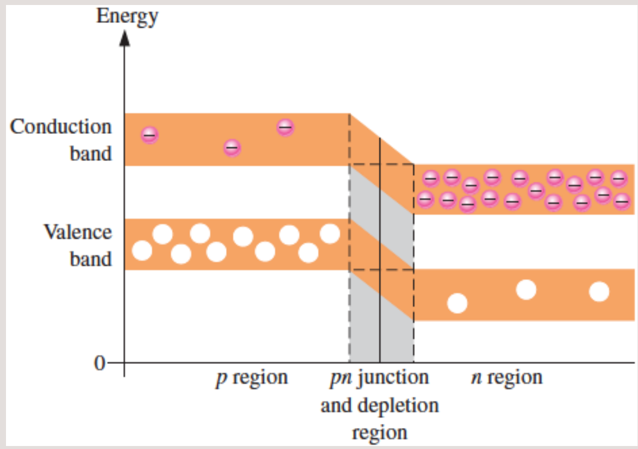


The free **electrons** in the *n* region that occupy the **upper part** of the conduction band in terms of their energy can easily **diffuse** across the junction and temporarily become free electrons in the **lower part** of the *p*-region conduction band. After crossing the junction, the electrons quickly lose energy and **fall into** the holes in the *p*-region valence band.

As the diffusion continues, the depletion region begins to form and the energy level of the *n*-region conduction band decreases.

The decrease in the energy level of the conduction band in the *n* region is due to the **loss of the higher-energy electrons** that have diffused across the junction to the *p* region.

After the depletion region is formed, there are no electrons left in the *n*-region conduction band with enough energy to get across the junction to the *p*-region conduction band, as indicated by the alignment of the top of the *n*-region conduction band and the bottom of the *p*-region conduction band.



Summary

- An *n*-type semiconductive material is created by adding impurity atoms that have five valence electrons. A *p*-type semiconductor is created by adding impurity atoms with only three valence electrons.
- The process of adding pentavalent or trivalent impurities to a semiconductor is called ***doping***.
- A *pn* junction is formed when part of a material is doped *n*-type and part of it is doped *p*-type. A depletion region forms starting at the junction that is devoid of any majority carriers. The depletion region is formed by ionization.
- The barrier potential is typically 0.7 V for a silicon diode and 0.3 V for germanium.

Review Questions

- Define doping.
- How is an n -type semiconductor formed?
- By what process are the majority carriers produced?
- By what process are the minority carriers produced?
- 10. What is the difference between intrinsic and extrinsic semiconductors?
- What is a pn junction?
- Explain diffusion.
- Describe the depletion region.
- Explain what the barrier potential is and how it is created.

Self-test

Try to solve the Self-test in your text book

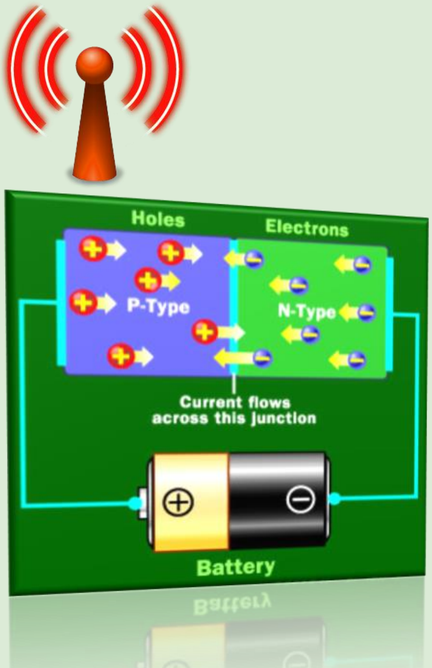
Electronic Devices

by

Floyd

9th Edition

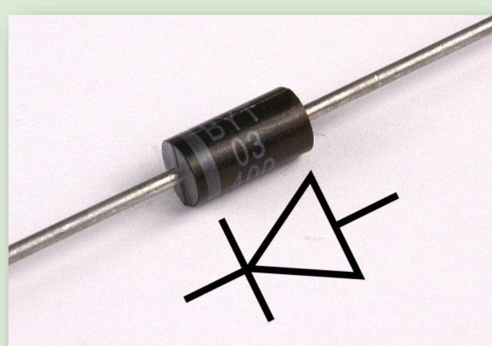
Pages 21-23



Lec 3: Diodes and Applications
Diode Operation &
V-I Characteristics of a Diode

Diodes and Applications

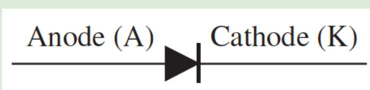
- Diode Operation
- *V-I* Characteristics of a Diode
- Diode Models
- Half-Wave and Full-Wave Rectifiers
- Power Supply Filters and Regulators
- Diode Limiters and Clampers
- Voltage Multipliers



