# Introduction to Semiconductors

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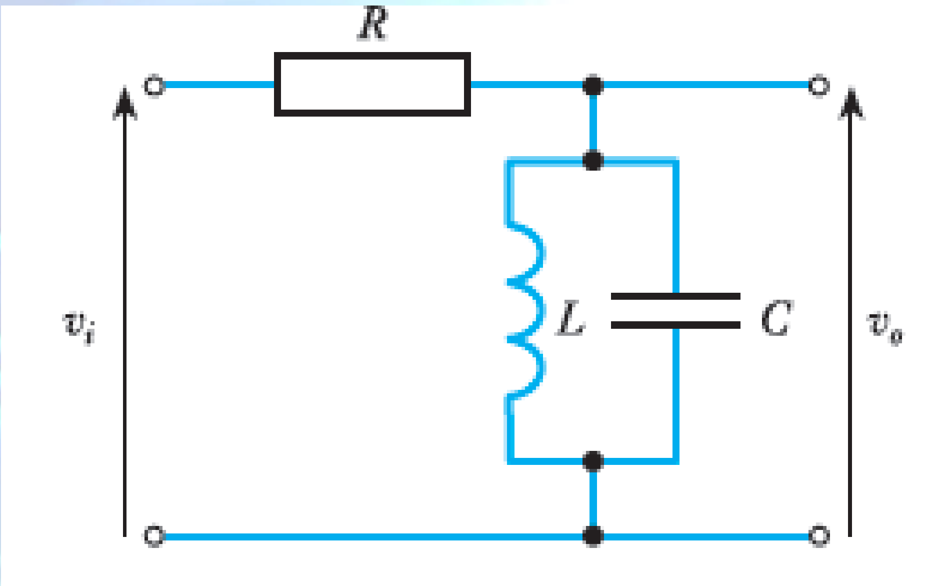
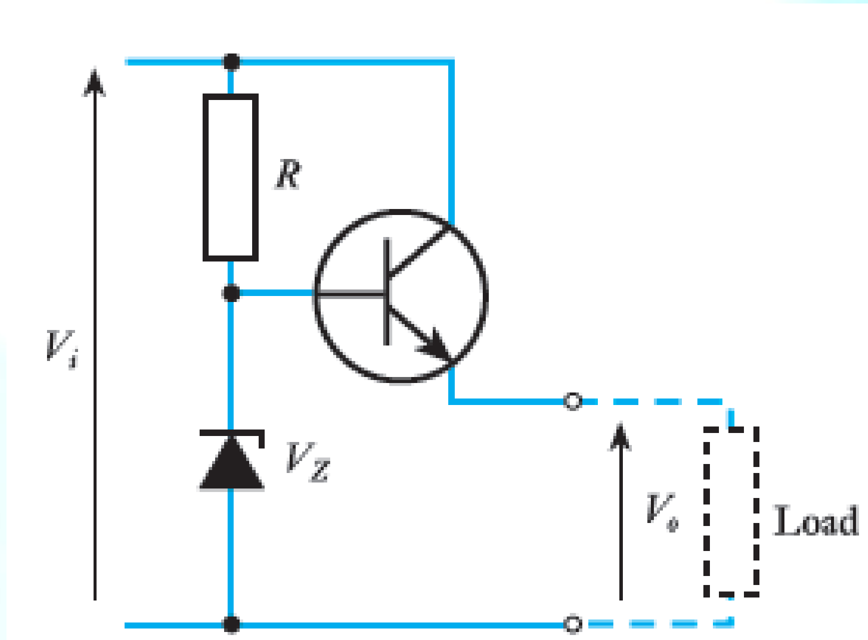
# Electrical Vs. Electronic Circuits

- **What is the significant about electronic circuits?**



# Electrical Vs. Electronic Circuits

- **The main difference:** electrical circuits have no decision making (processing) capability, whilst electronic circuits do
- An electric circuit simply powers machines with electricity. However, an electronic circuit can interpret a signal or an instruction, and perform a task to suit the circumstance
- Most modern appliances use a combination of electronic and electrical circuitry

# Electrical Vs. Electronic Circuits

- E.g. : **A washing machine**
  - **Electrical circuit:** comprising a plug socket, fuse, on/off switch, heater and motor, which rotates the drum
  - **Electronic circuit:**
    - The desired wash cycle and temperature are inputted by the user via the control panel and are are interpreted by electronic circuits.
    - When the electronic circuit has interpreted these commands, it sends signals to the electrical circuit to operate the heater and motor, to heat and rotate the drum

# Electrical Vs. Electronic Circuits

- **Control of Conductivity is the Key to Modern Electronic Devices**
  - Conductivity, is the ease with which a given material conducts electricity
    - Metals: High conductivity
    - Insulators: Low Conductivity
    - Semiconductors: Conductivity can be varied by several orders of magnitude

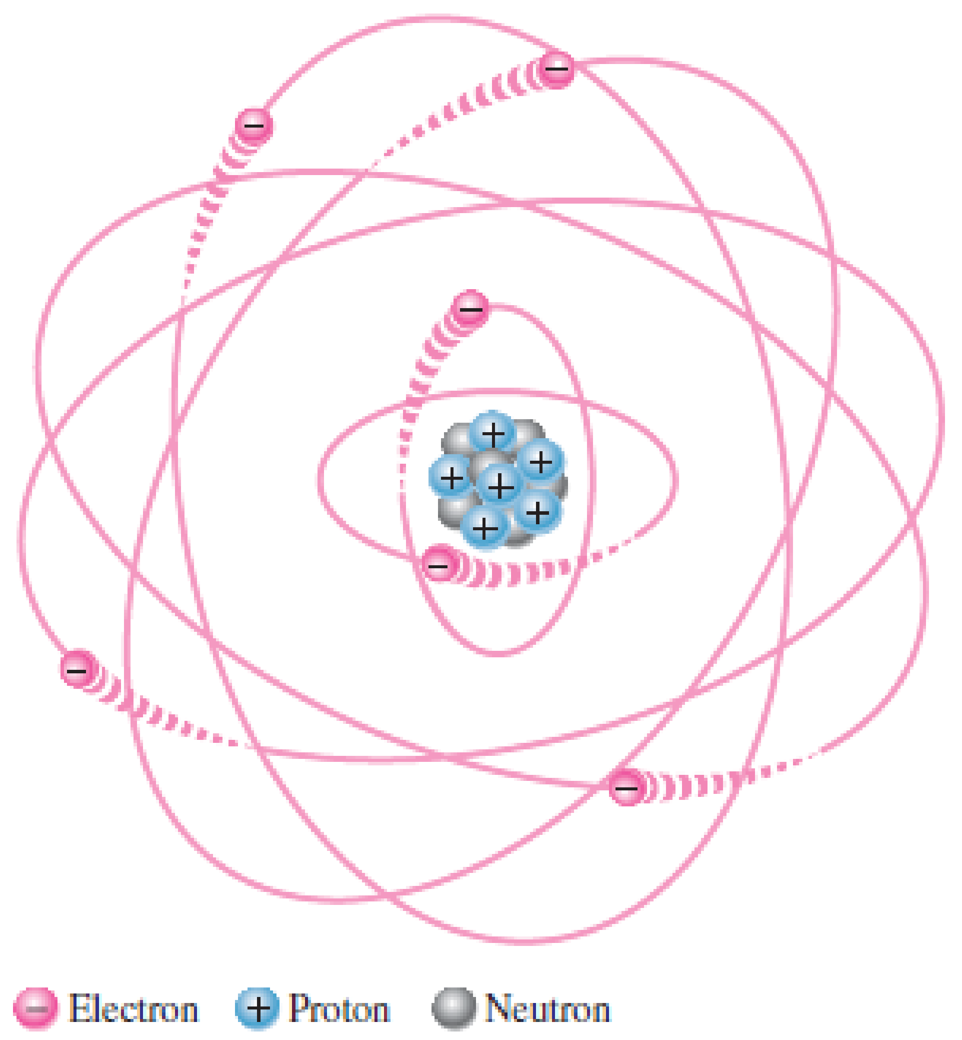
- **It is the ability to control conductivity that make semiconductors useful as “current/voltage control elements”.**

# Atomic Structure

- An **atom** is the smallest particle of an element that retains the characteristics of that element

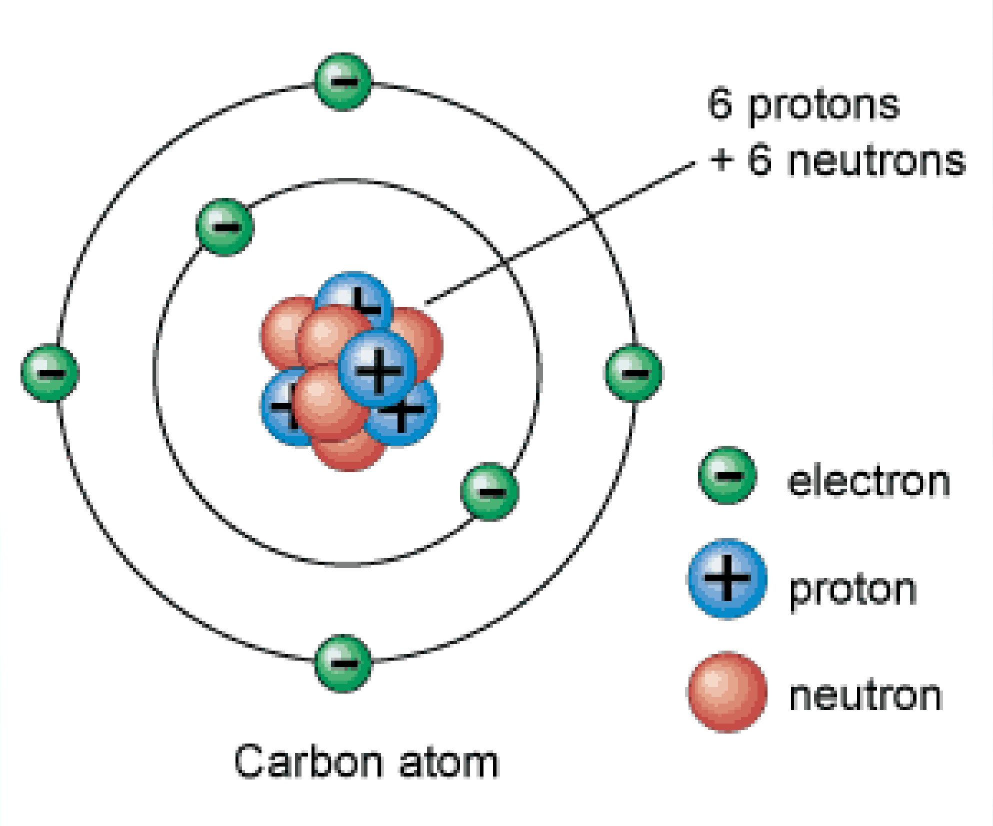
- Contains Electrons, Protons & Neutrons

- Electrons orbit around the nucleus, that consists of neutrons and protons



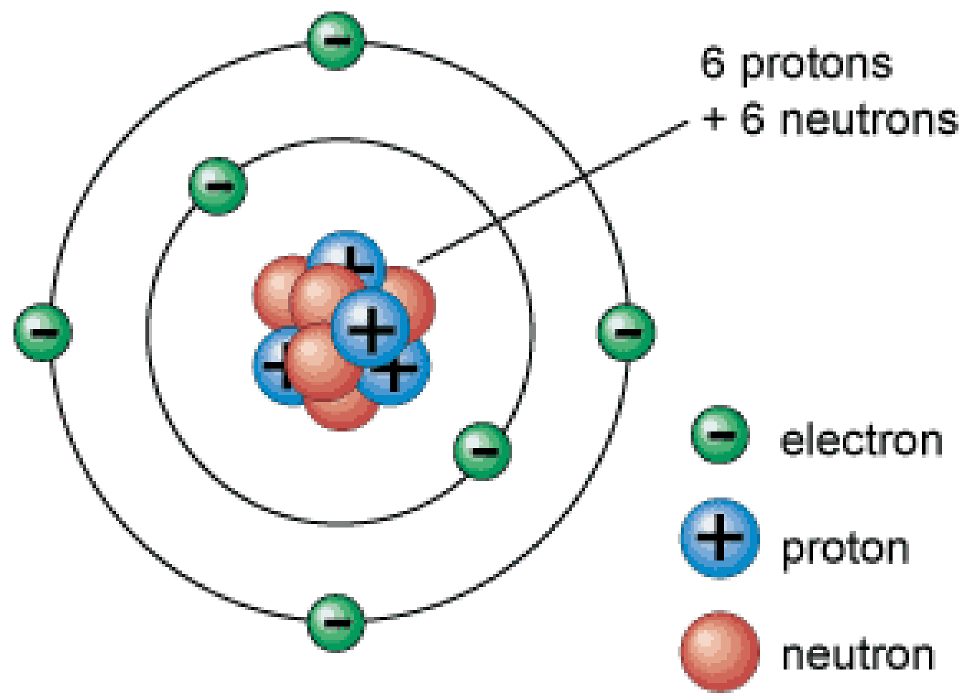
# Atomic Structure

- Electrons orbit the nucleus at a certain distance
- The electrons closer to the nucleus have less energy, than those further away
- The orbits are grouped into energy bands, called **‘Shells’**



# Valance Electrons

- Electrons furthest away from the nucleus are called **valence electrons**
- The outermost shell is the **valence shell**, or **valence band**
- Valence electrons contribute to chemical reactions, bonding and electrical properties of a material
- That is, its conductivity




Carbon atom

# Valance Electrons

- Electrons furthest away from the nucleus are called **valence electrons**
- If a Valence electron acquire sufficient energy it can escape from the outer shell and atom's influence $\longrightarrow$ **Ionization**
- An escaped electron is a **free electron**, that **enables conductivity in materials**.

