Communication Circuits Design

Academic year 2018/2019 – Semester 2 – Week 1

Lecture 1.3: Semiconductors and PN Junction

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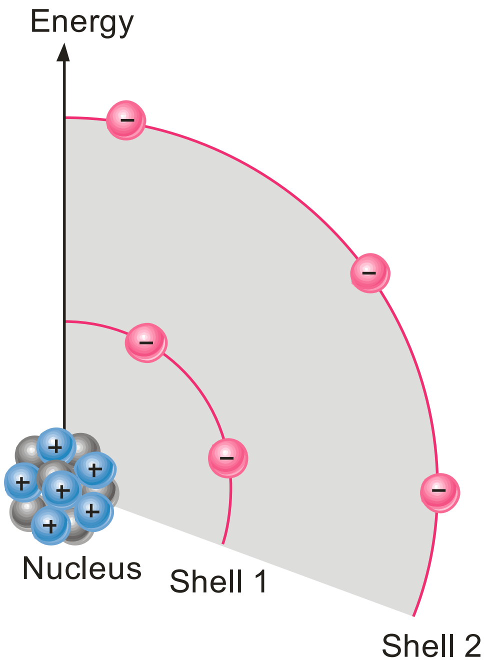
Objectives

- After completing this lecture, you will be able to:
  - Describe the structure of an atom
  - Discuss insulators, conductors, and semiconductors and how they differ
  - Describe how current is produced in a semiconductor
  - Describe the properties of *n*-type and *p*-type semiconductors
  - Describe how a *pn* junction is formed
  - Use a diode in common applications
  - Analyze the voltage-current (*V*-*I*) characteristic of a diode
  - Explain how the three diode models differ

The Bohr Model

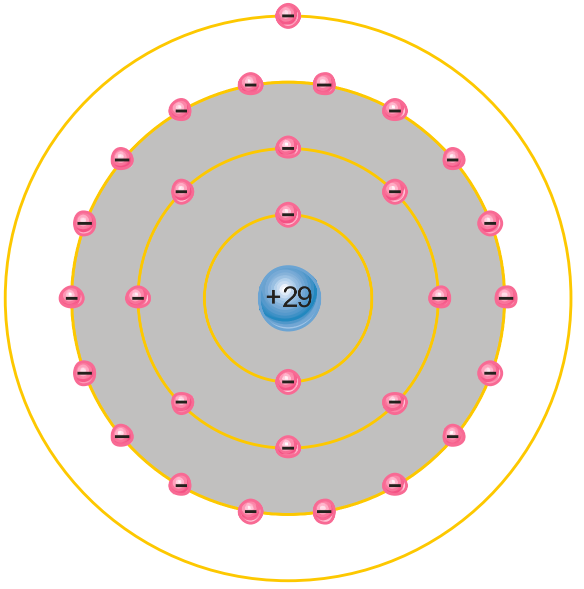
The Bohr model of the atom is that electrons can circle the nucleus only in specific orbits, which correspond to discrete energy levels called **shells**.



Valence Electrons

Materials can be classified by their ability to conduct electricity. This ability is related to the valence electrons.

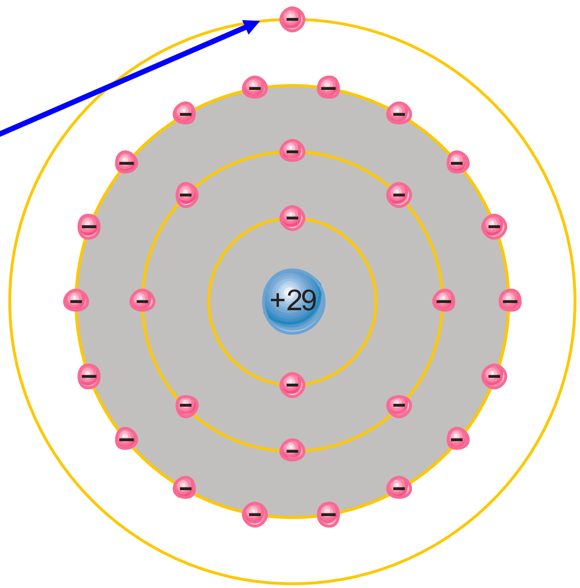
Valence electrons are those electrons that occupy the outer shell.



Conductor

Materials can be classified by their ability to conduct electricity. This ability is related to the valence electrons.

Copper is an example of an excellent **conductor**. It has only one electron in its valence band, which can easily escape to the conduction band, leaving behind a **positive ion** (the core). Like all metals, copper has many free electrons which are loosely held by the attraction of the positive metal ions.



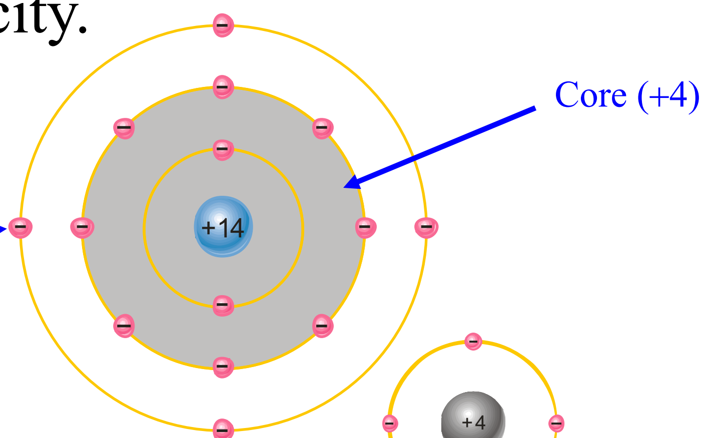
Insulators

Insulators have tightly bound electrons with few electrons available for conduction.

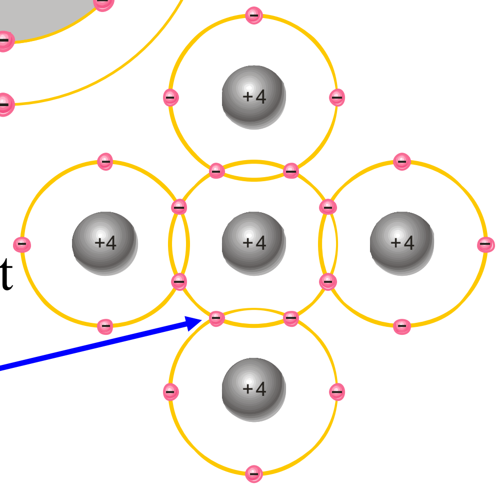
Nonmetals, such as glass, air, paper, and rubber are excellent insulators and widely used in electronics. Even these materials can break down and conduct electricity if the voltage is high enough such as in the case of lightning, which breaks down air.

Semiconductors

Semiconductors are between conductors and insulators in their ability to conduct electricity.



