Unit I

Introduction to Electronics and Semiconductor diodes

Unit Outcome

- **At the end of this unit, student will be able to**
  - Implement different diode circuits.
  - Understand different types of diodes and its applications

Semiconductor diode

- **Diode** : Di – ode : Two – electrodes

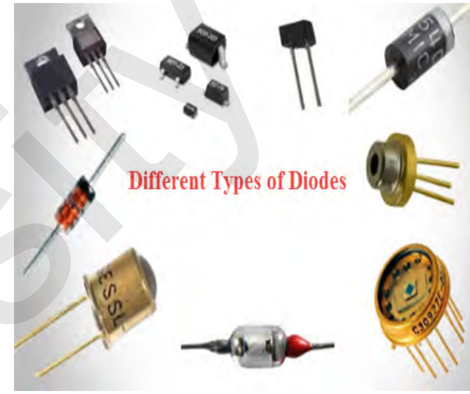
➢ p-type and n-type material sandwiched together to form a a depletion region between the two.

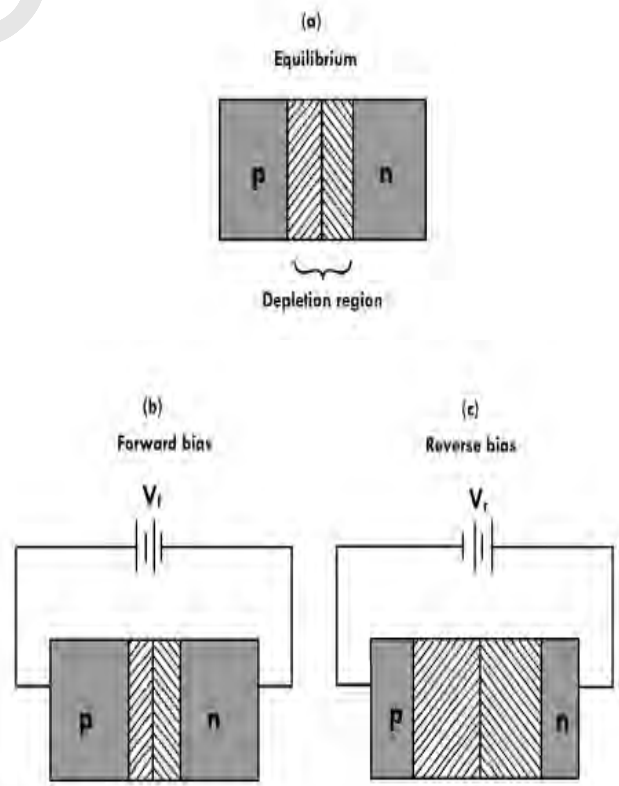
➢ Semiconductor diode may be either of Silicon or Germanium material

Biasing of diodes :

➢ **Forward Bias** : A material type connected to the same polarity terminal of the voltage source

➢ **Reverse Bias** : A material type connected to the opposite polarity terminal of the voltage source