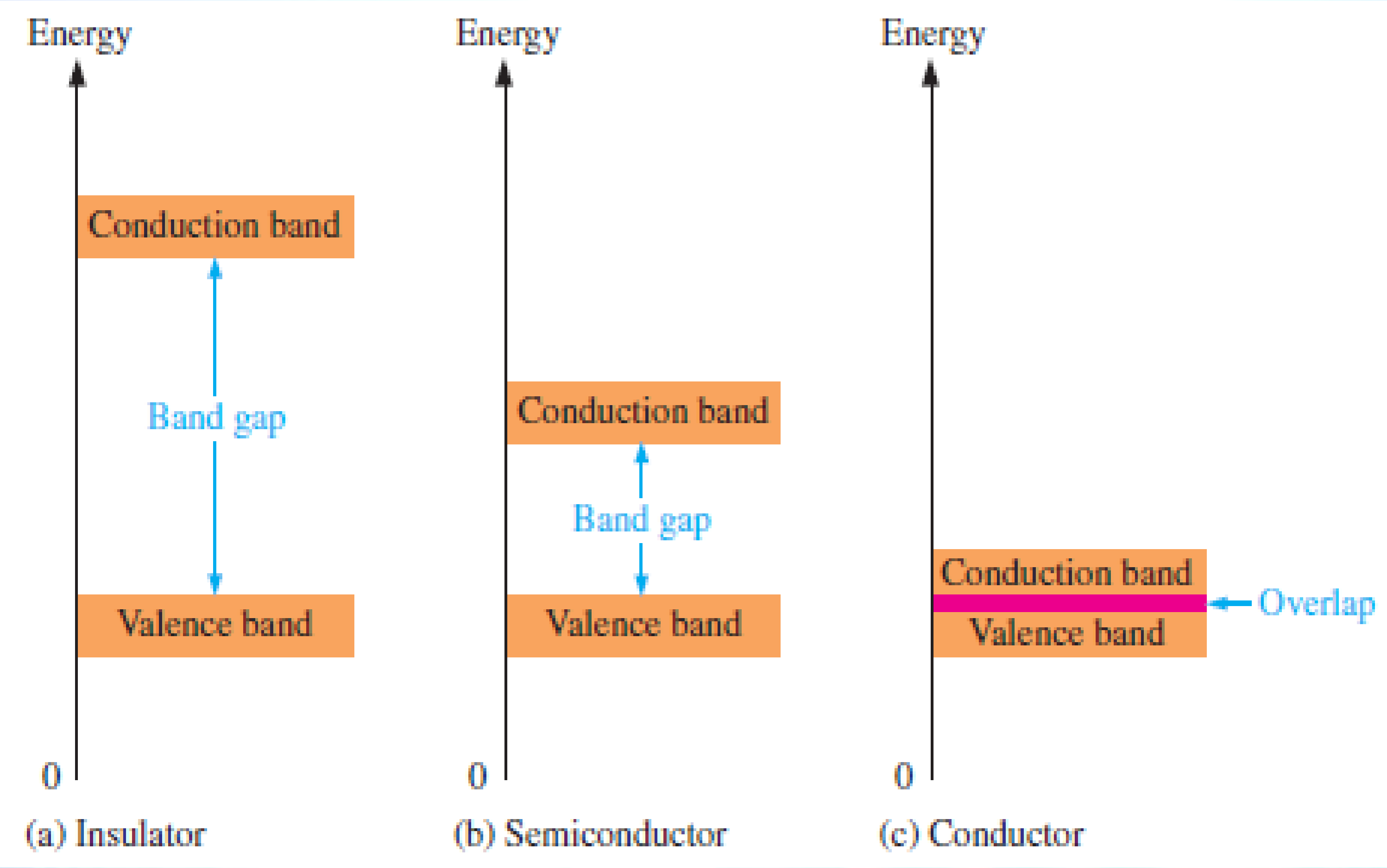
# Electrical Classification of Materials

- **Conductors:** is a material that easily conducts electrical current. Most metals are good conductors

- **Insulators:** is a material that does not conduct electrical current under normal conditions

- **Semiconductor:** is a material that is between conductors and insulators in its ability to conduct electrical current

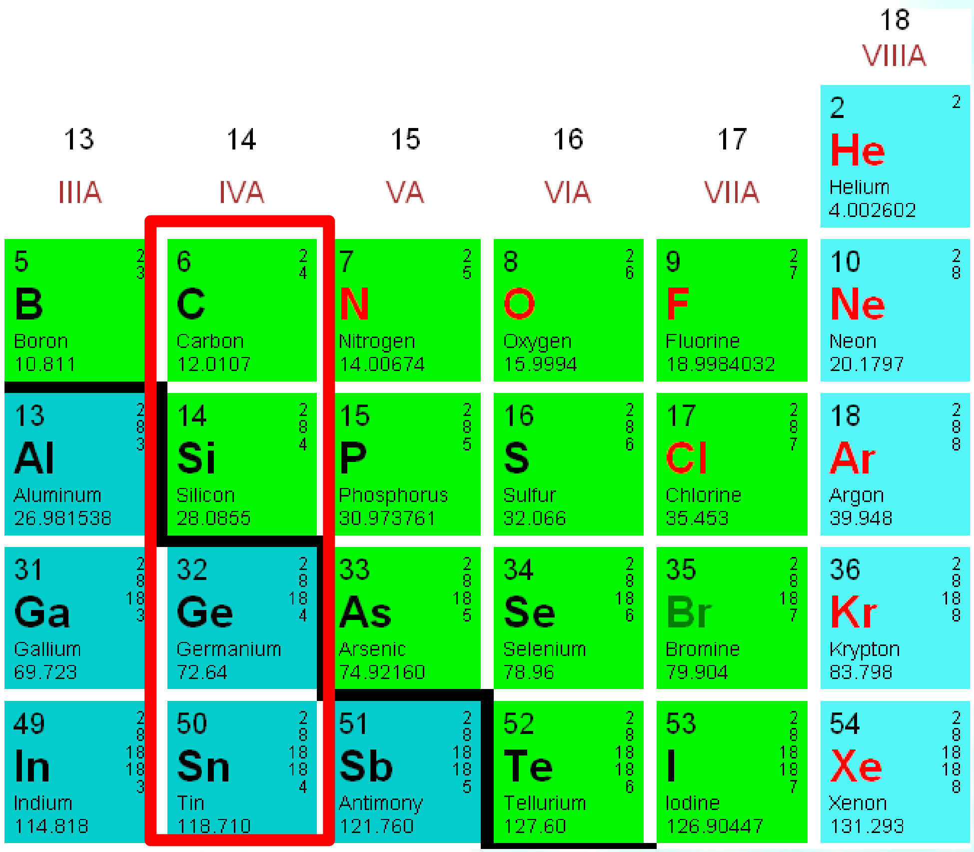
# Energy Gap


Energy
Conduction band
Band gap
Valence band
0
(a) Insulator
Energy
Conduction band
Band gap
Valence band
0
(b) Semiconductor
Energy
Conduction band
Overlap
Valence band
0
(c) Conductor

# Semiconductors

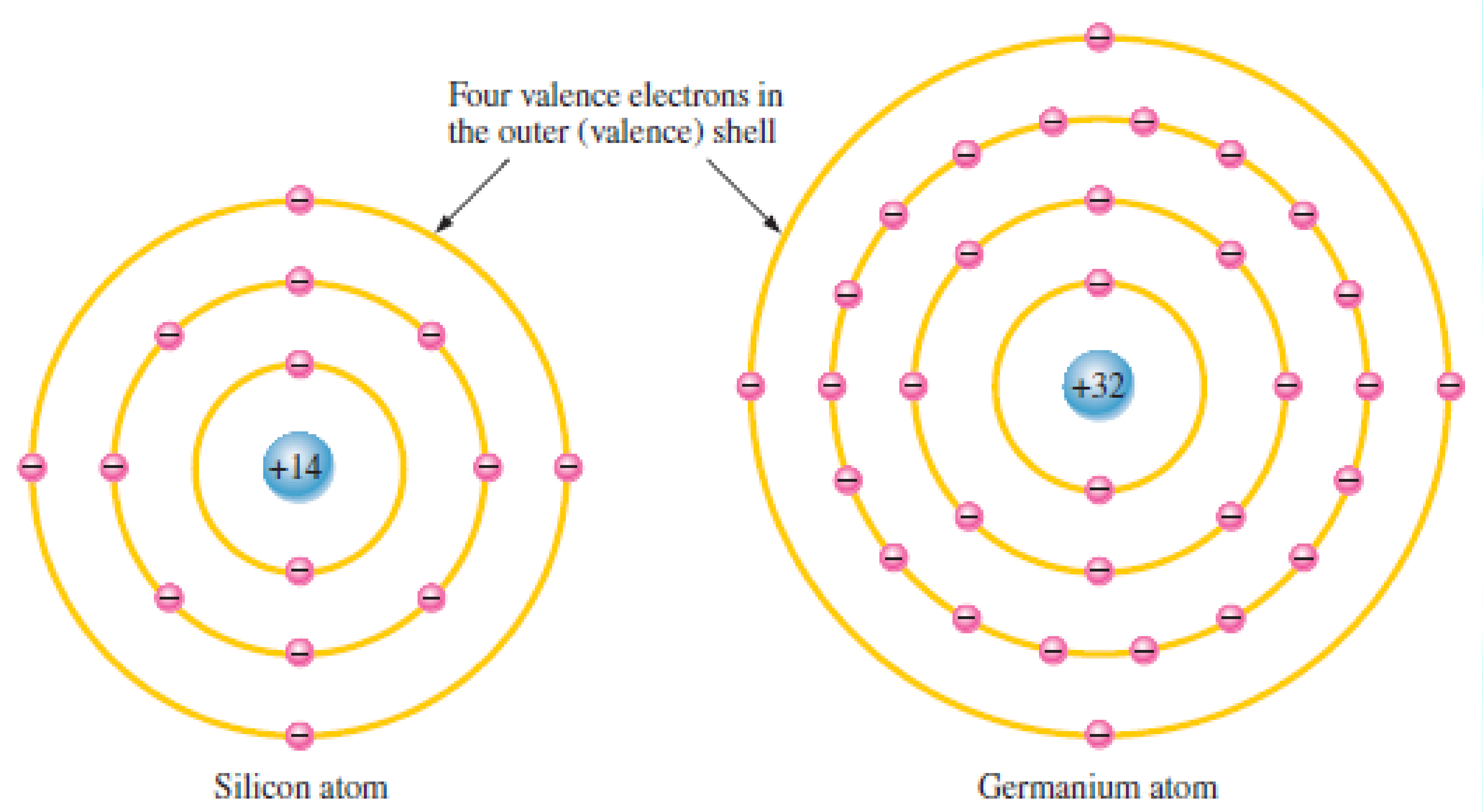
- Types of semiconductors:
  - **Single-element semiconductors (intrinsic):** carbon (C), silicon (Si), germanium (Ge)
  - **Compound semiconductors (extrinsic):** gallium arsenide, gallium nitride, silicon carbide