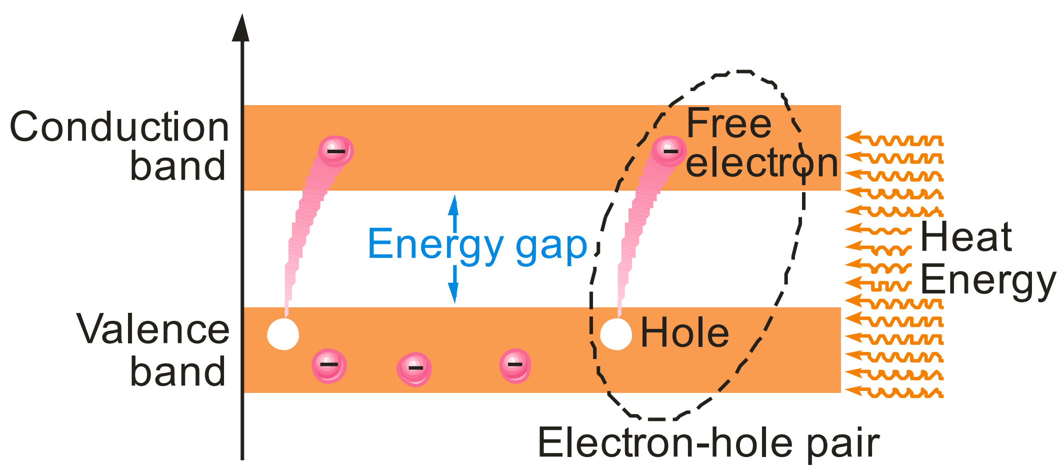
Silicon is an example of a single element **semiconductor**. It has four electrons in its valence band.



Unlike metals, silicon forms strong **covalent** bonds (shared electrons) with its neighbors. Intrinsic silicon is a poor conductor because most of the electrons are bound in the crystal and take part in forming the bonds between atoms.

Conduction Electrons and Holes

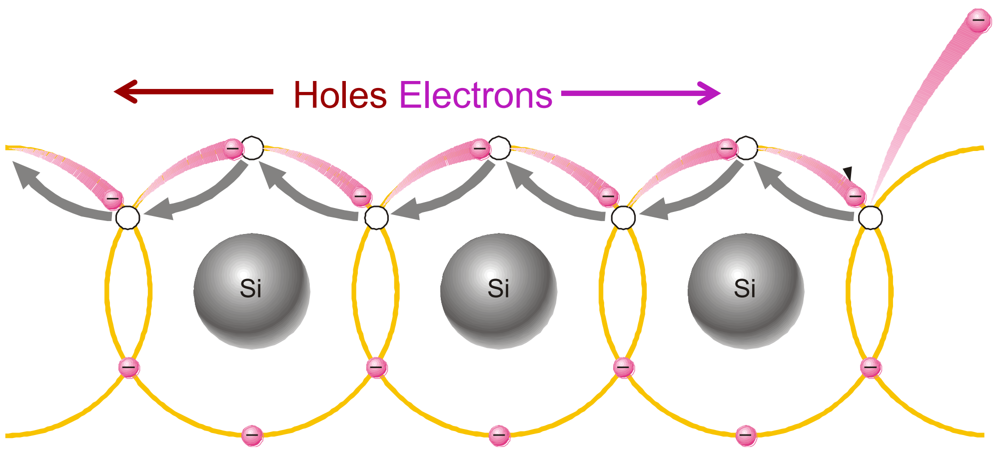
In intrinsic silicon, a few electrons can jump the energy gap between the valence and conduction band. Having moved into the conduction band, a "hole" (vacancy) is left in the crystal structure.



Conduction Electrons and Holes

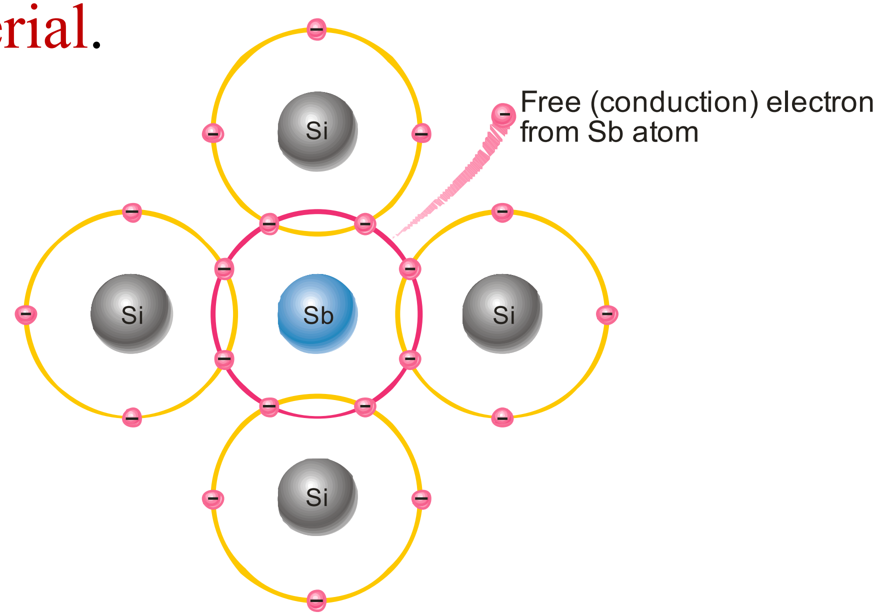
Within the crystalline structure, there are two types of charge movement (current):

1) The conduction band electrons are free to move under the influence of an electric field.
2) The bound (valence) electrons move between atoms, effectively moving holes from one atom to another as illustrated. Holes act like positive charges, with their own mobility.



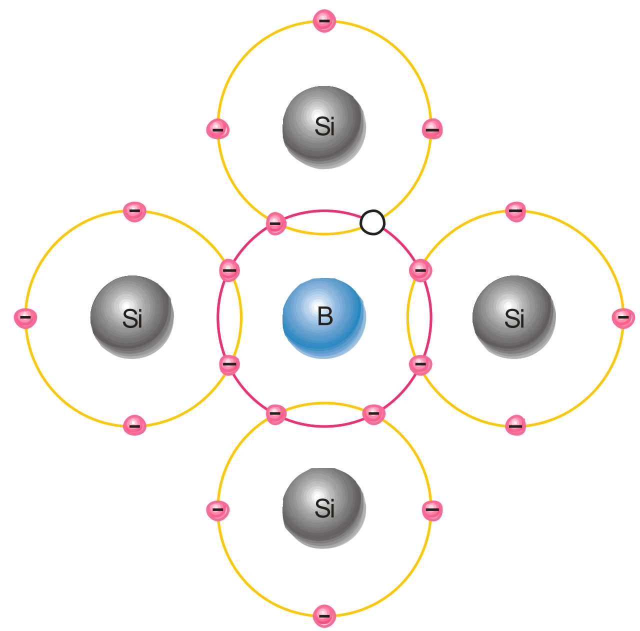
Electron and Hole Current

Certain impurities will change the conductivity of silicon. An impurity such as Antimony (Sb^{51}) has an electron that is not part of the bonding electrons so is free. This creates an *n*-material.