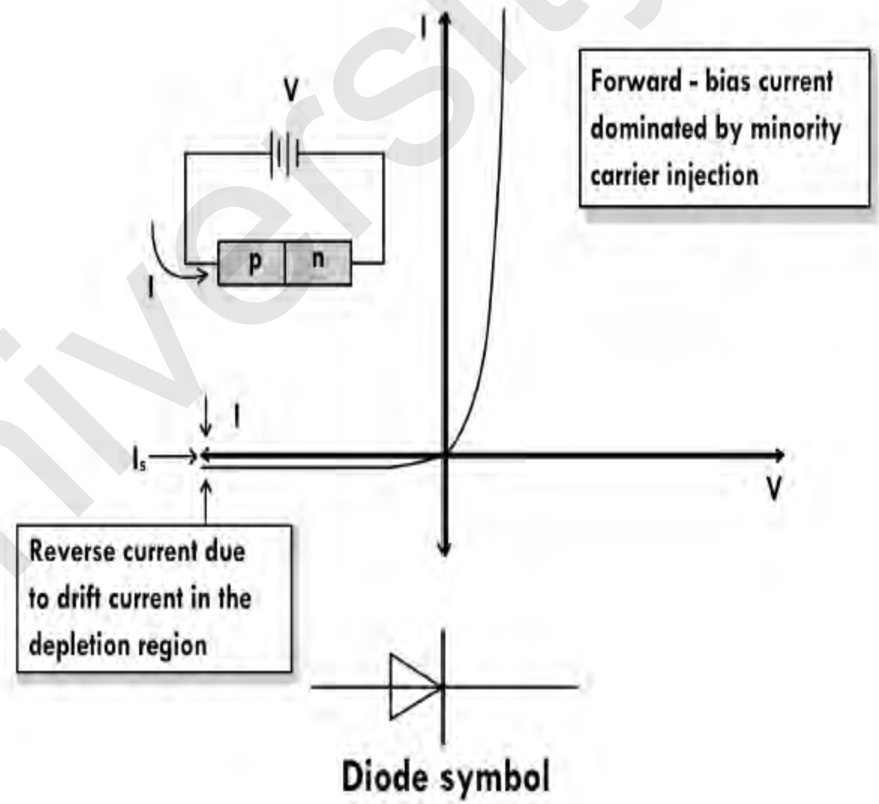




V-I characteristics

- **Knee voltage** (Vk) is also known as cut in **voltage**. The minimum amount of **voltage** threshold inspections required for conducting the **diode** is known as **knee voltage** or cut in **voltage**.

- The forward **voltage** at which the current through PN junction starts increasing rapidly is known as **knee voltage**.