*C, Si, Ge all have 4 valence electrons*



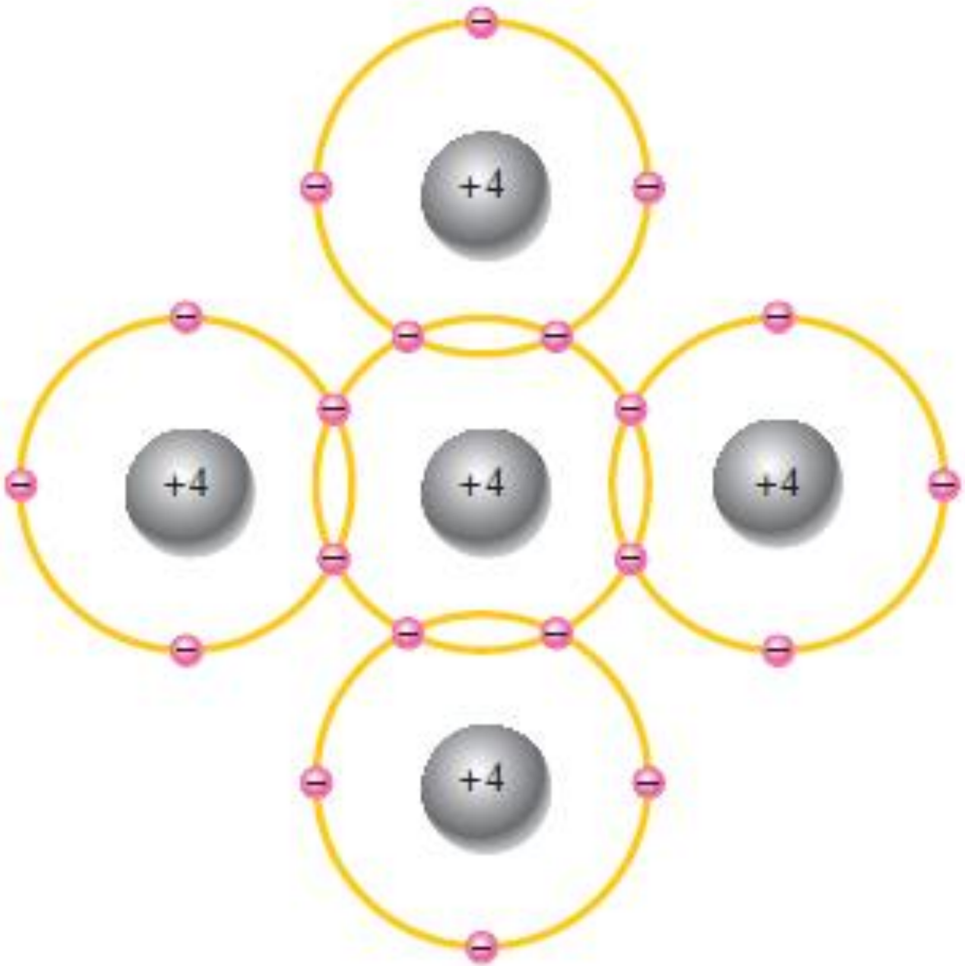
# Atomic Structure of Si & Ge

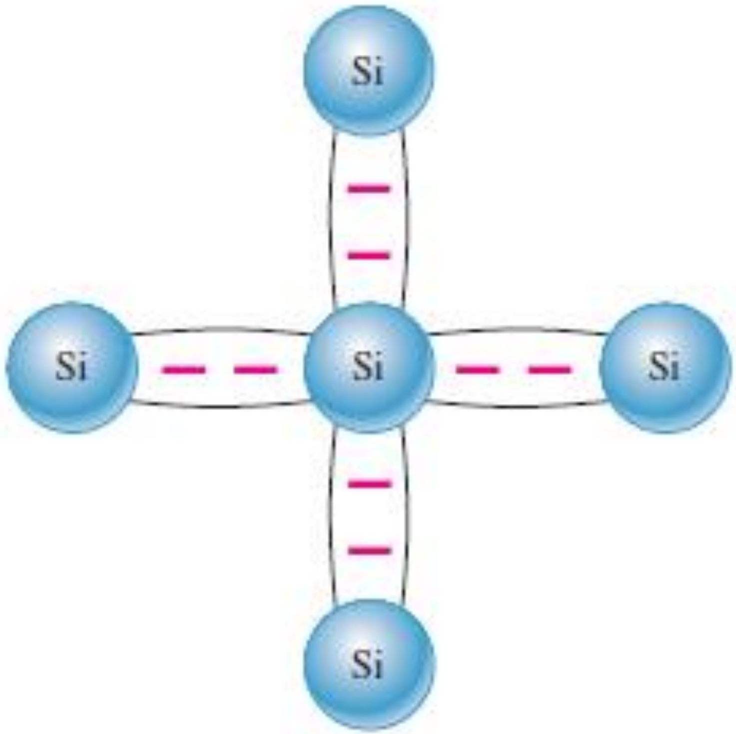
- **4 valance electrons in the outer shell**



# Covalent Bond

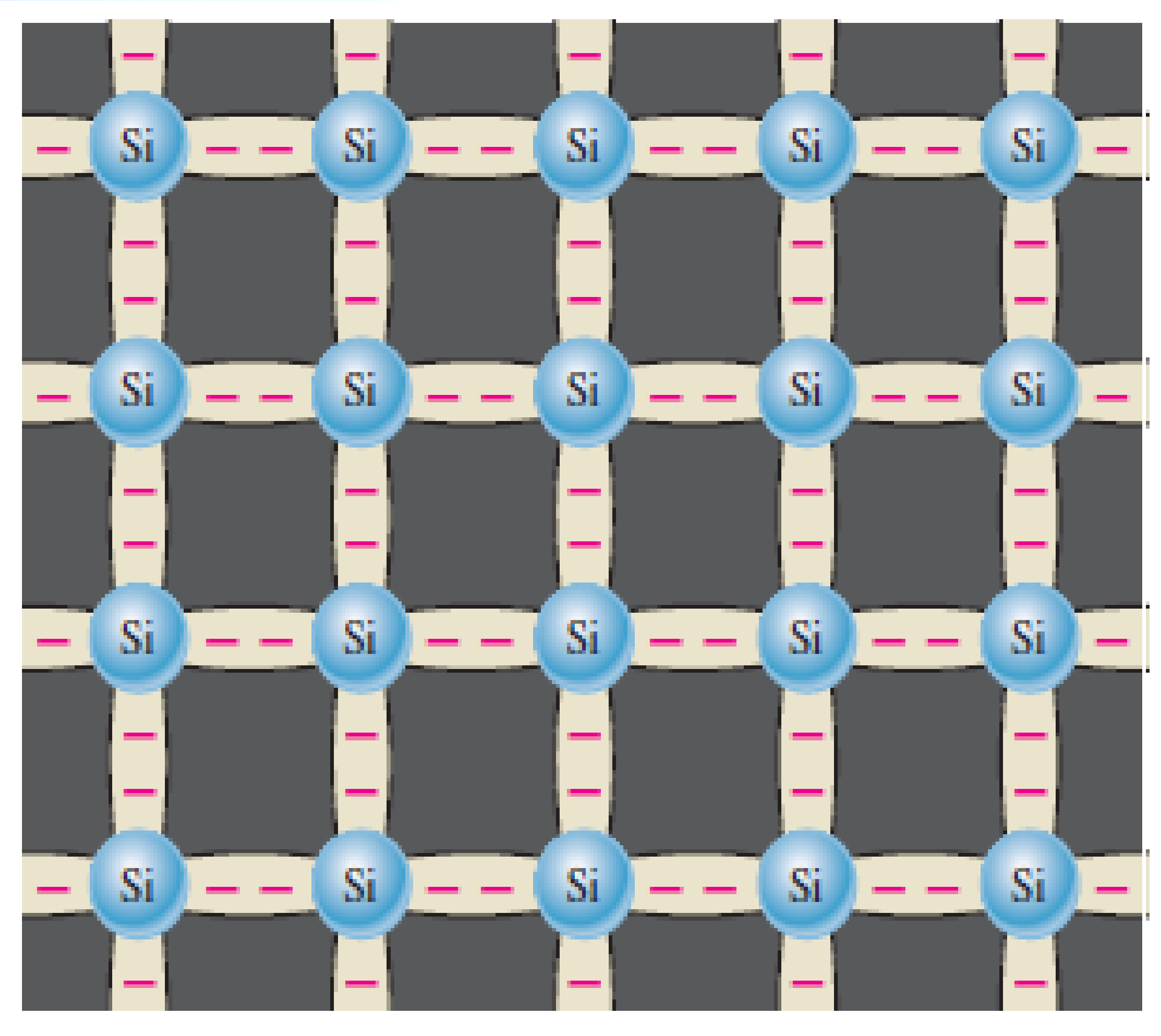
- When atoms combine to form solids they arrange them in a crystal structure held together by **covalet bonds**



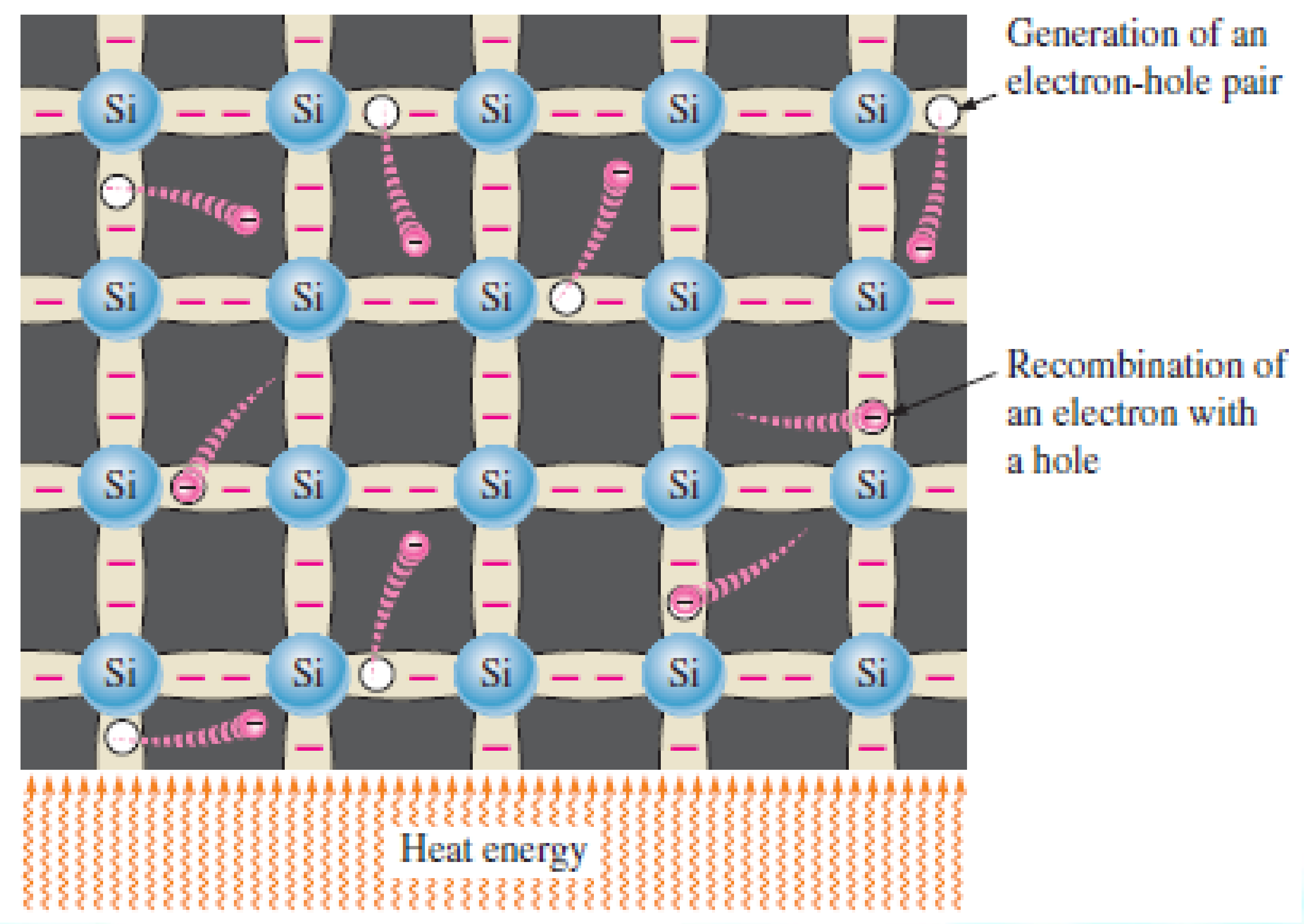

Two electrons are shared in each bond

# Intrinsic Si Crystal



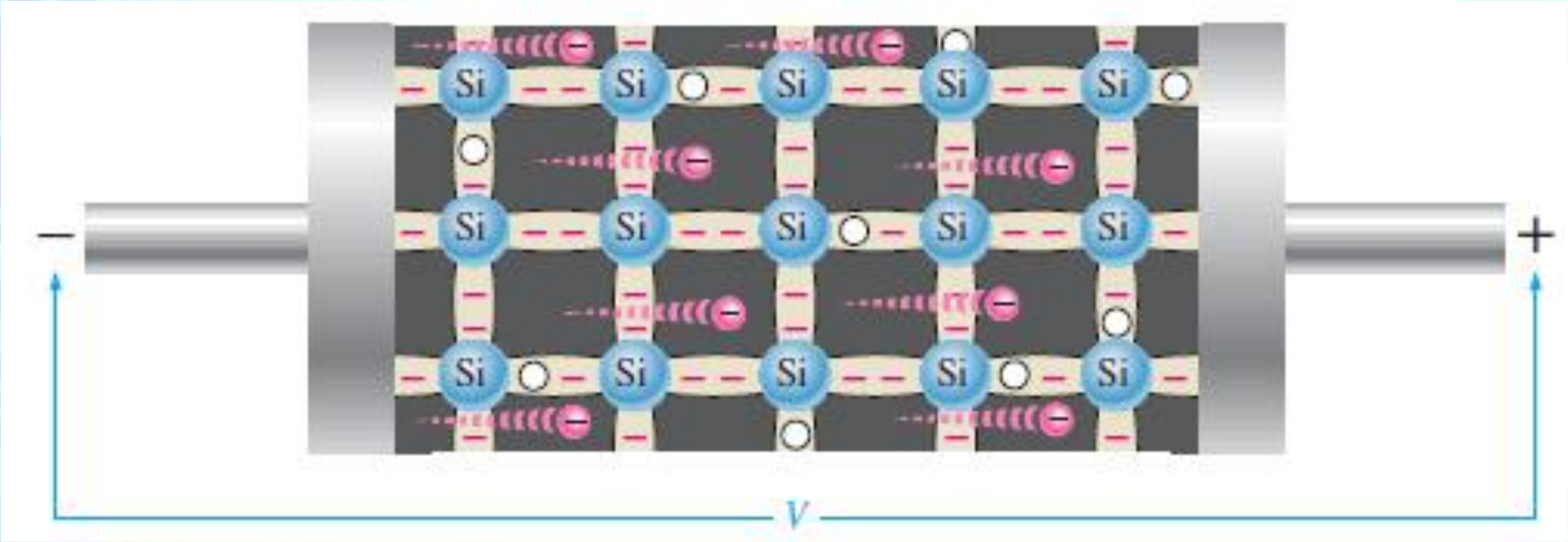
# Intrinsic Si Crystal

- An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some valence electrons to jump the gap from the valence band into the conduction band to create **conduction electrons**