N-Type and P-Type Semiconductors

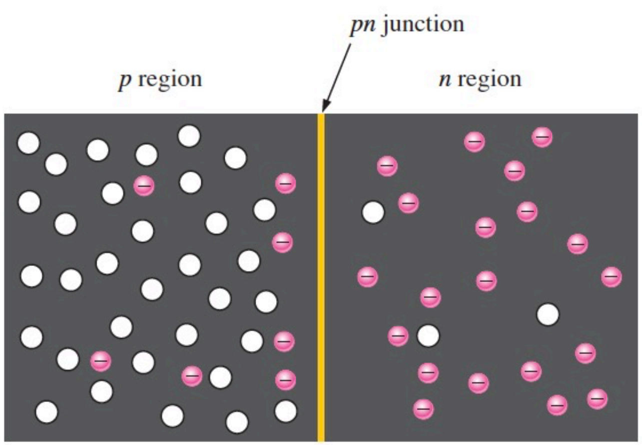
An impurity such as Boron (B^5) leaves a vacancy in the valence band, creating a *p*-material. Both *p*- and *n*-materials have energy levels that are different than intrinsic silicon.

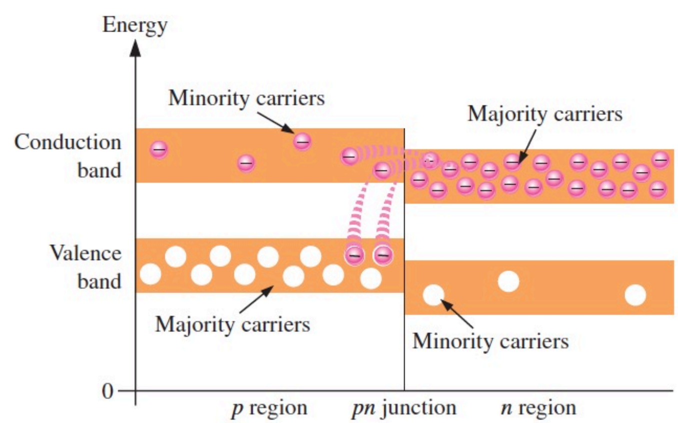


The *PN* junction

A *p*- and an *n*-material together form a *pn* junction.

The basic silicon structure at the instant of junction formation showing only the majority and minority carriers. Free electrons in the *n*-region near the *pn* junction begin to diffuse across the junction and fall into holes near the junction in the p region.





The *PN* junction

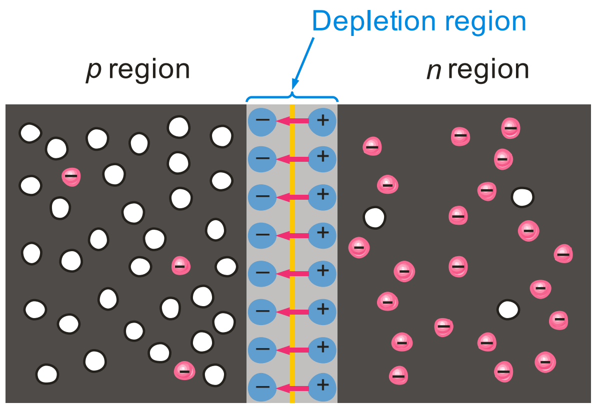
A *p*- and an *n*-material together form a *pn* junction.

When the junction is formed, conduction electrons move to the *p*-region, and fall into holes. Filling a hole makes a negative ion and leaves behind a positive ion in the *n*-region. This creates a thin region that is depleted of free charges at the boundary.

Question:

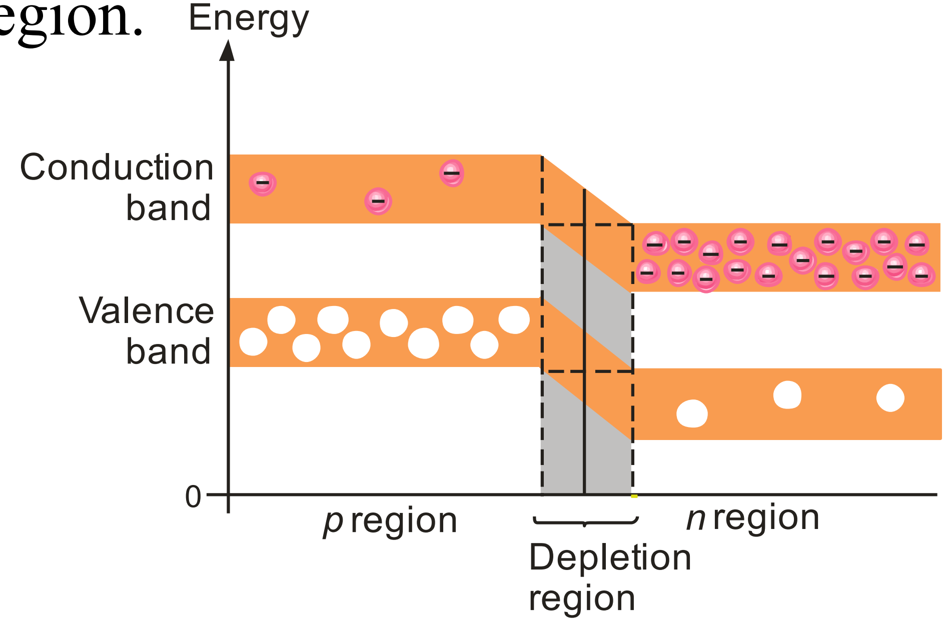
What process stops the migration of charge across the boundary?

Answer:



Energy Diagrams the *PN* junction

The energy diagram for the *n*-region shows a lower potential than for the *p*-region.



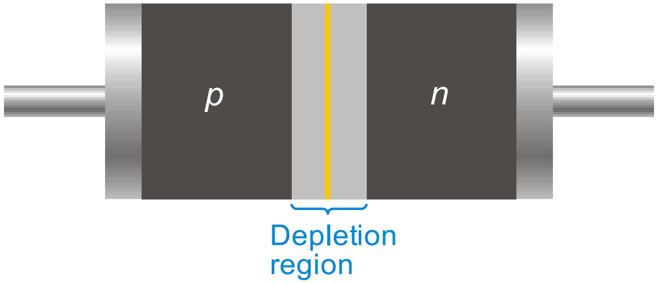
Question:

Why do you think that the energy level in the *n*- region is lower than the *p*-region?