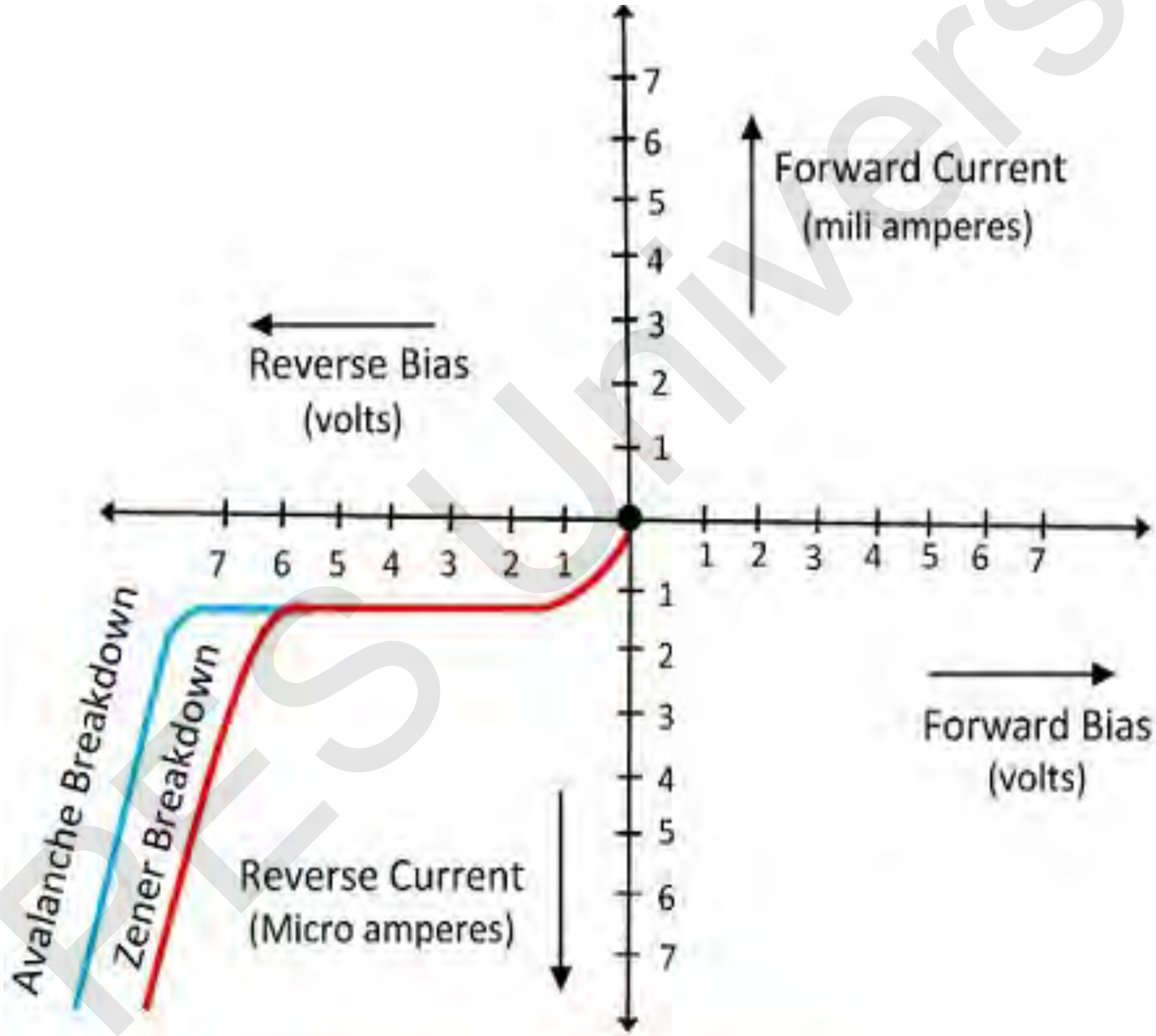
V-I characteristics

- The maximum **reverse** bias **voltage** that can be applied to a p-n **diode** is limited by **breakdown**. **Breakdown** is characterized by the rapid increase of the current under **reverse** bias. The corresponding applied **voltage** is referred to as the **breakdown voltage** (VBR)

- Two types of breakdown occurs :
  - **Zener breakdown** : The process in which the electrons are moving across the barrier from the valence band of the p-type material to the conduction band of the lightly filled n-material is known as the Zener breakdown.

  - **Avalanche breakdown** : The avalanche breakdown is a phenomena of increasing the free electrons or electric current in semiconductor and insulating material by applying the higher voltage.

Zener and Avalanche Breakdown



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Zener and Avalanche Breakdown

Basis For Comparison	**Avalanche Breakdown**	**Zener Breakdown**
Definition	The avalanche breakdown is a phenomena of increasing the free electrons or electric current in semiconductor and insulating material by applying the higher voltage.	The process in which the electrons are moving across the barrier from the valence band of the p-type material to the conduction band of the lightly filled n-material is known as the Zener breakdown.
Depletion Region	Thick	Thin
Junction	Destroy	Not Destroy
Electric Field	Weak	Strong
Produces	Pairs of electron and hole.	Electrons.
Doping	Low	Heavy
Reverse potential	High	Low
Temperature Coefficient	Positive	Negative
Ionization	Because of collision	Because of Electric Field
Breakdown Voltage	Directly proportional to temperature.	Inversely proportional to temperature.
After Breakdown	Voltage vary.	Voltage remains constant

Shockley's Equation

- Shockley's Equation also called the **diode equation** helps us determine the current at a given temperature knowing the diode voltage and
  - When V_D is negative

$$I_D \sim -I_S$$

  - When V_D is positive

$$I_D \sim I_S e^{\frac{qV_D}{nkT}}$$

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

Ideal Diode Equation

Where

I_D and V_D are the diode current and voltage, respectively

q is the charge on the electron

n is the ideality factor: n = 1 for indirect semiconductors (Si, Ge, etc.)
n = 2 for direct semiconductors (GaAs, InP, etc.)