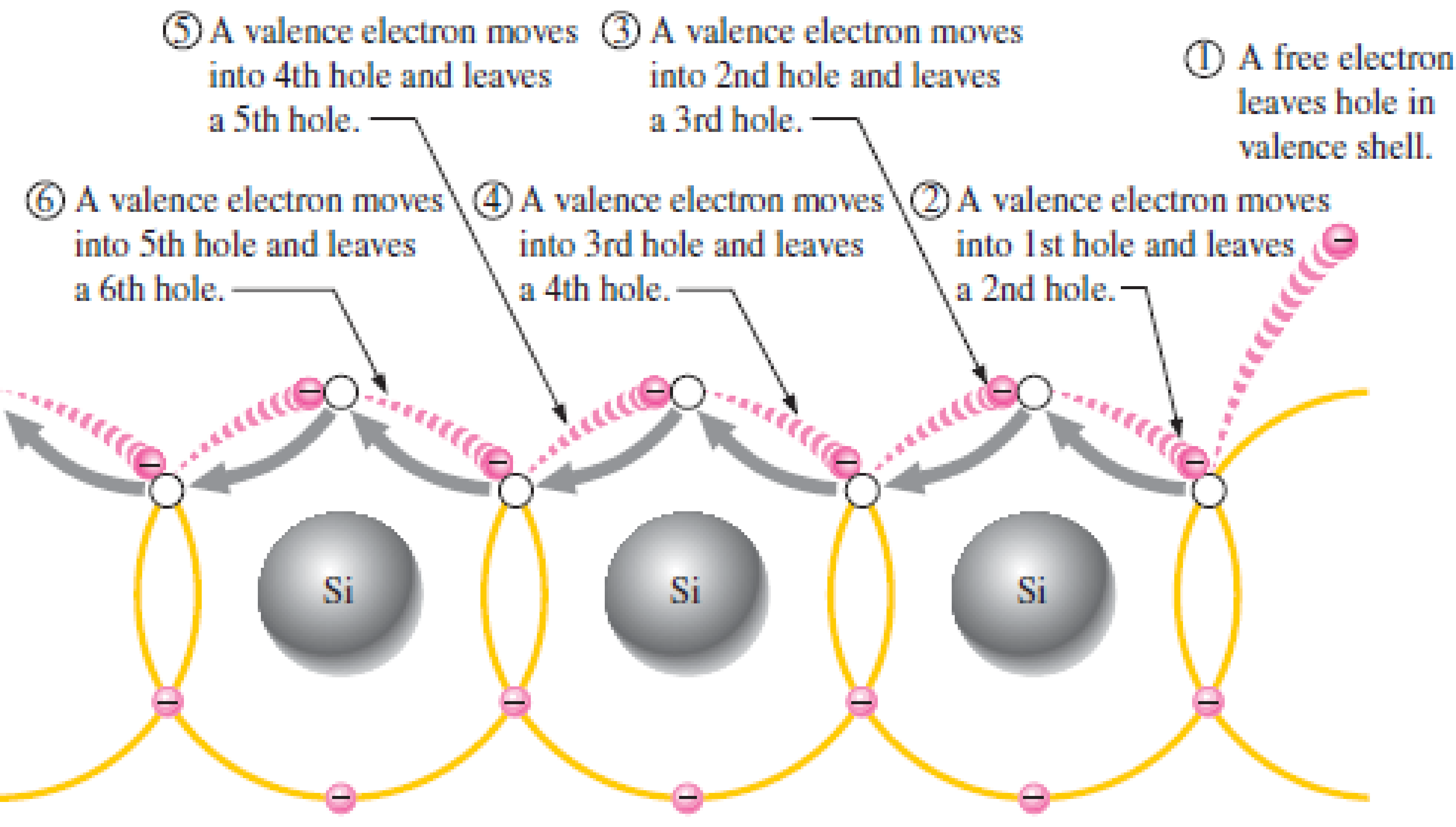
# Electron and Hole Current

- In the presence of an electric field…
- Electron Current



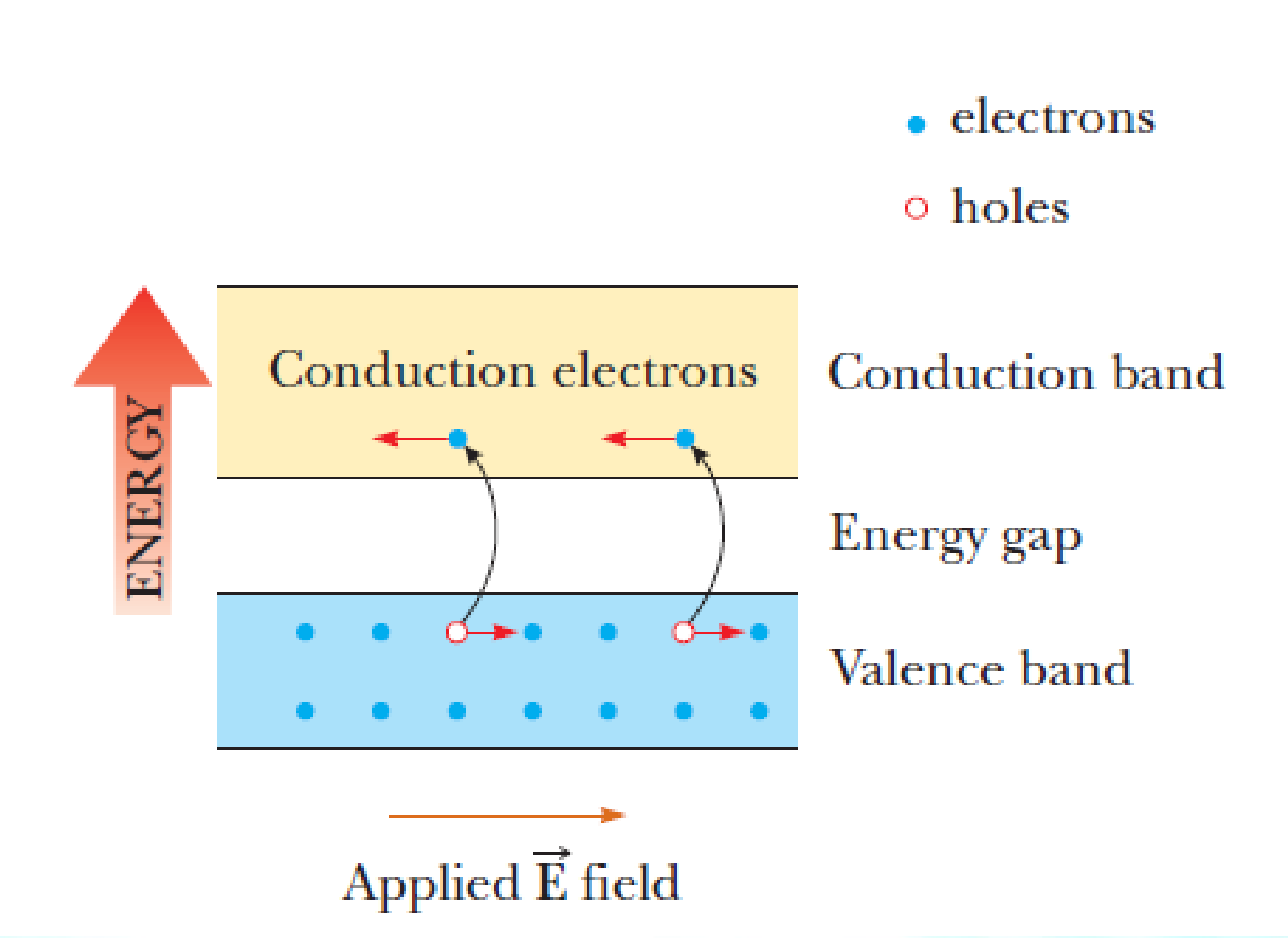
# Electron and Hole Current

- Hole Current



# Electron and Hole Current

- In the presence of an electric field: Electron & Hole Current



# Extrinsic Semiconductors

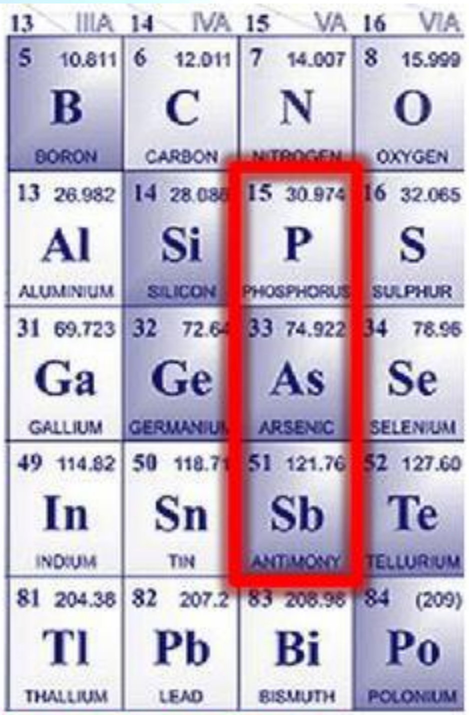
- Because of the limited number of free electrons in the conduction band and holes in the valence band intrinsic materials do not conduct current well

- Thus 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 (know as **Doping**)

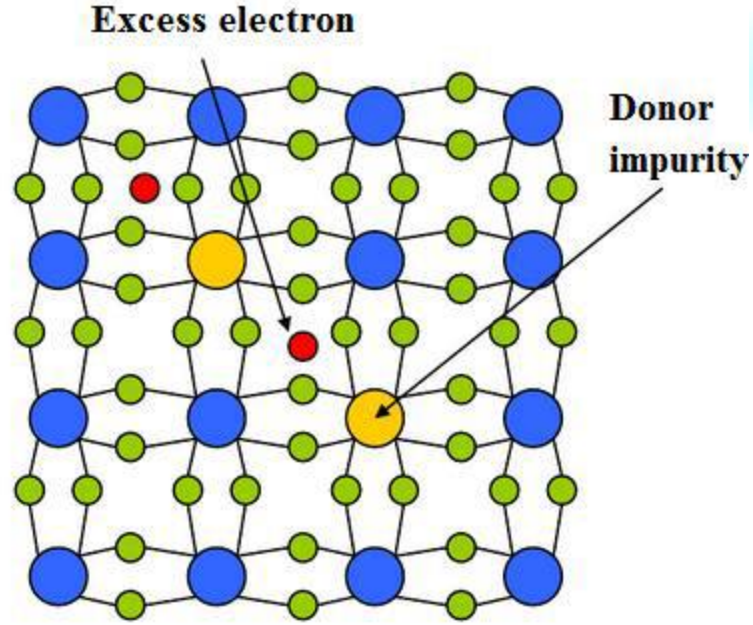
# N-type Semiconductors

- To increase the number of electrons in the conduction-band **Group-V** elements are added