Answer:

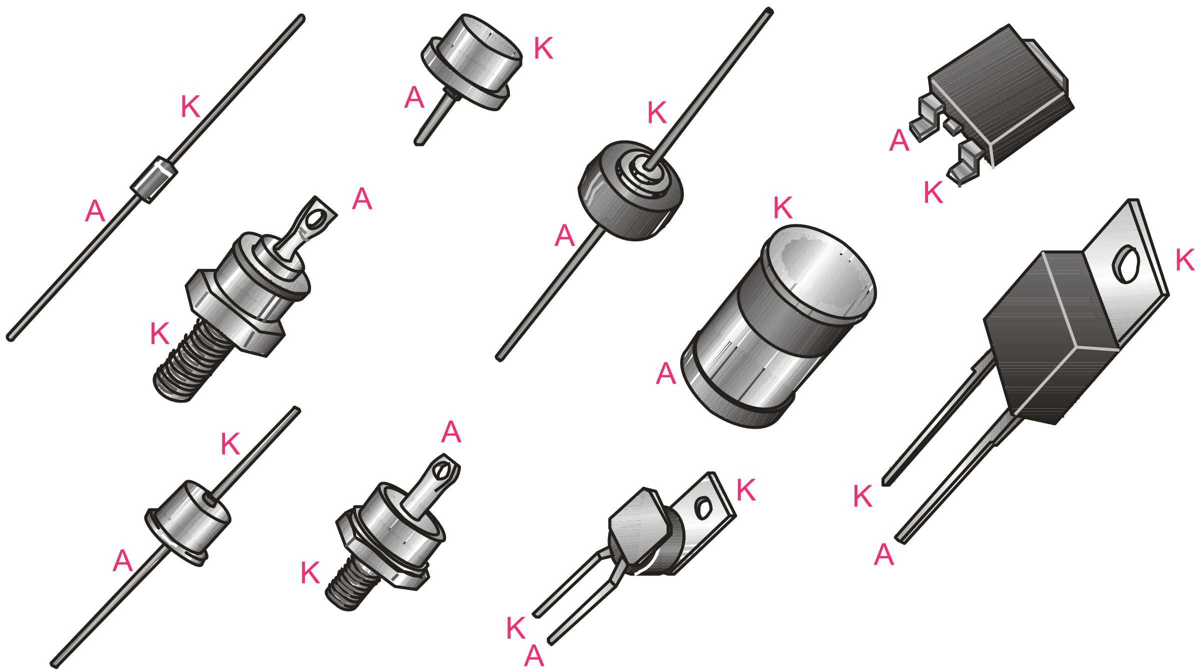
The Diode

A diode is a semiconductor device with a single *pn* junction and metal connections to leads. It has the ability to pass current in only one direction.



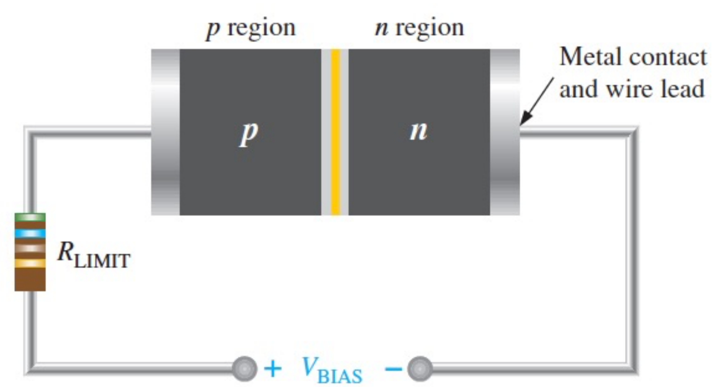
Typical Diode Packages

Some common configurations are



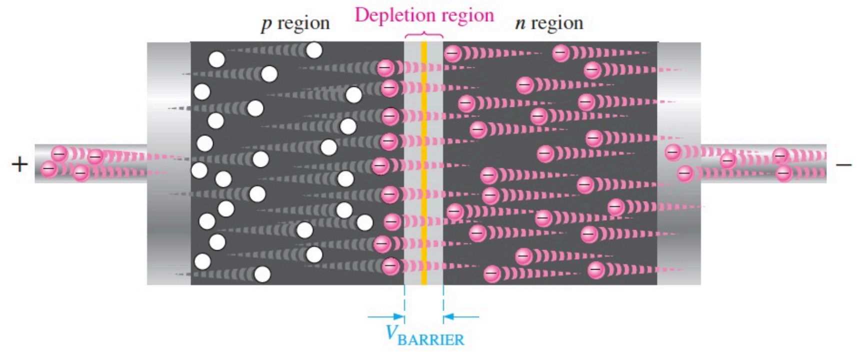
Forward Bias (1)

- To bias a diode, you apply a dc voltage across it.
- Forward bias is the condition that allows current through the *pn* junction
- This external bias voltage is designated as V_{BIAS}.
- The resistor limits the forward current to a value that will not damage the diode
- 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.
- the bias voltage, V_{BIAS}, must be greater than the barrier potential.



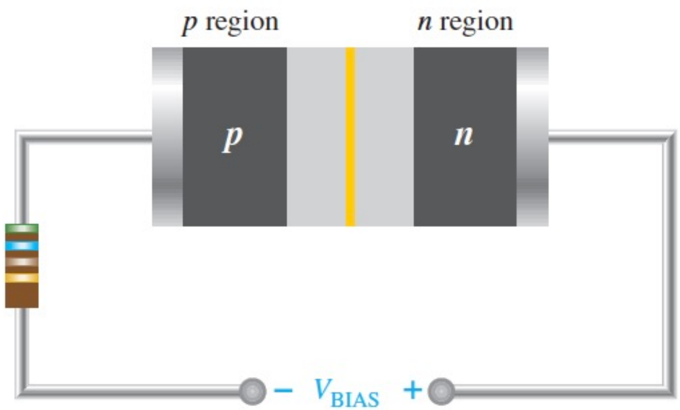
Forward Bias (2)

- Because like charges repel, the negative side of the bias-voltage source "pushes" the free electrons, which are the majority carriers in the *n* region, toward the *pn* junction.
- This flow of free electrons is called electron current.
- The bias-voltage source imparts sufficient energy to the free electrons for them 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.



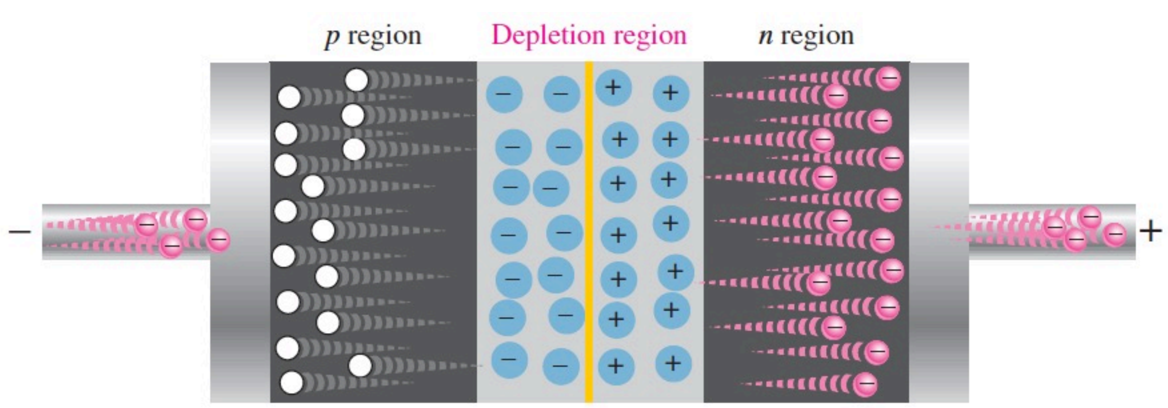
Reverse Bias (1)

- Reverse bias is the condition that essentially prevents current through the diode.
- Figure shows a dc voltage source connected across a diode in the direction to produce reverse bias.
- This external bias voltage is designated as V_{BIAS} just as it was for forward bias.
- 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.