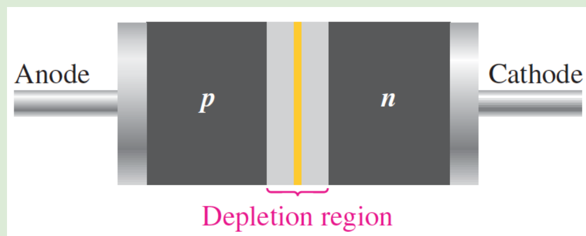
The Diode

Diode is made from a small piece of semiconductor material, usually silicon, in which half is doped as a *p* region and half is doped as an *n* region with a *pn* junction and depletion region in between.

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.



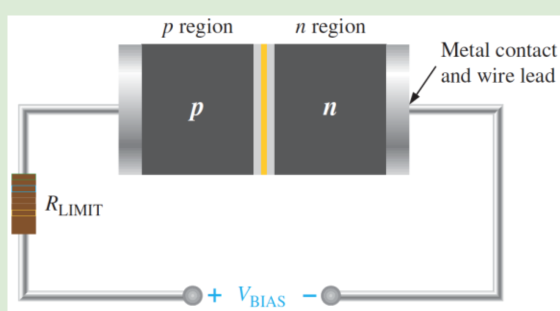
Diode Symbol



Forward Bias

- **Forward bias** is the condition that allows current through the *pn* junction.

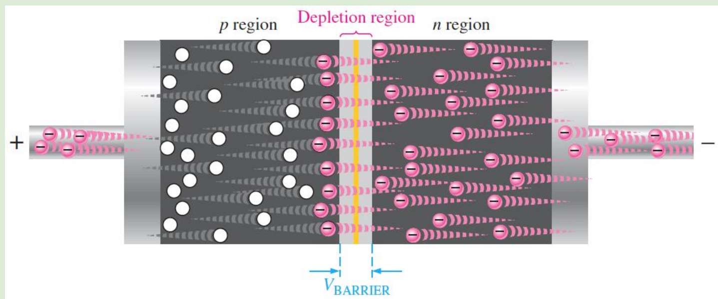
- **Notice** that the negative side of V_{BIAS} is connected to the *n* region of the diode and the positive side is connected to the *p* region.



- V_{BIAS}, must be **greater** than the **barrier potential**.

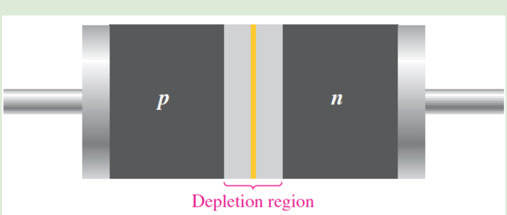
What happens when a diode is forward-biased?

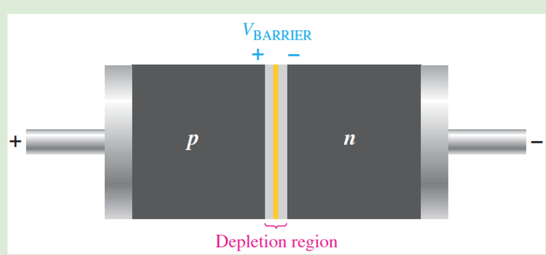
- The bias-voltage source imparts sufficient energy to the free electrons to overcome the barrier potential of the depletion region and move on through into the *p* region.
- Once in the *p* region, these conduction electrons have lost enough energy to immediately combine with holes in the valence band.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

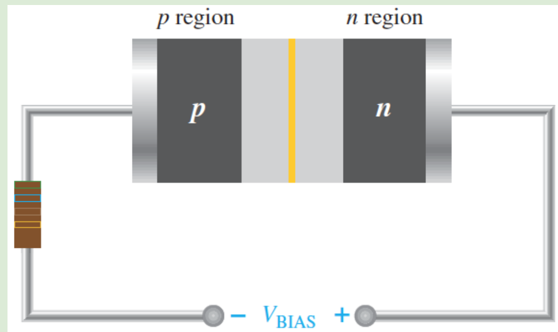
- Under the electrons flow into the depletion region, the number of positive ions is reduced.
- As more holes effectively flow into the depletion region, the number of negative ions is reduced.
- This reduction in positive and negative ions during forward bias causes the **depletion region** to **narrow**.