**Donor dopants**

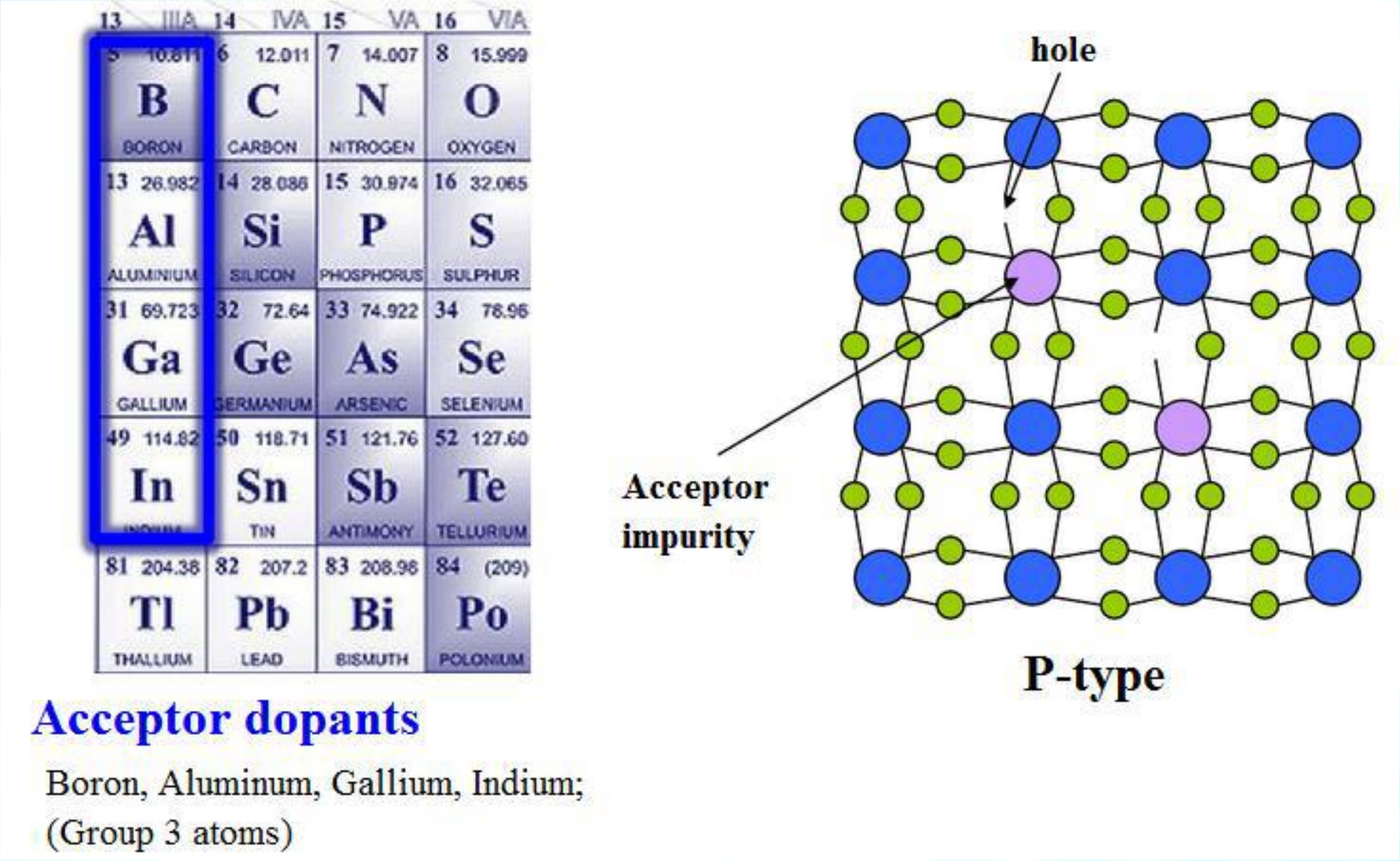
Phosphorus, Arsenic, Antimony;
(Group 5 atoms)



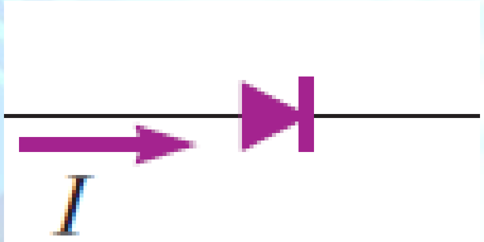

N-type

# P-type Semiconductors

- To increase the number of holes **Group-III** elements are added

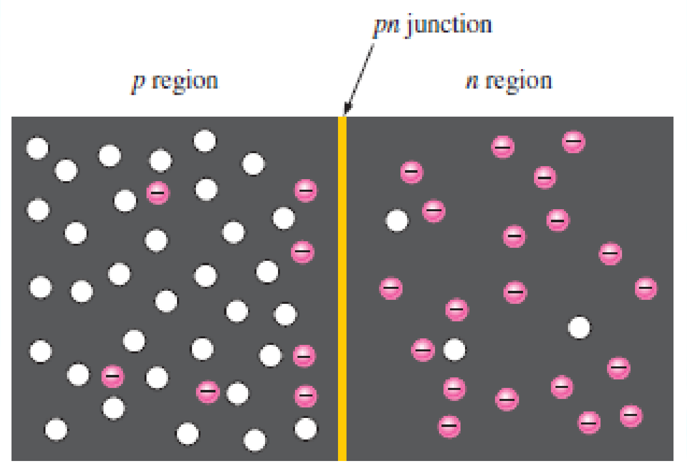


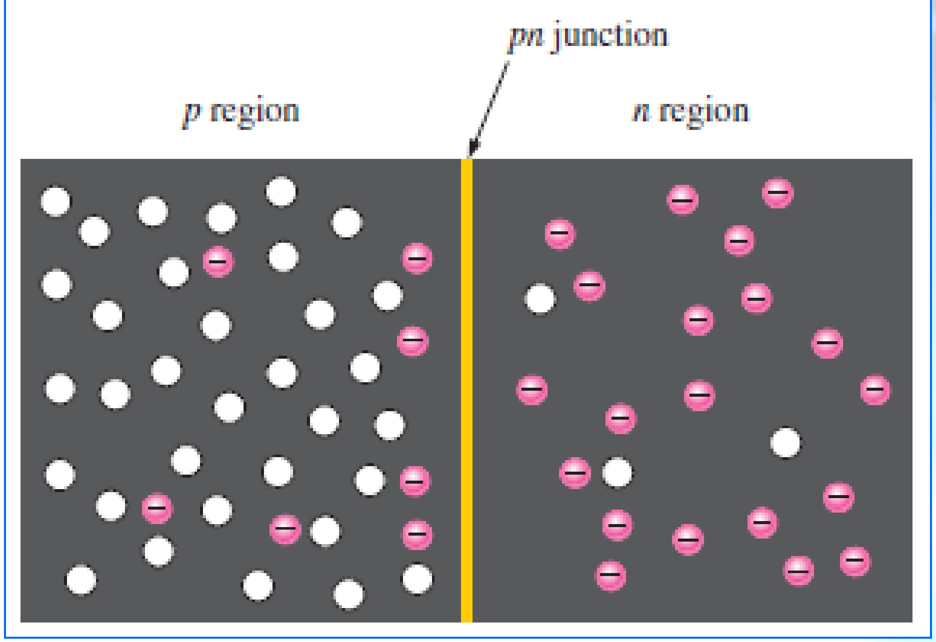
# The PN-Junction (Diode)

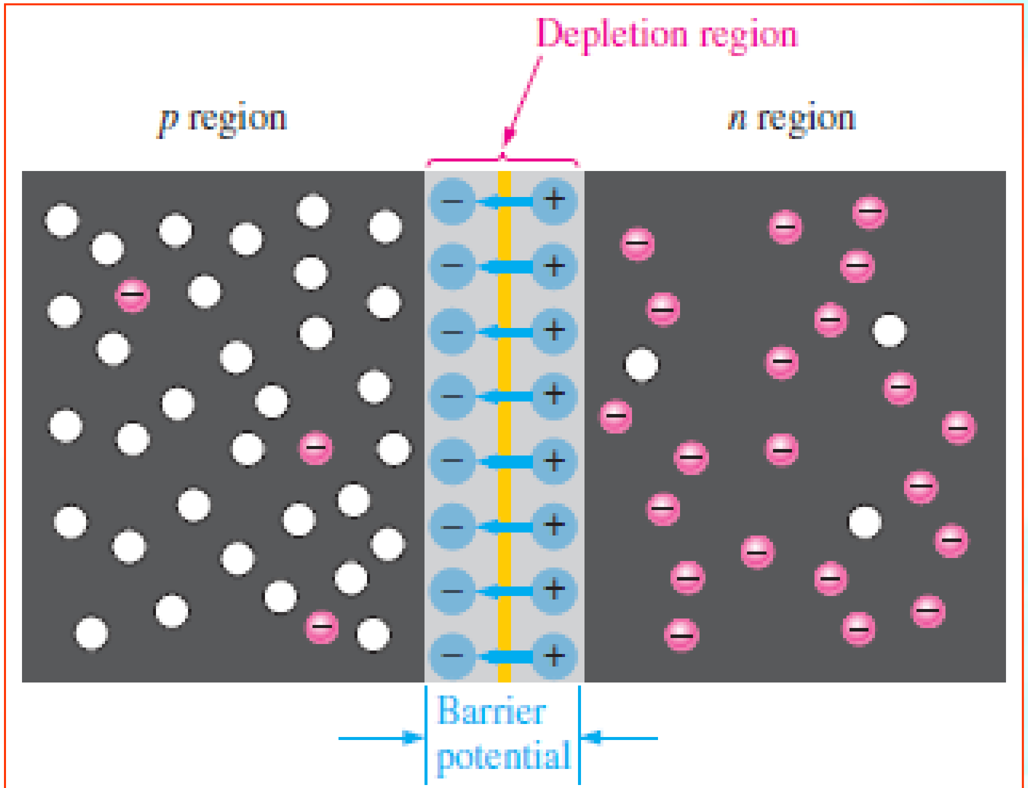




# The PN-Junction (Diode)

- The net charge in the **n** or **p** type semiconductor is zero
  - The no. of electrons and protons are equal throughout the material
- When a pn-junction is formed
  - n-region has more electrons and p-region has more holes
  - Free electrons near the junction in n-region diffuse across to p-region to combine with the holes near the junction
  - Near the junction, this creates a layer of +ve charges in n-region and a layer of –ve charges in p-region (known as **depletion region**)

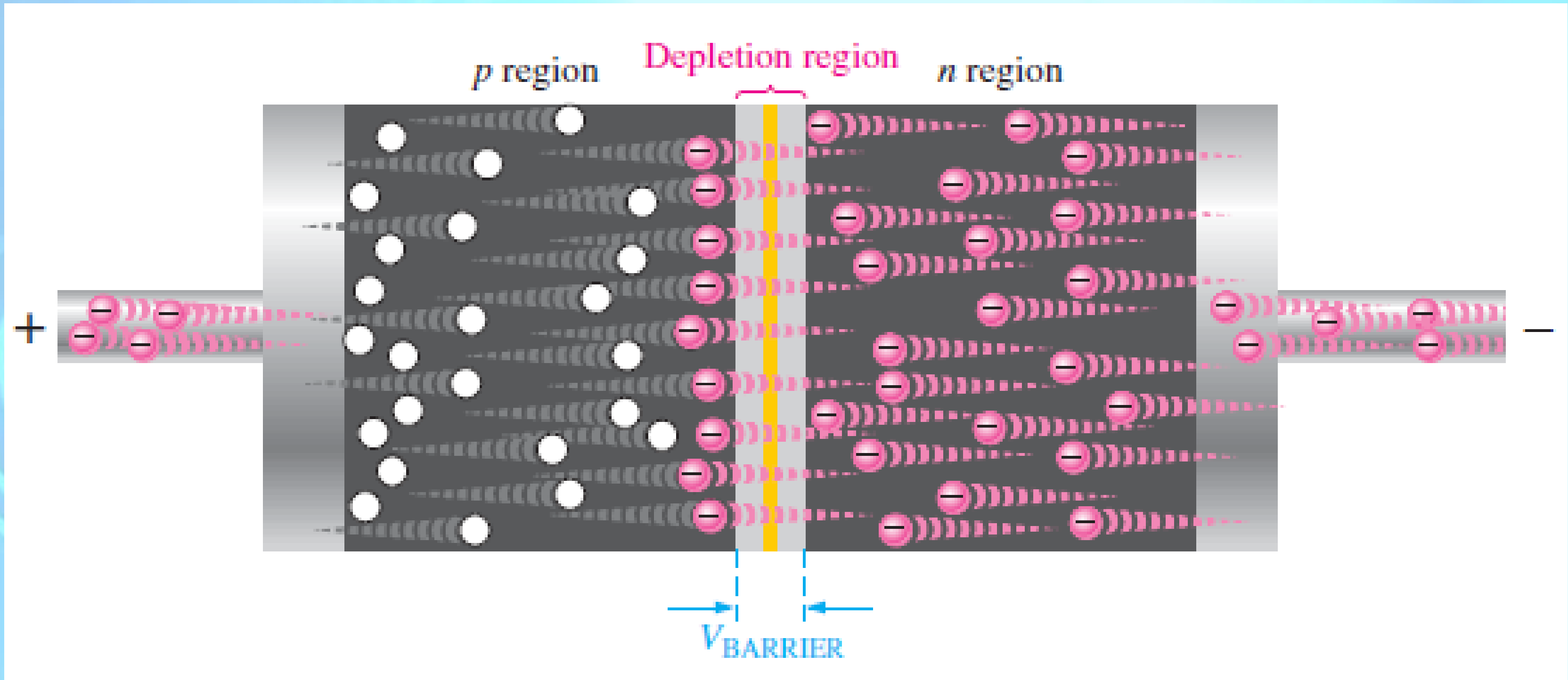





- Equilibrium of the Depletion region is achieved when the total negative charge in the depletion region repels any further diffusion of electrons

# Forward Bias

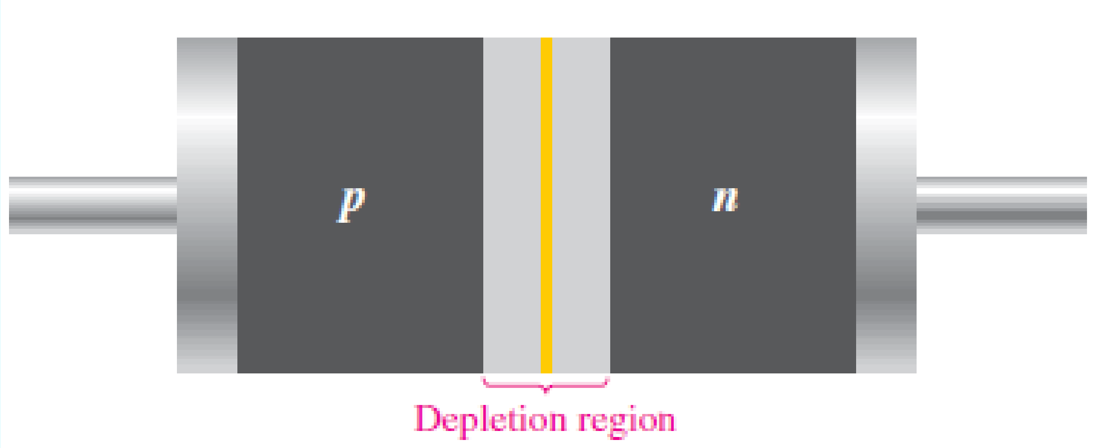



- The bias voltage provides sufficient energy to free electrons to overcome the barrier potential