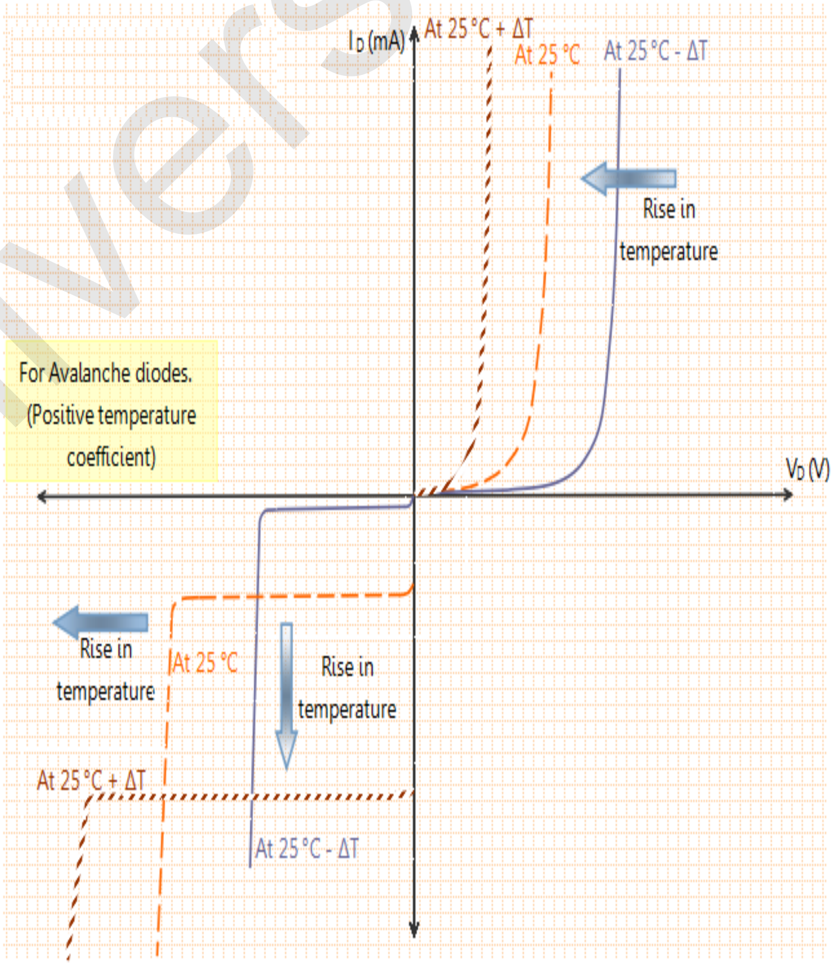
k is Boltzmann's constant

T is temperature in Kelvin

kT/q is also known as V_{th}, the thermal voltage. At 300K (room temperature), kT/q = 25.9mV

Temperature Effects

- For Ideal diode at room temperature in **forward bias** condition, if the knee voltage is at Vk, then for the practical diode
    - If the **temperature** is **increased**, then the **conduction** takes place **earlier** than at room temperature.
    - If the **temperature** is **decreased**, then the **conduction** takes place **later** than at room temperature.



Temperature Effects Contd.

- For Ideal diode in **reverse bias** condition, if breakdown appears as shown, then for practical diode
  - With temperature **increased**, then the breakdown is a **Avalanche** type, where the breakdown appears later and is much more slower
  - With temperature **decreased**, then the breakdown is **Zener** type, where the breakdown appears much earlier and is much rapid

Solved example - 8

Reverse saturation current of silicon diode at 20 degree is 0.1µA. Determine its value if the temperature is increased 40degree.

$$T = 20^o C : I_s = 0.1 \mu A$$

$$T = 30^o C : I_s = 0.2 \mu A$$

$$T = 40^o C : I_s = 0.4 \mu A$$

$$T = 50^o C : I_s = 0.8 \mu A$$

$$T = 60^o C : I_s = 1.6 \mu A$$

Ideal v/s Practical diode

- A semiconductor diode works similar to a mechanical switch such that when the switch is closed current flows in one direction.
- Using Ohm's law : $R_F = V_D / I_D = 0$ & $R_R = V_D / I_D =$ infinity
- At any current on the vertical line of diode characteristics, the voltage across ideal diode is 0 V and resistance is 0 ohm.
- As the current is 0mA anywhere on horizontal line, the resistance is infinity at any point on the axis of the characteristics.

Diode resistances

- When the diode is forward biased, the width of depletion region is thin and atoms in the diode offer some resistance to electric current. This resistance is called forward resistance.
  - The two types of resistance takes place in forward biased diode are
    - **Static resistance or DC resistance** : The resistance offered by a p-n junction diode when it is connected to a DC circuit is called static resistance.

$$R_f = \frac{\text{DC voltage}}{\text{DC current}}$$

    - **Dynamic resistance or AC resistance** : The dynamic resistance is the resistance offered by the p-n junction diode when AC voltage is applied.

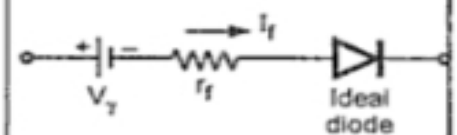
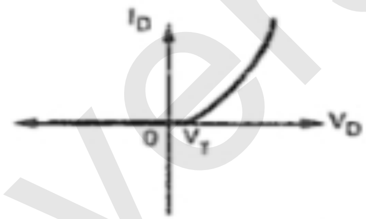
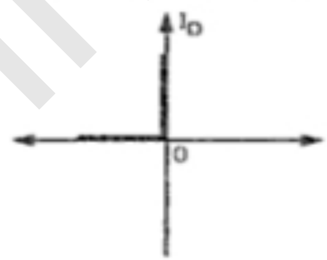
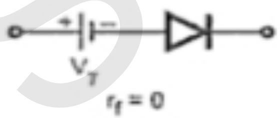
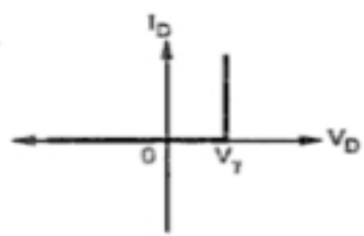
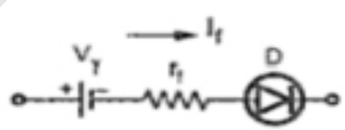
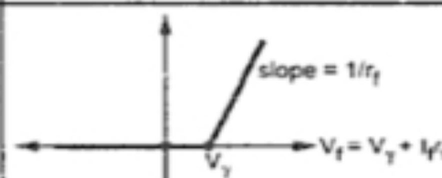
$$r_f = \frac{\text{Change in voltage}}{\text{Change in current}}$$