Reverse Bias

- **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.

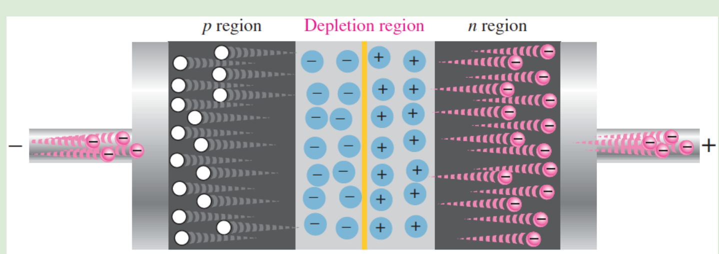


- Note that the **depletion region** is shown much **wider** than in forward bias or equilibrium.

What happens when a diode is Reverse-biased?

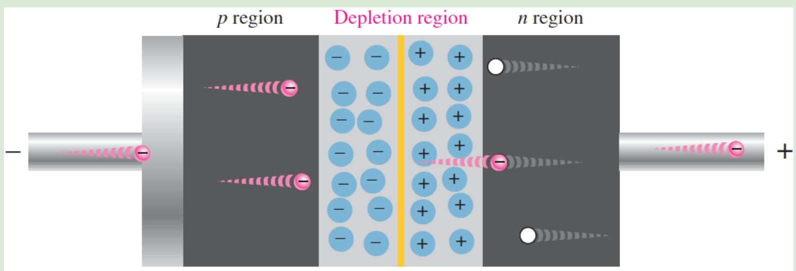
- **In the *n* region,** as the electrons flow toward the positive side of the voltage source, additional **positive** ions are created. This results in a **widening** of the depletion region and a depletion of majority carriers.
- **In the *p* region,** electrons from the negative side of the voltage 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.



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.

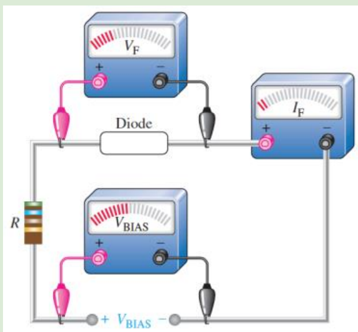


Reverse Breakdown

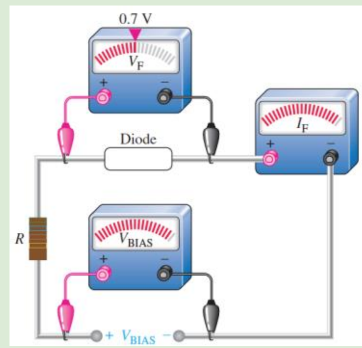
- If the external reverse-bias voltage is **increased** to a value called the ***breakdown voltage,*** the reverse current will drastically increase.
- The high reverse-bias voltage imparts energy to the free minority electrons so that as they speed through the *p* region, they collide with atoms with 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,**

V-I Characteristic for **Forward Bias**

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



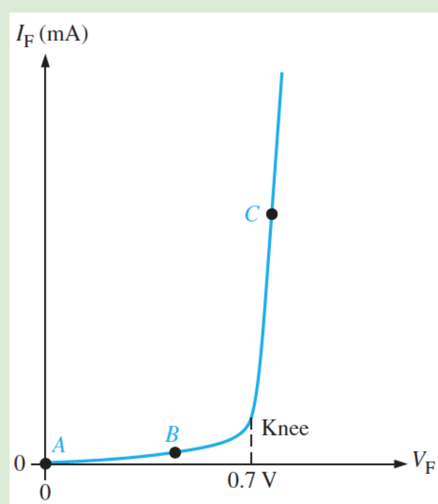
Small forward-bias voltage (V_F < 0.7 V), very small forward current.