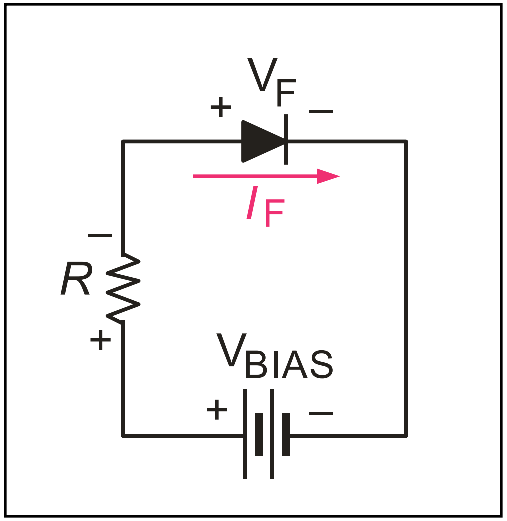
Reverse Bias (2)

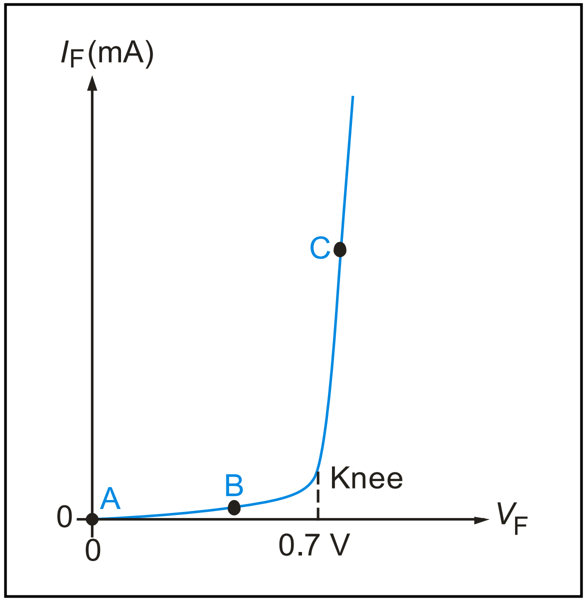
- Because unlike charges attract, the positive side of the bias-voltage source "pulls" the free electrons, which are the majority carriers in the *n* region, away from the *pn* junction.
- As the electrons flow toward the positive side of the voltage source, additional positive ions are created. This results in a widening of the depletion region and a depletion of majority carriers.



Voltage-current Characteristic of a Diode

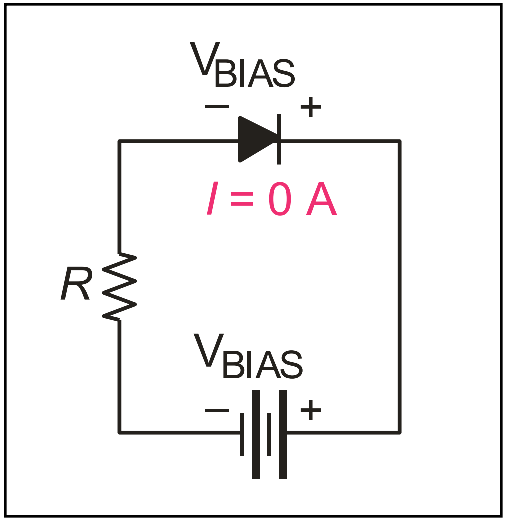
Forward bias is the condition which allows current in the diode. The bias voltage must be greater than the barrier potential.

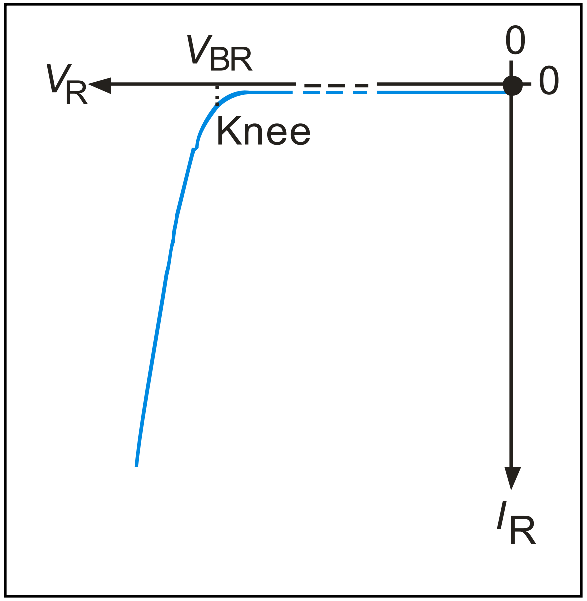




V-I Characteristic for Reverse Bias

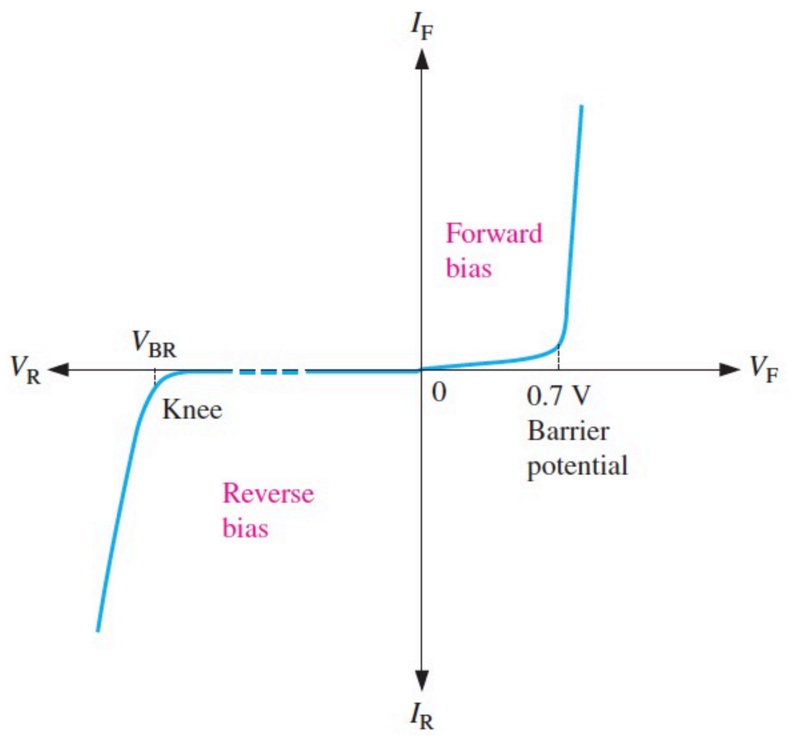
Reverse bias is the condition in which current is blocked.