Diode resistances contd.

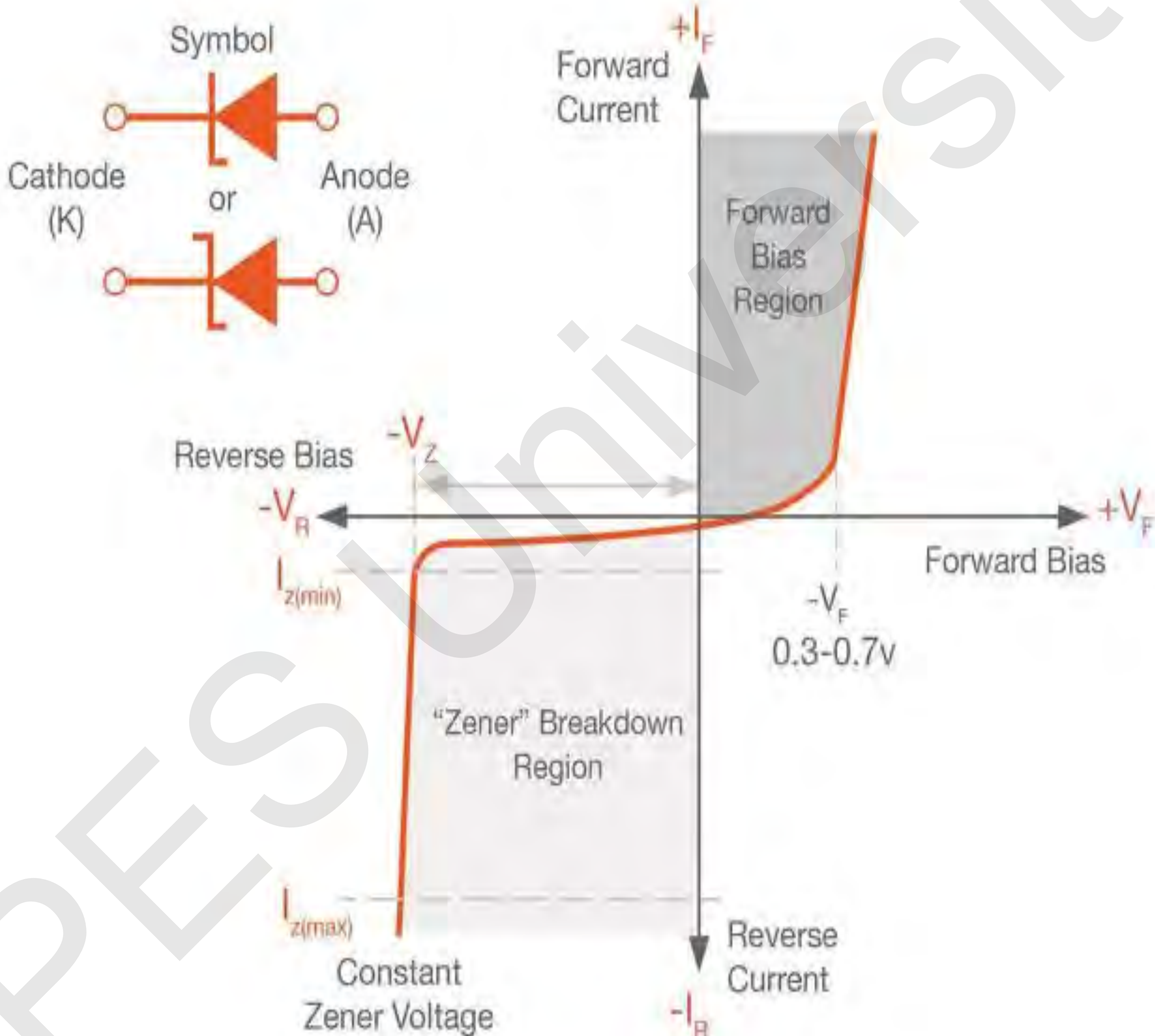
- When the diode is reverse biased, the width of depletion region increases. Hence only a small amount of electric current flows carried by the minority carriers. Reverse biased diode offer **large resistance** to the electric current. This resistance is called reverse resistance. The reverse resistance is in the range of mega ohms (MΩ).
- **Average AC Resistance :** If the input signal is sufficiently large to produce a broad swing then the resistance associated with the device for this region is called average AC resistance.