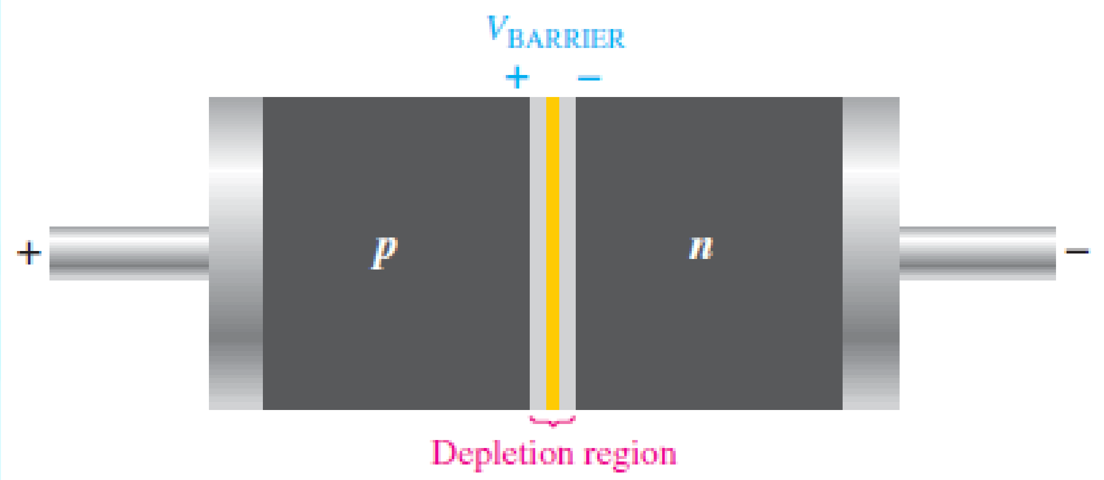
- A current flows through the diode created by the majority carriers

# Forward Bias

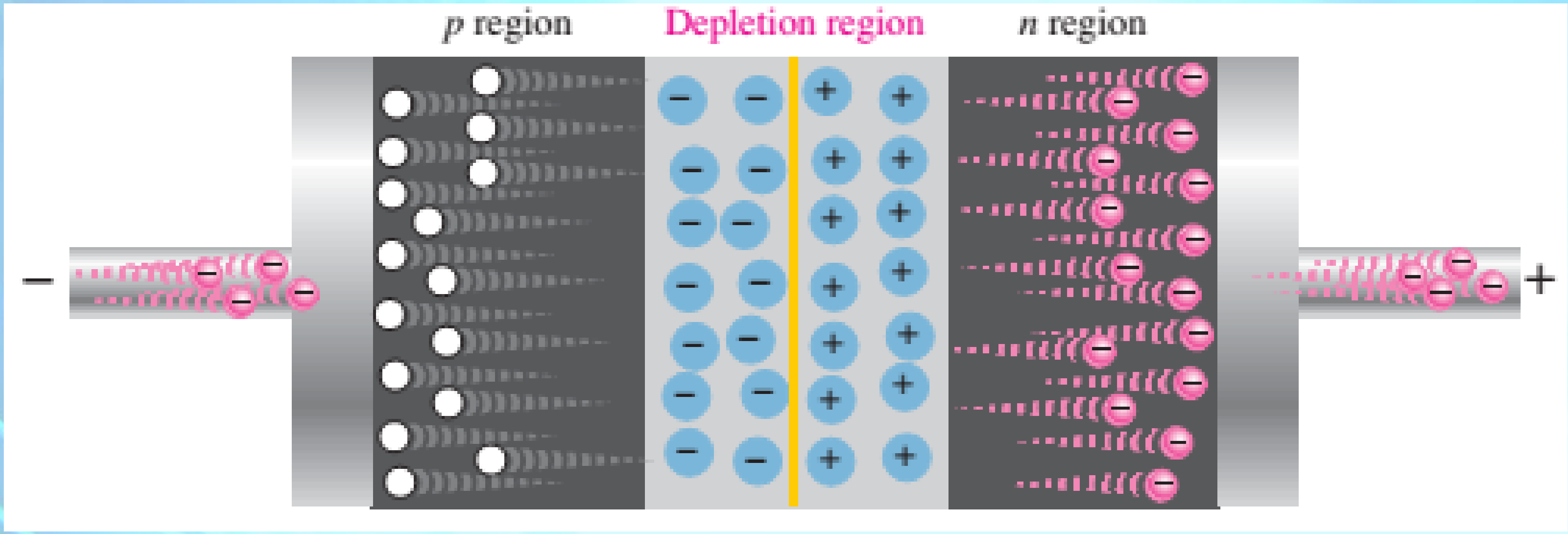
- At equilibrium (no bias)




- Forward bias narrows the depletion region and produces a voltage drop across the junction equal to the barrier potential

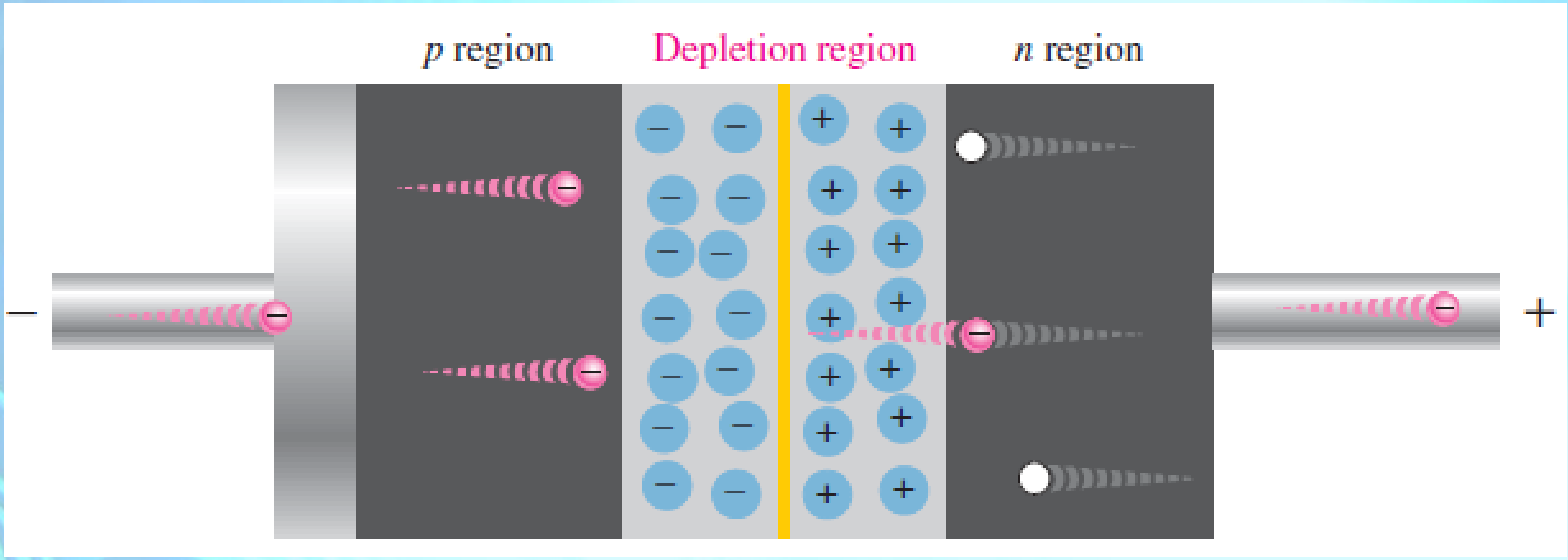


# Reverse Bias




- The diode during the short transition time immediately after reverse-bias voltage is applied
- Depletion region increases and the barrier voltage reaches the bias voltage

# Reverse Bias



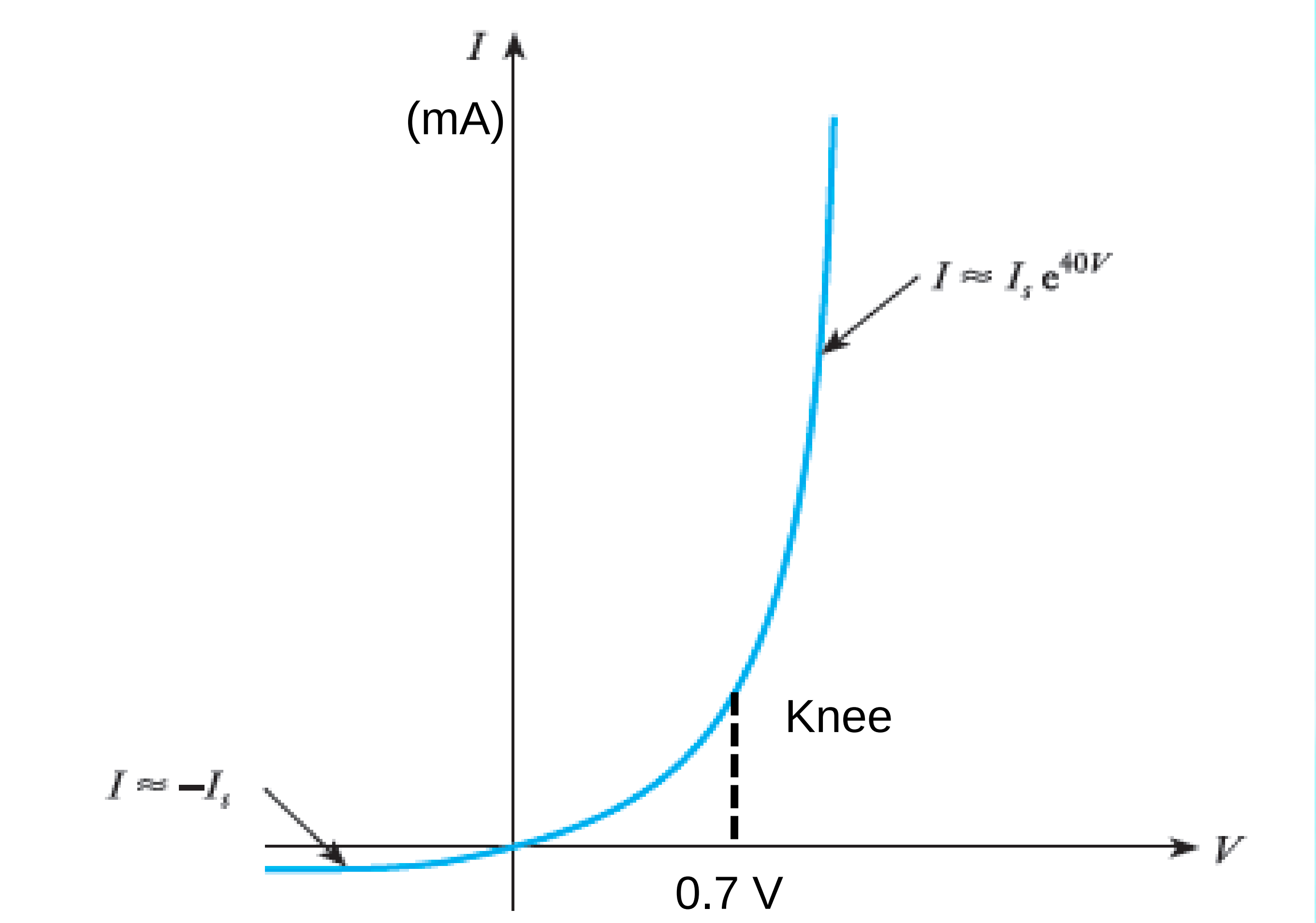

- Depletion region increases and the barrier voltage reaches the bias voltage
- A extremely small current through the diode is created by the minority carries

# Reverse Bias

- Reverse breakdown
  - Normally, the reverse current is so small that it can be neglected
  - However, if the external reverse-bias voltage is increased to a value called the ***breakdown voltage***, the reverse current will drastically increase