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*

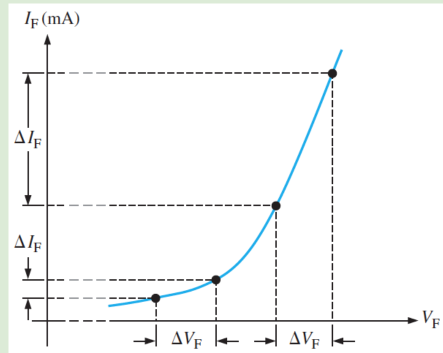
- The diode forward voltage (V_F) increases to the right along the horizontal axis, and the forward current (I_F) increases upward along the vertical axis.
- **Point *A*** corresponds to a zero-bias condition.
- **Point *B*** where the forward voltage is less than the barrier potential of 0.7 V.
- **Point *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 0.7 V.



V-I characteristic curve for forward bias

Dynamic Resistance

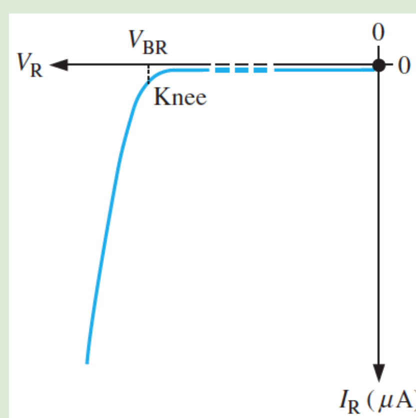
- The resistance of the forward-biased diode is **not constant** over the entire curve. It is called *dynamic* or *ac resistance* r'_d.
- **Below the knee** of the curve the resistance is **greatest** because the current increases very little for a given change in voltage ($r'_d = \Delta V_F / \Delta I_F$).
- 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.



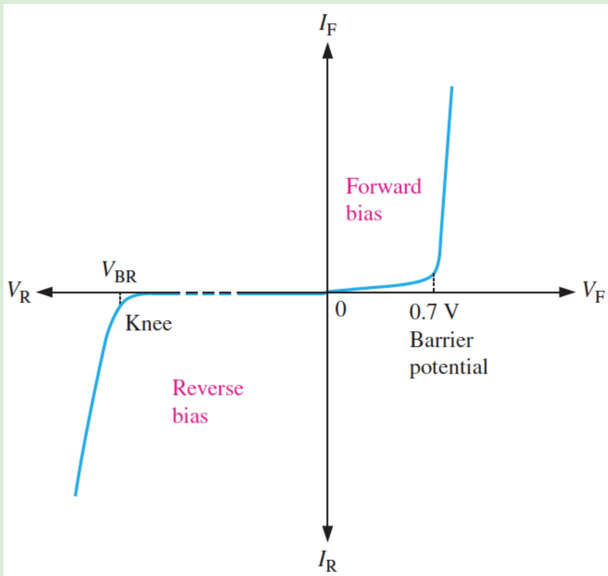
Expanded view of a portion of the previous curve

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 0 V** 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



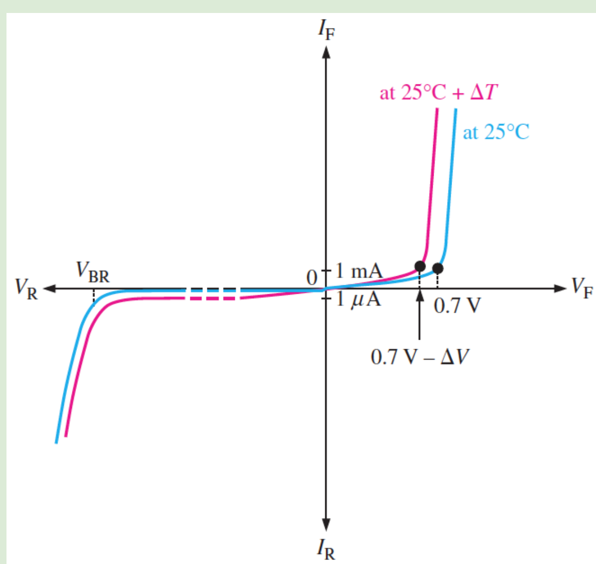
Temperature Effects

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.



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?