$$R_{av} = \Delta V_d / \Delta I_d$$

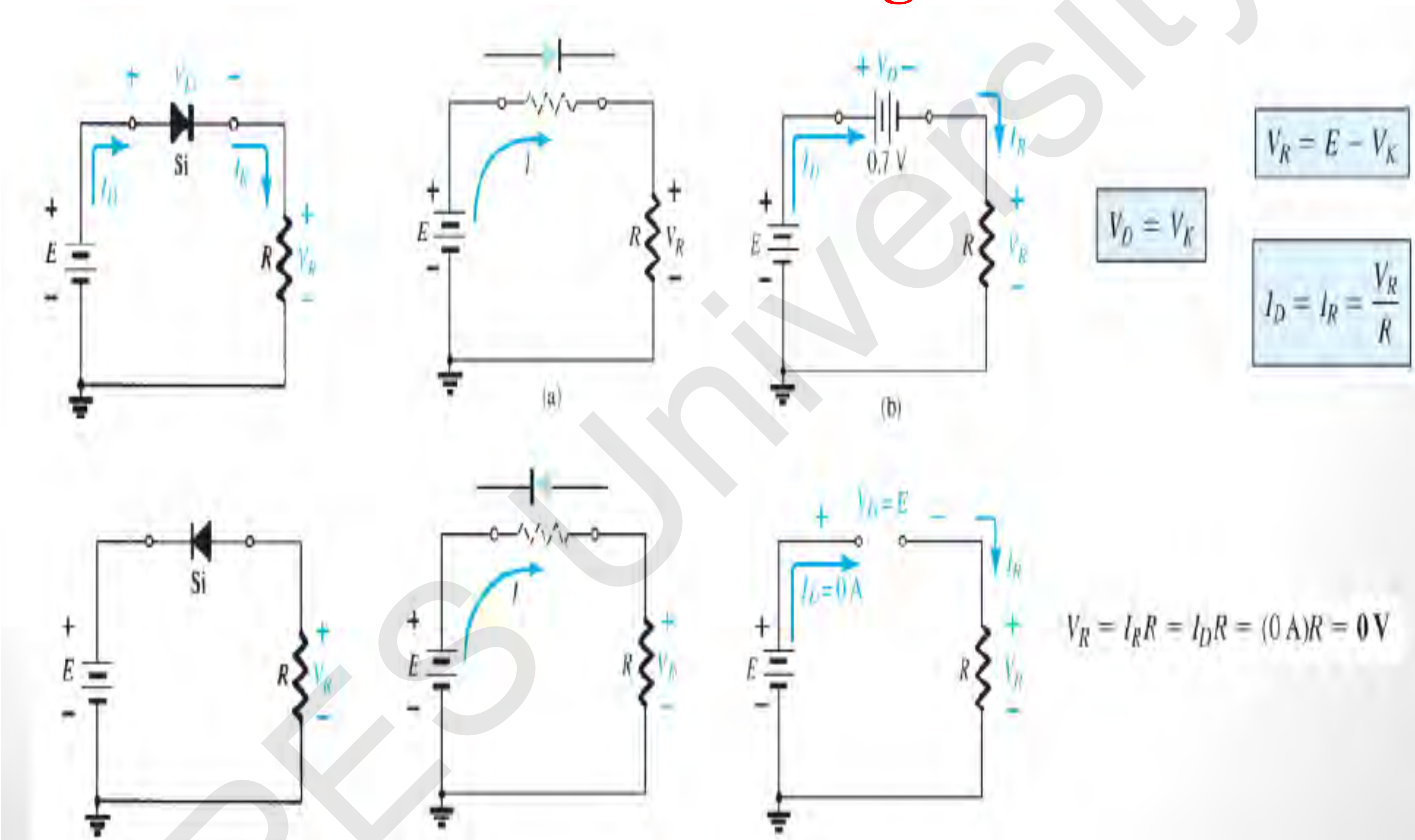
Diode Equivalent Circuits

Type	Model in forward biased	V-I characteristics	Drop across diode
Practical diode			$V_f = V_\gamma + I_f r_f$
Ideal diode			$V_f = 0$
Piecewise linear with $r_f = 0\,\Omega$			$V_f = V_\gamma$
Piecewise linear with finite r_f			$V_f = V_\gamma + I_f r_f$

Zener Diode Characteristics



Series Diode Configuration

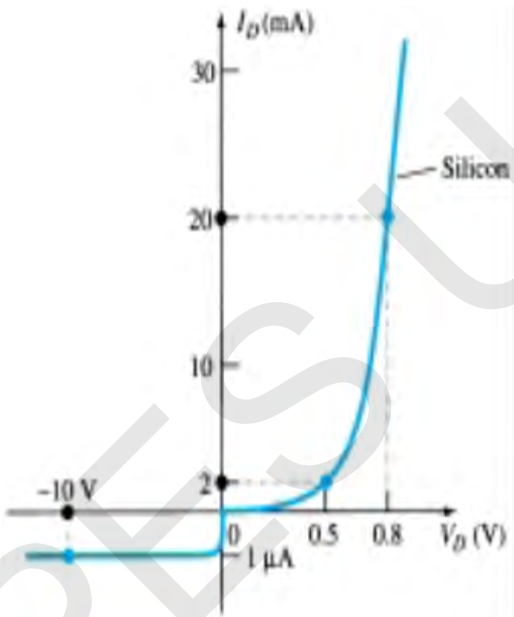


Practice problem - 1

1. The reverse saturation current of a Germanium diode is 200A at room temperature of 27·C. Calculate the current in forward biased condition, if forward biased voltage is 0.2V at room temperature. If temperature is increased by 30· C, calculate the reverse saturation current and the forward current for the same forward voltage at new temperature.

