ELA 1110

DIODE

Introduction

- The semiconductor diode is created by simply joining an n -type and a p -type material together.
- At the instant the two materials are "joined" the electrons and the holes in the region of the junction will combine, resulting in a lack of free carriers in the region near the junction, as shown in Fig.1.
- Diode Symbol with the defined polarity and the current direction and the current direction is shown in fig.2.

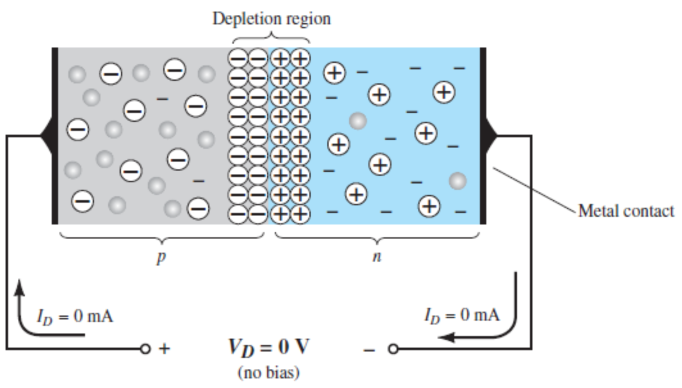


Fig. 1: p–n junction with no external bias

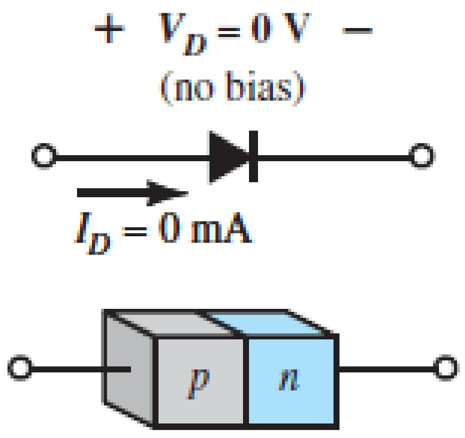


Fig. 2: Diode Symbol

Operation

- In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.
- Under reverse bias, external potential is applied across the p – n junction such that the positive terminal is connected to the n -type material and the negative terminal is connected to the p -type material as shown in fig.4.
- The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by I_S .
- Depletion region widens in reverse bias operation.
- A forward-bias or "on" condition is established by applying the positive potential to the p -type material and the negative potential to the n -type material as shown in Fig.3.
- The application of a forward-bias potential reduces the width of the depletion region.

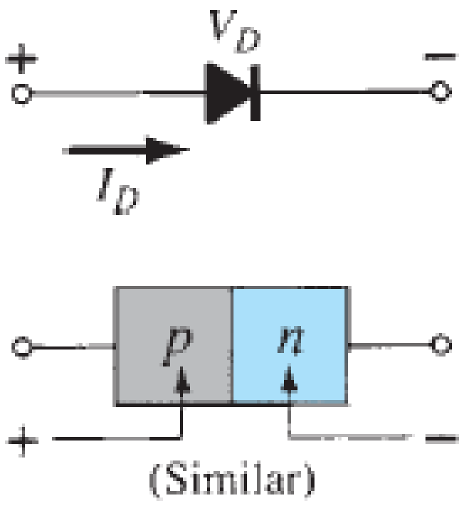


Fig. 3: Forward-biased p–n junction

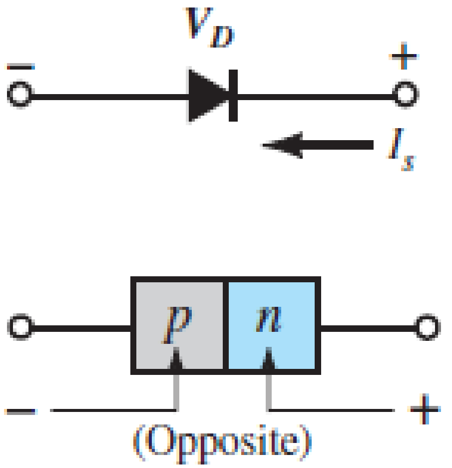


Fig.4: Reverse-biased p–n junction

Diode Equation

- The general characteristics of a semiconductor diode can be defined by the following equation, referred to as Shockley's equation, for the forward- and reverse-bias regions.

$$I_D = I_s(e^{V_D/nV_T} - 1)$$

Where,
I_S is the reverse saturation current
V_D is the applied forward-bias voltage across the diode
η is an ideality factor, (Value:1to2)
V_T is called the thermal voltage

- The thermal Voltage is given as

$$V_T = \frac{kT_K}{q}$$

Where,
k is Boltzmann's constant 1.38 10 23 J/K
T_K is the absolute temperature in kelvins = 273 + the temperature in °C
q is the magnitude of electronic charge 1.6 x 10^{-19} C

Example1: At a temperature of 27°C, determine the thermal voltage V_T.