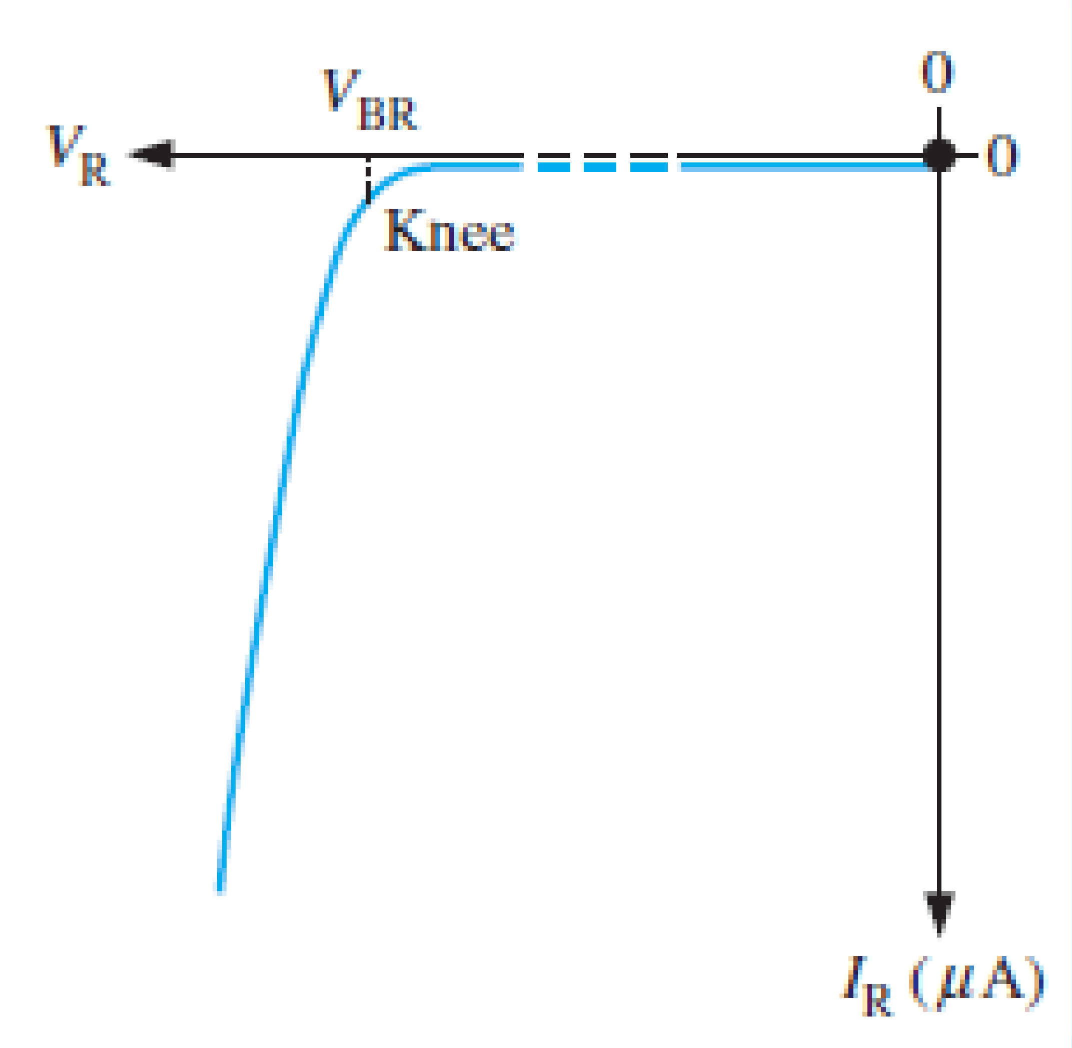
# Diode V-I Characteristics

- Forward bias



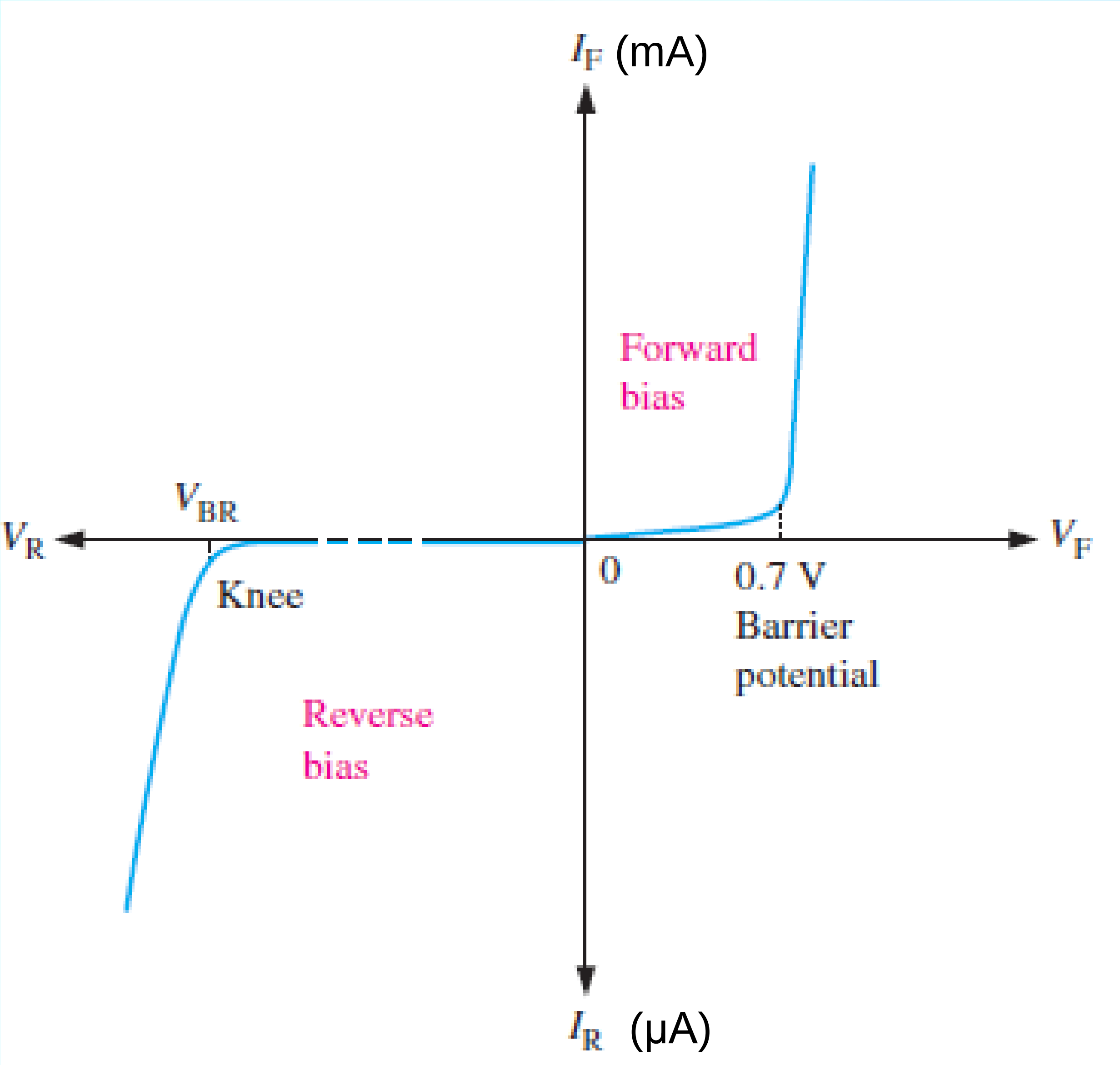
# Diode V-I Characteristics

- Reverse bias



# Diode V-I Characteristics

- Complete V-I curve

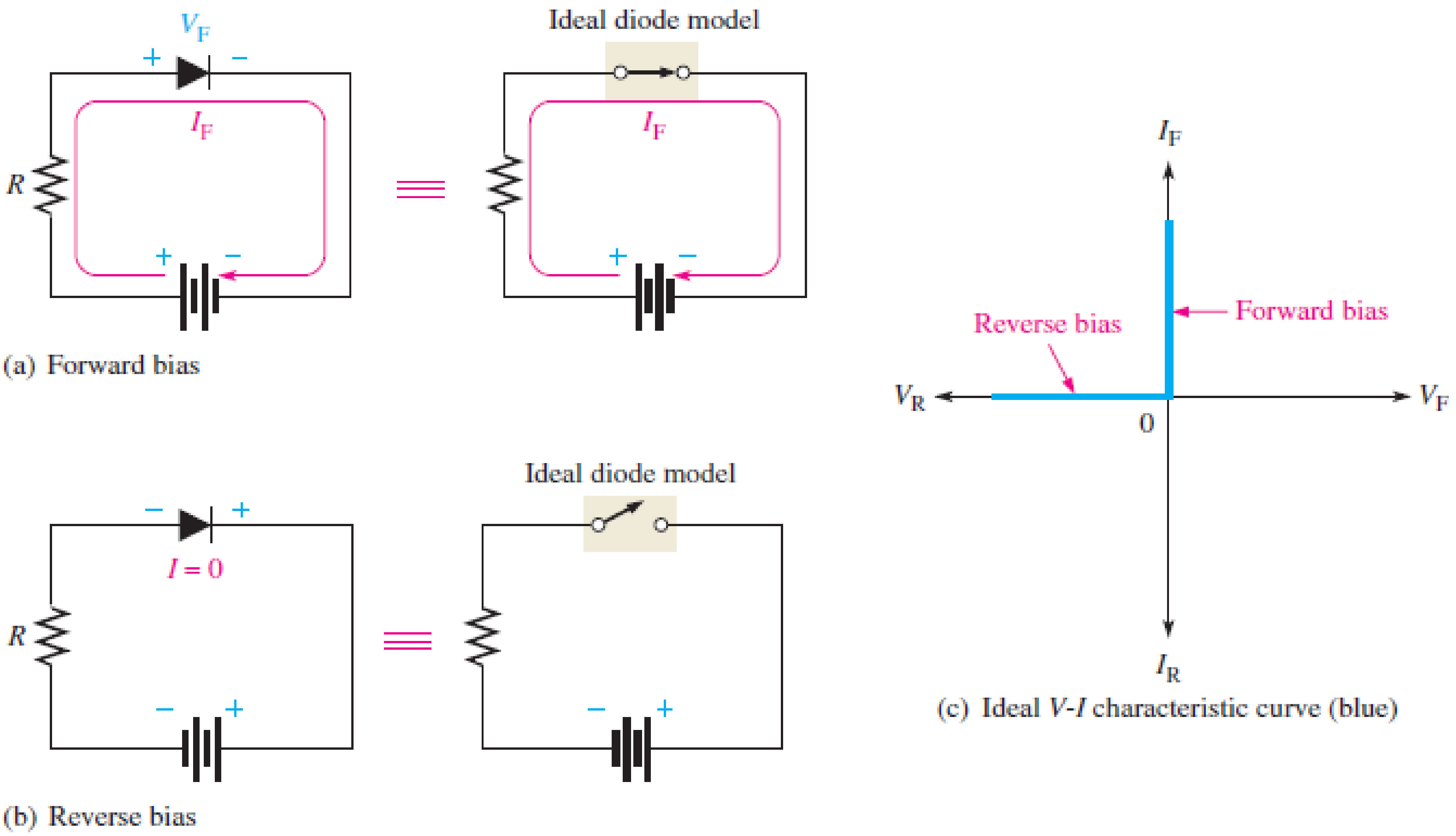


# Diode Models

- **Ideal model**
  - No barrier potential
  - No forward dynamic resistance

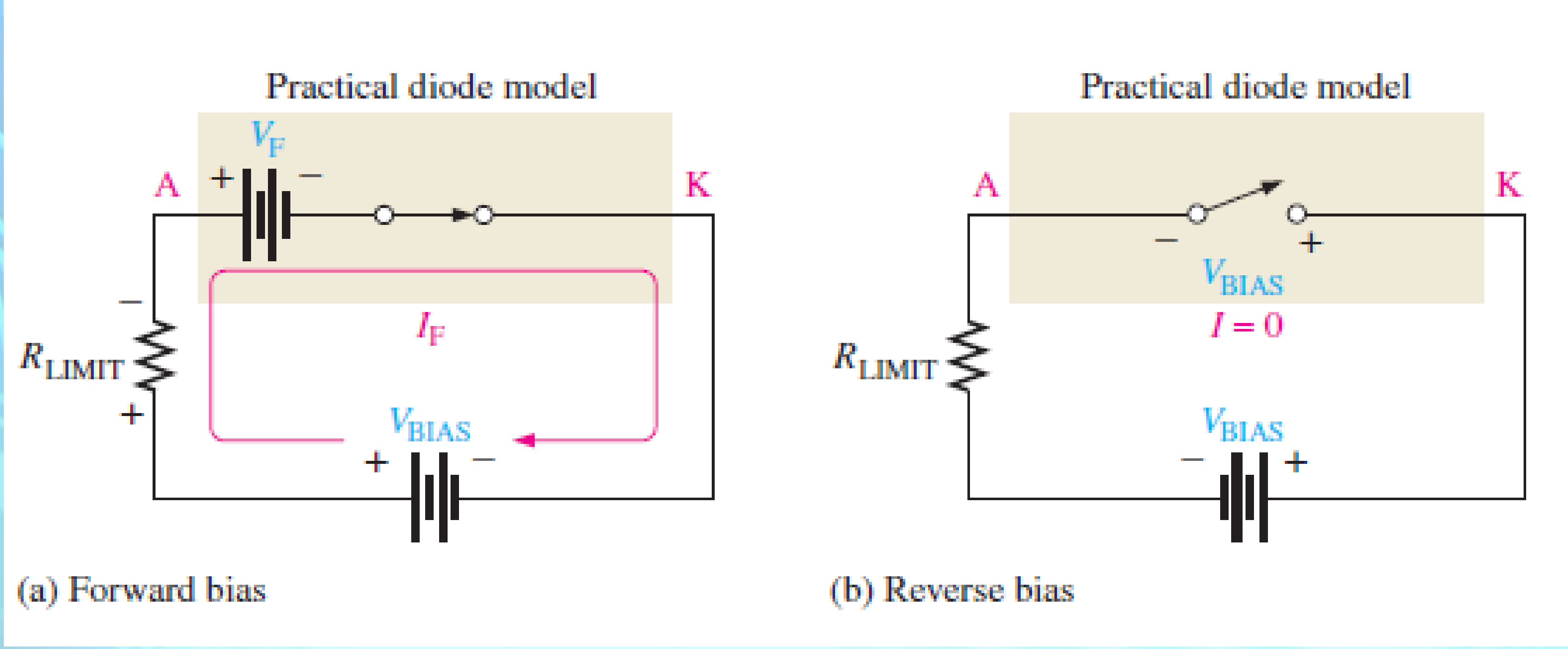
- Functions as a “switch”