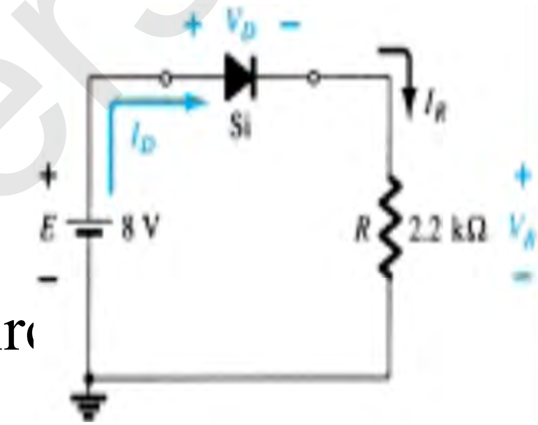
Practice problem - 2

1. Determine the dc resistance levels for the diode of Fig at (a) I_D= 2 mA (b) I_D= 20 mA (c) V_D= -10 V

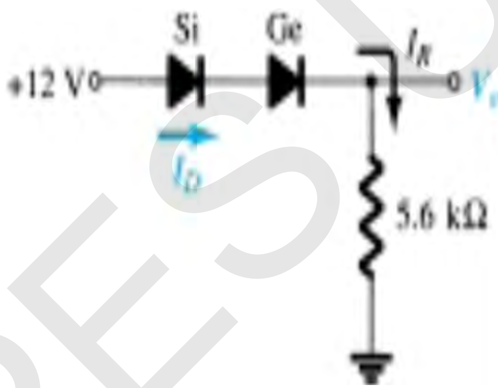


Practice problem - 3

1. For the series diode configuration shown below, determine V_D, V_R, and I_D. Repeat the same if the diode is reversed.



2. Determine *Vo* and *ID* for the series cir



Resources on diodes

- https://www.coursera.org/lecture/electronics/4-1-introduction-to-pn-junctions-xr0ZQ
- https://www.coursera.org/lecture/electronics/4-2-models-of-diode-behavior-tfHbH
- https://www.coursera.org/lecture/electronics/solved-problem-diodes-1-4FKr4
- https://www.coursera.org/lecture/electronics/solved-problem-diodes-2-L5Hoe