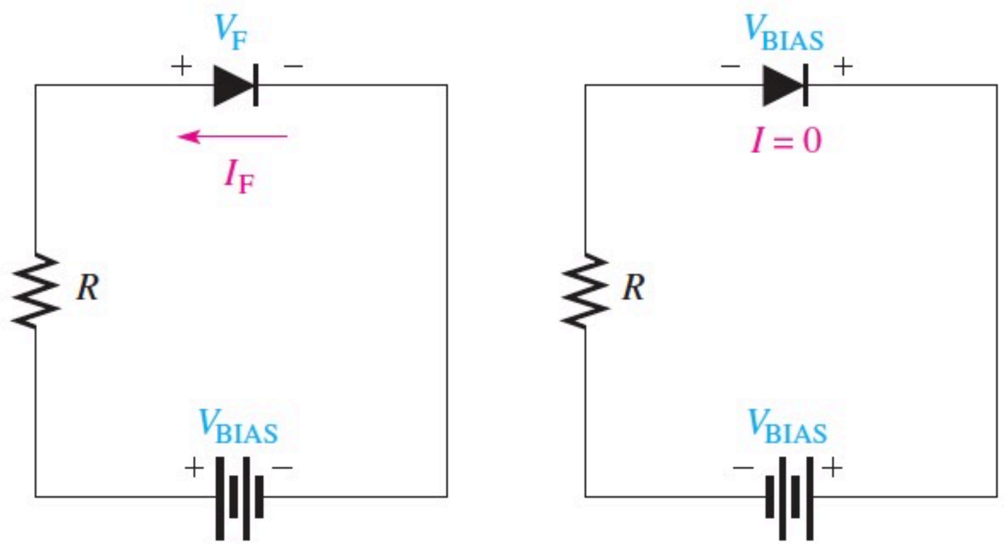
The Complete V-I Characteristic Curve

- Combine the curves for both forward bias and reverse bias, and you have the complete V-I characteristic curve for a diode.



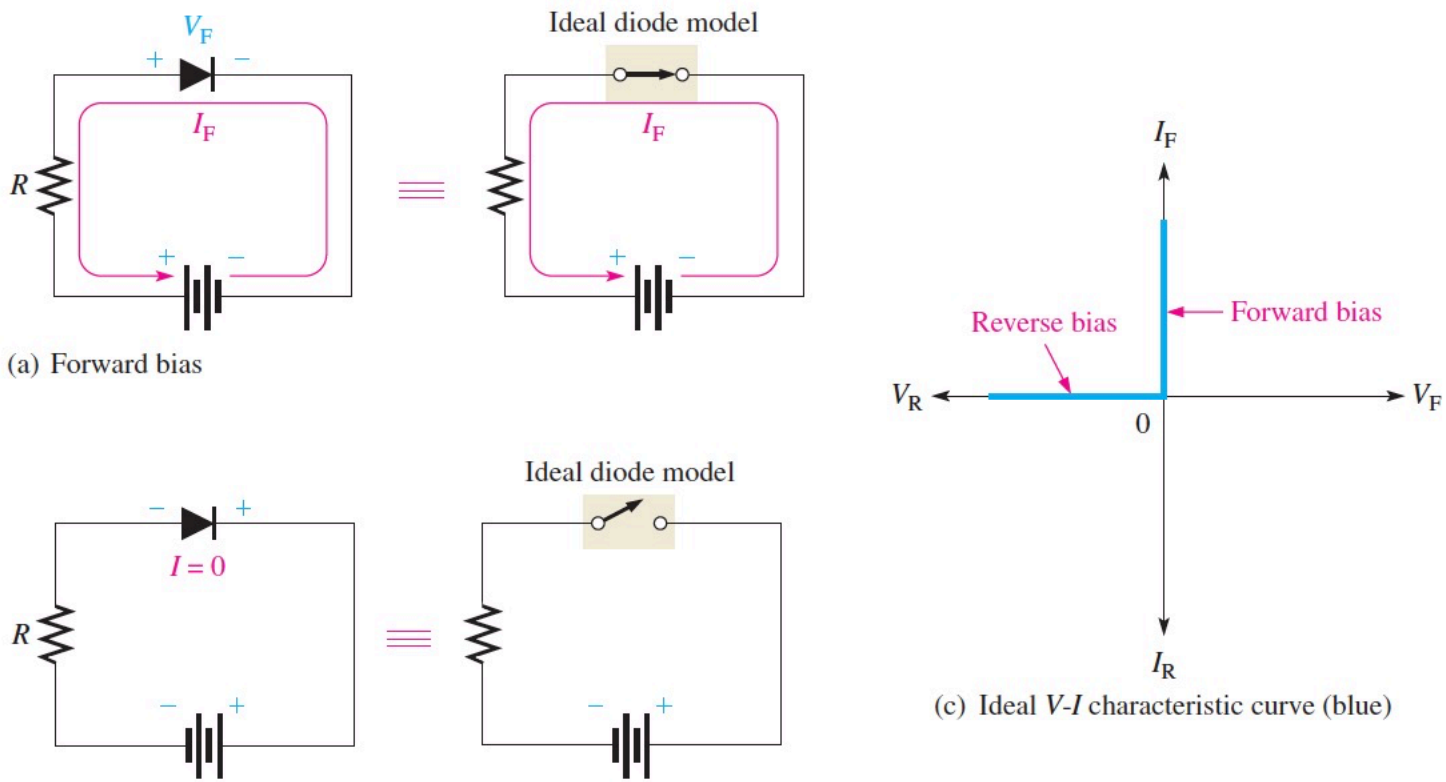
Bias Connections

- Forward-bias and reverse-bias connections showing the diode symbol.



(a) Forward bias (b) Reverse bias

The Ideal Diode Model

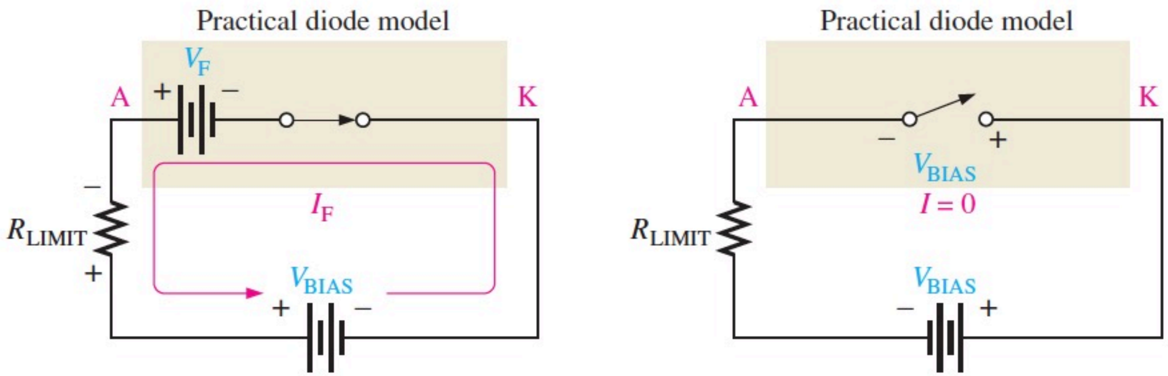


(a) Forward bias

(b) Reverse bias

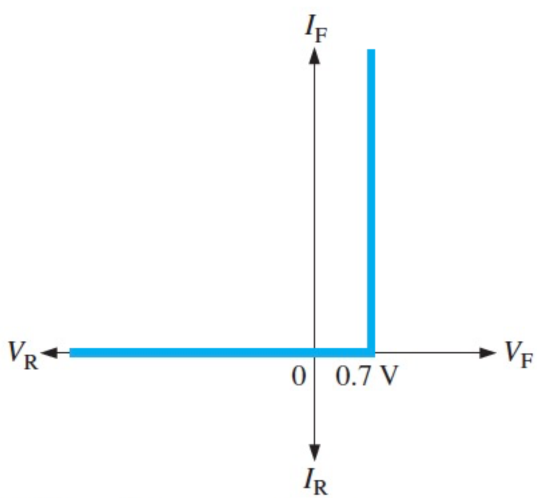
(c) Ideal V-I characteristic curve (blue)