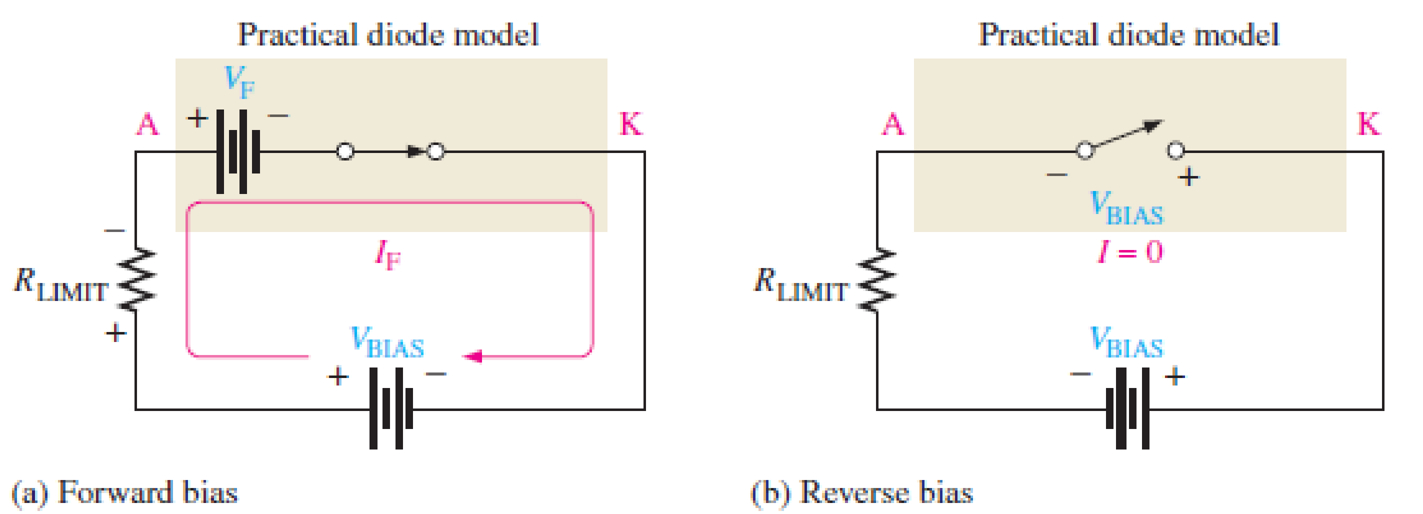
# Diode Models



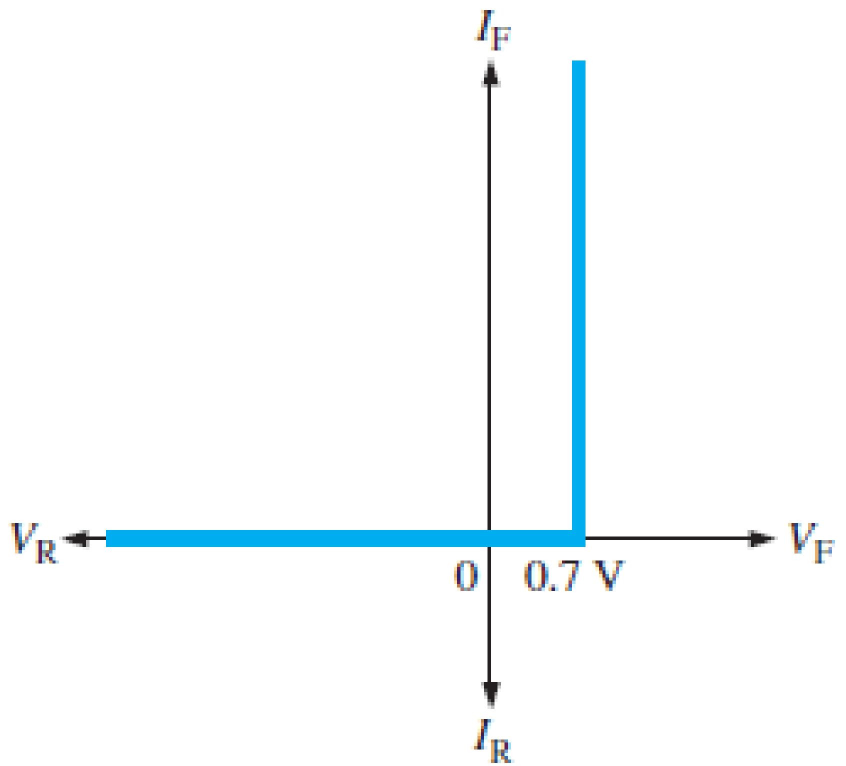
# Diode Models

- **Practical model**
  - With barrier potential
  - No forward dynamic resistance



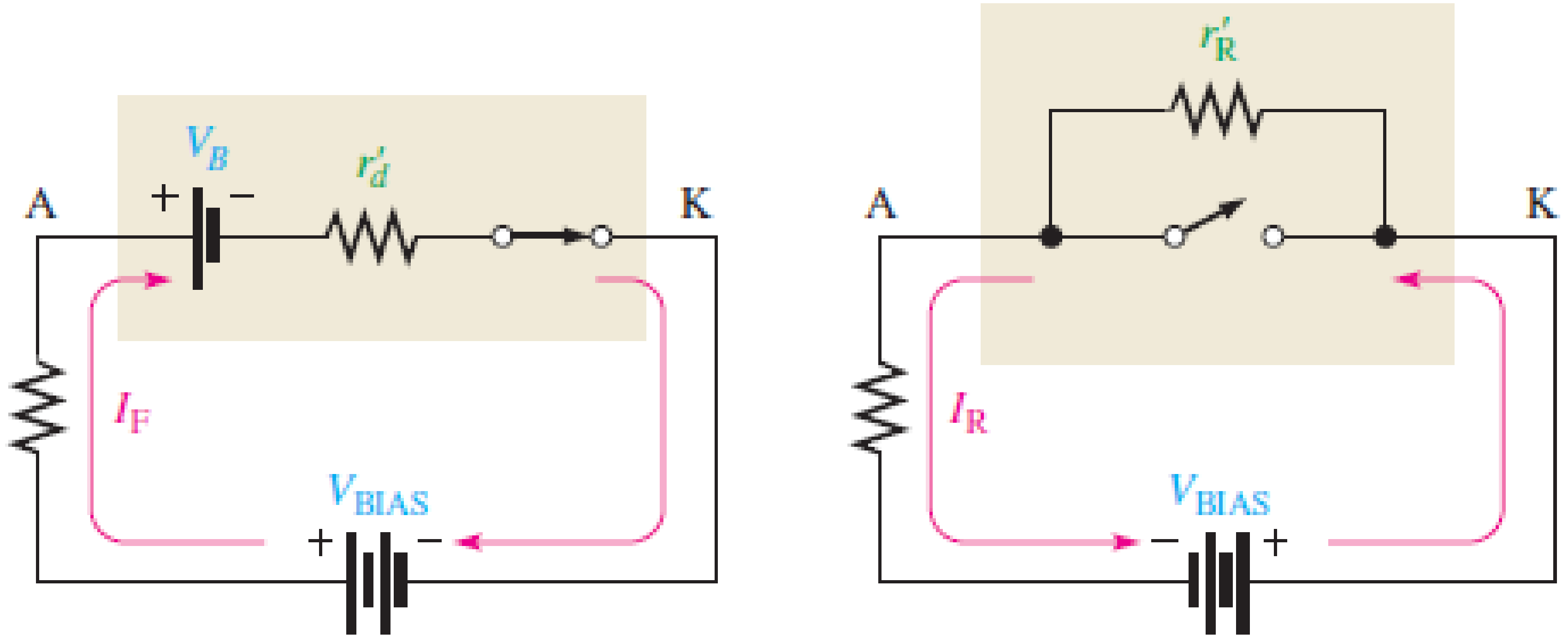


(a) Forward bias
(b) Reverse bias

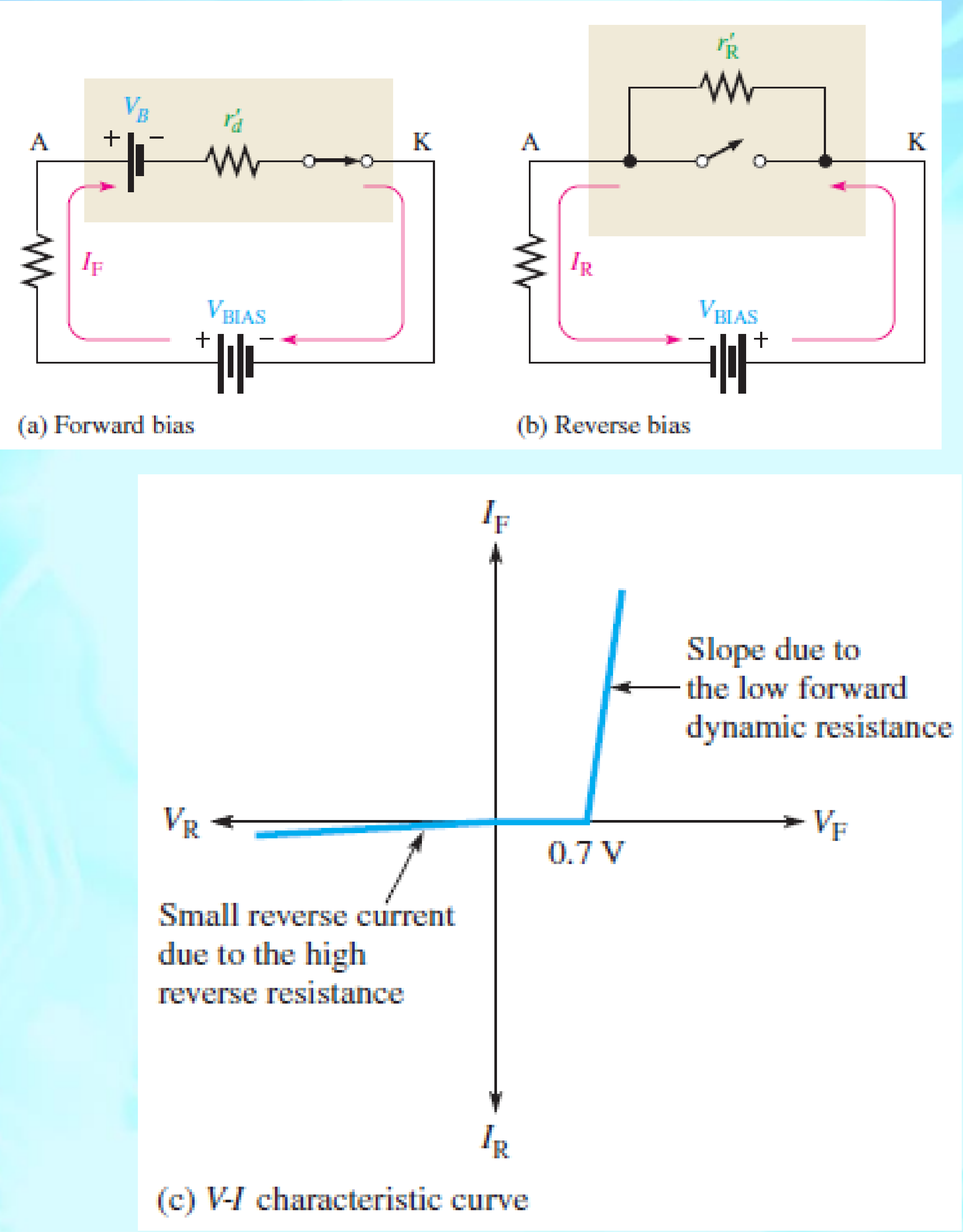


# Diode Models

- **Complete model**
  - With barrier potential
  - With forward dynamic resistance




(a) Forward bias (b) Reverse bias



$V_B$
$r'_d$
A
K
$I_F$
$V_{BIAS}$
(a) Forward bias
$r'_R$
A
K
$I_R$
$V_{BIAS}$
(b) Reverse bias
$I_F$
Slope due to the low forward dynamic resistance
$V_R$
$V_F$
0.7 V
Small reverse current due to the high reverse resistance
$I_R$
(c) *V-I* characteristic curve

# Problem

- **Analyze the circuit shown below using the ideal diode model**