The Practical Diode Model



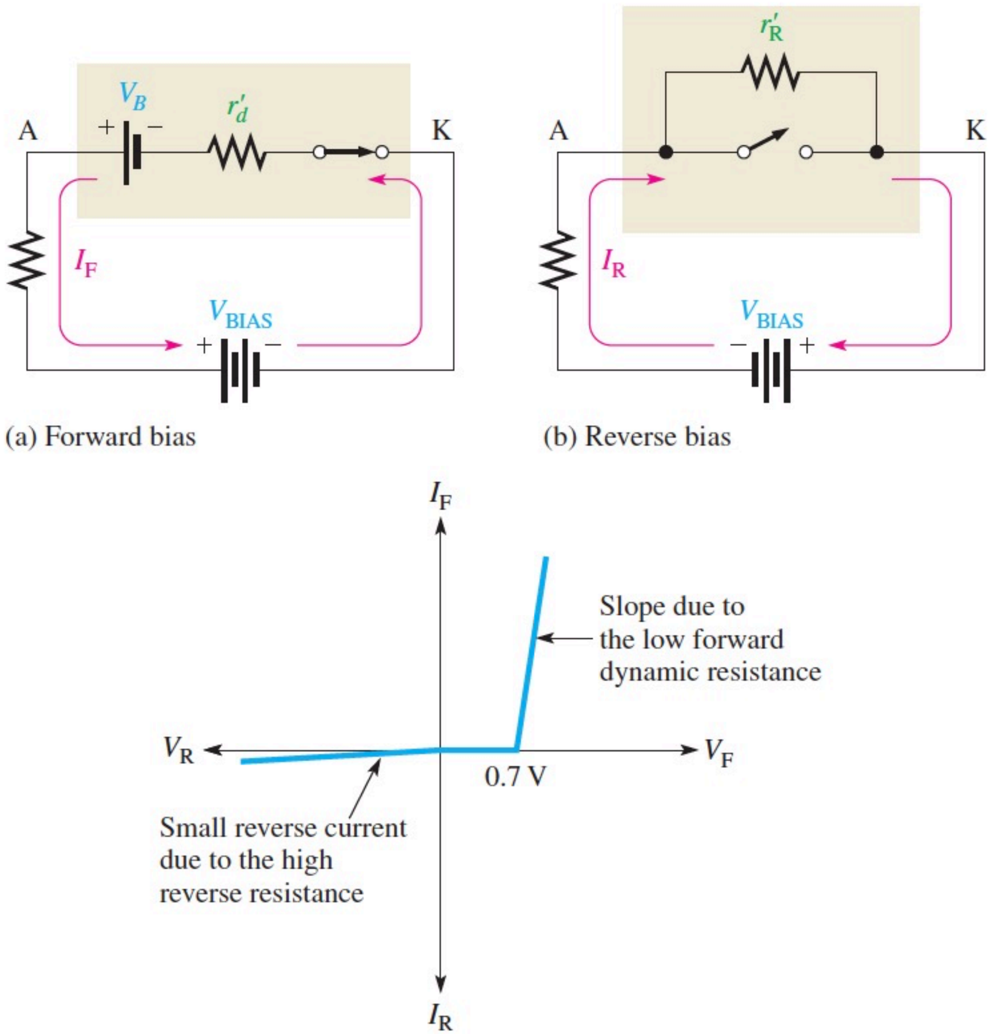
(a) Forward bias

(b) Reverse bias



(c) Characteristic curve (silicon)

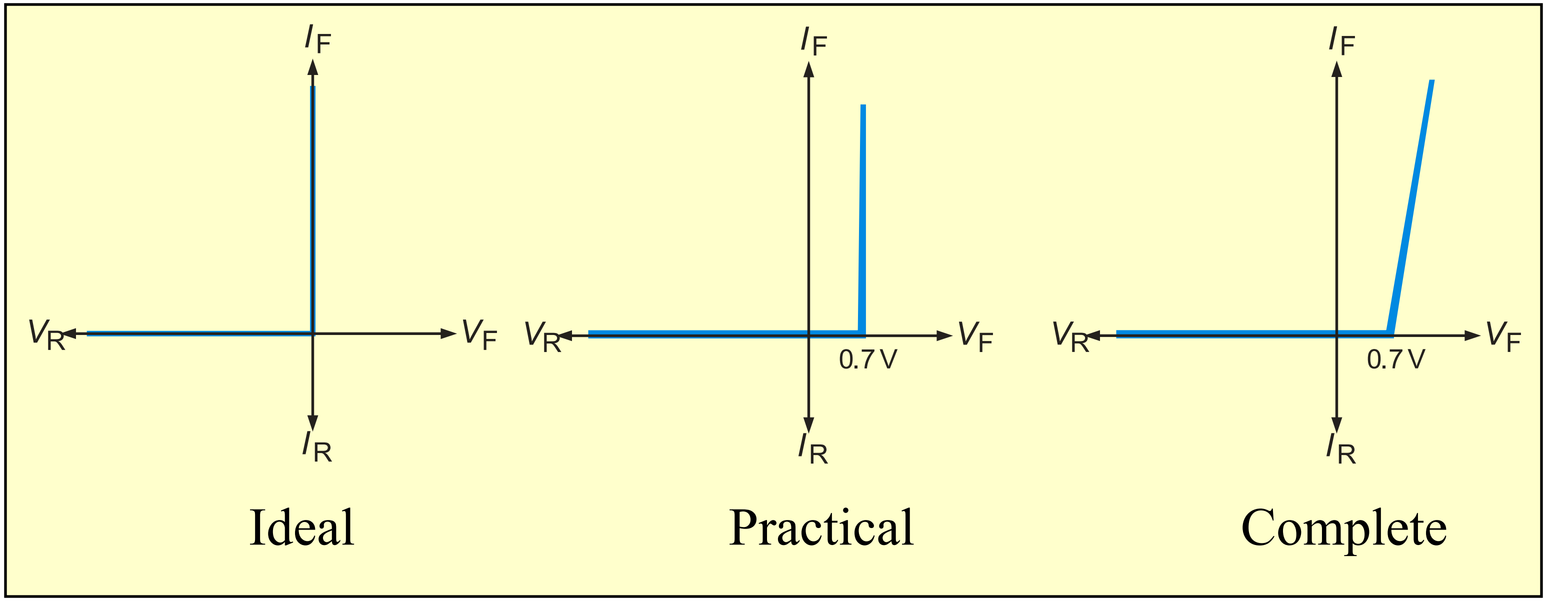
The Complete Diode Model



(c) *V-I* characteristic curve

Diode Models

Three diode approximations are:

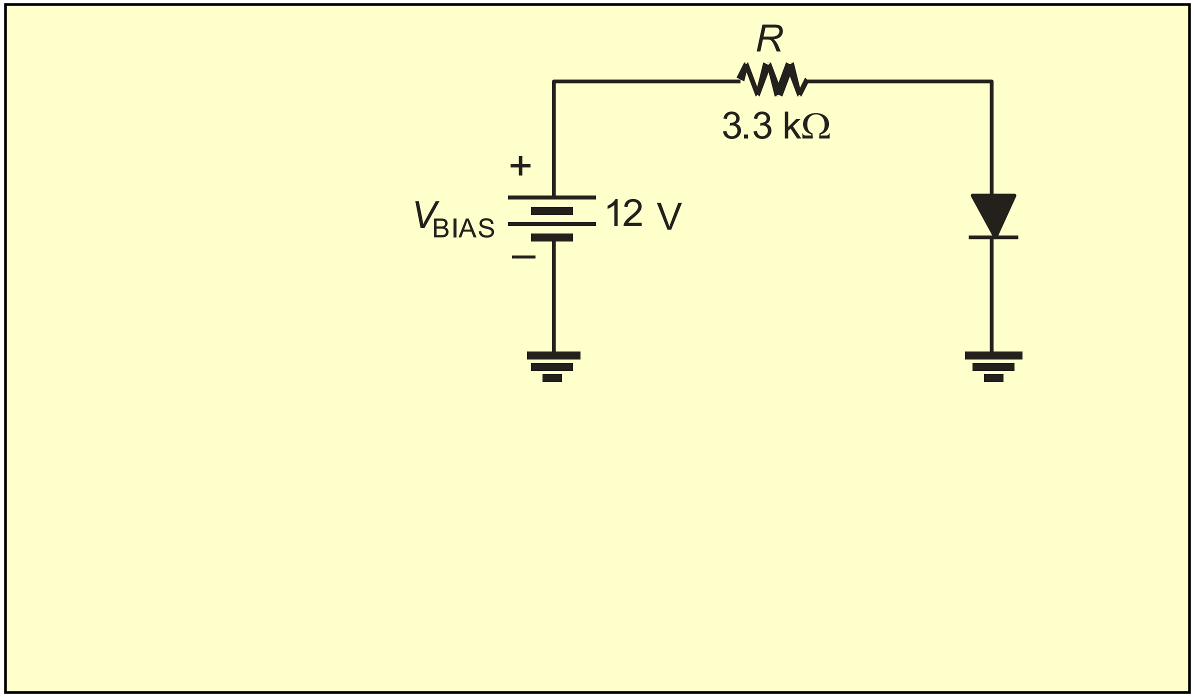


In addition, the complete model includes the effect of a large reverse resistance that accounts for a tiny current when reverse-biased.

Question-1

Question:

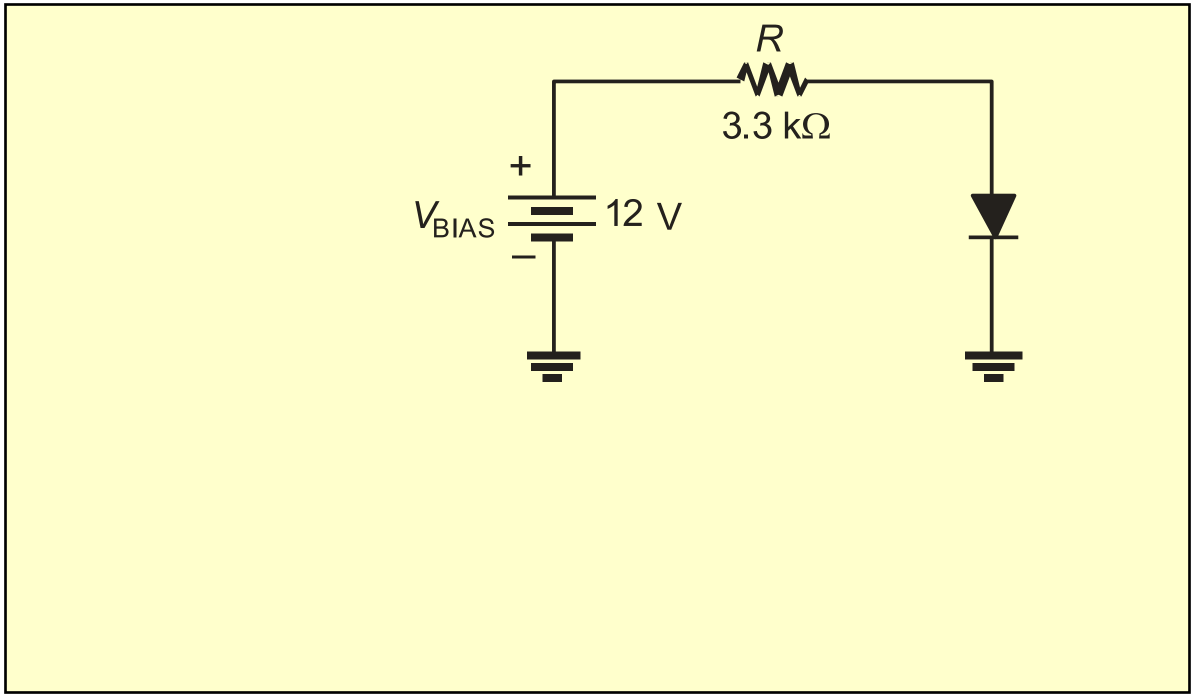
Use the practical model to determine the current in the circuit:



Solution

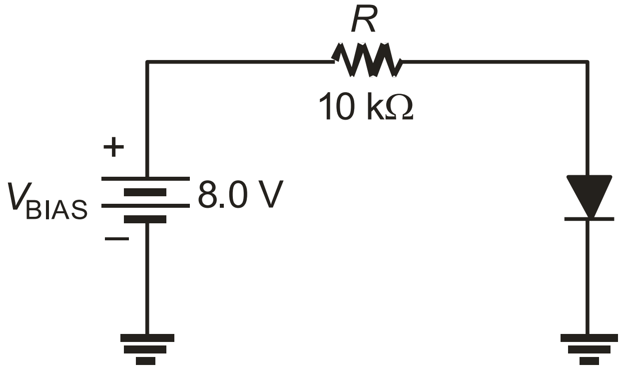
Solution:

Use the practical model to determine the current in the circuit:



Question-2

Using the practical diode model, the current in the circuit shown is



References

- Thomas Floyd, “Electronic Devices”, 9th Ed, Prentice Hall, Chapter-1 & 2