Solution:

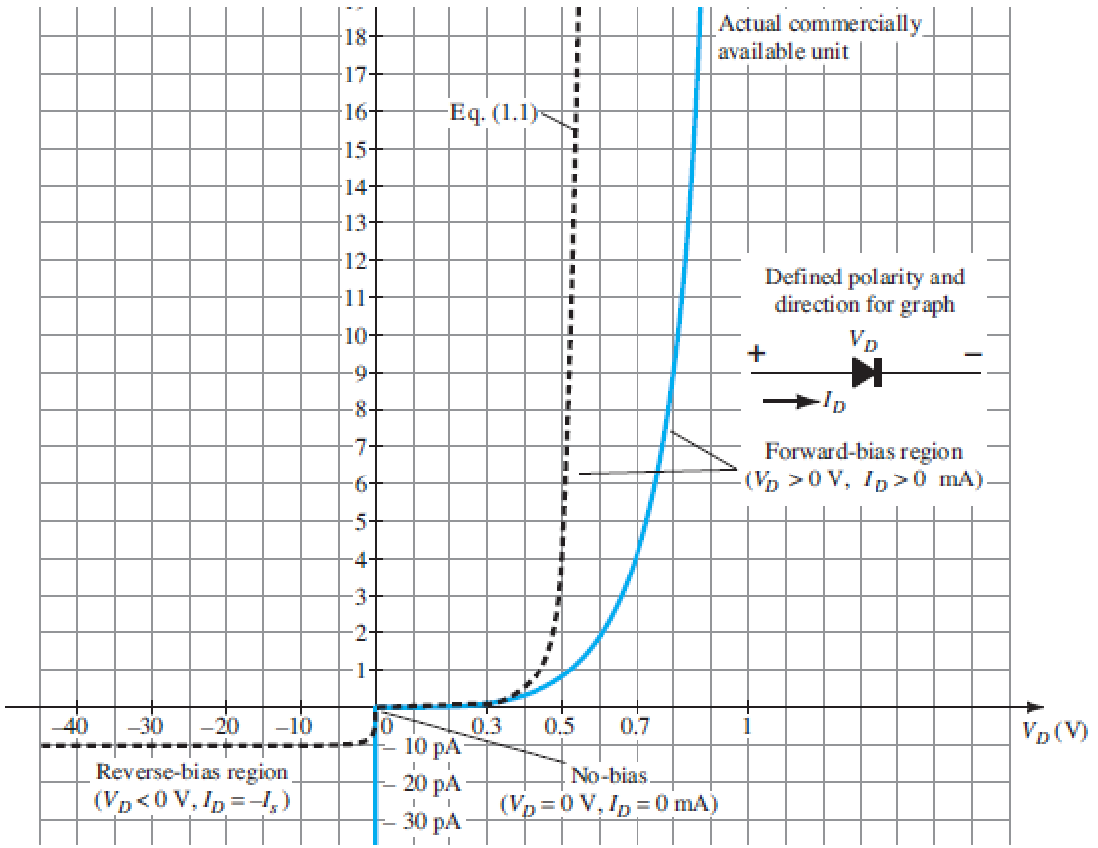
$$T = 273 + {}^\circ\text{C} = 273 + 27 = 300\ \text{K}$$

$$V_T = \frac{kT_K}{q} = \frac{(1.38 \times 10^{-23}\ \text{J/K})(30\ \text{K})}{1.6 \times 10^{-19}\ \text{C}}$$

$$= 25.875\ \text{mV} \cong 26\ \text{mV}$$

V-I Characteristics of Diode

- For negative values of V_D ,
  - $\mathbf{I_D = -I_S}$
- At V_D = 0V,
  - $\mathbf{I_D = I_S(e^0 - 1) = I_S(1 - 1) = 0\ mA}$
- The defined direction of conventional current for the positive voltage region matches the arrowhead in the diode symbol.
- The actual reverse saturation current of a commercially available diode will normally be measurably larger than that appearing as the reverse saturation current in Shockley's equation.



Breakdown Region

- In V-I characteristics of diode, there is a point where the application of too negative a voltage with the reverse polarity will result in a sharp change in the characteristics, as shown in Fig. 5
- The reverse-bias potential that results in this dramatic change in characteristics is called the breakdown potential and is given the label V_{BV}
- The current increases at a very rapid rate in a direction opposite to that of the positive voltage region.
- The two break-down mechanism in diode are:
    - Avalanche Breakdown
    - Zener Breakdown

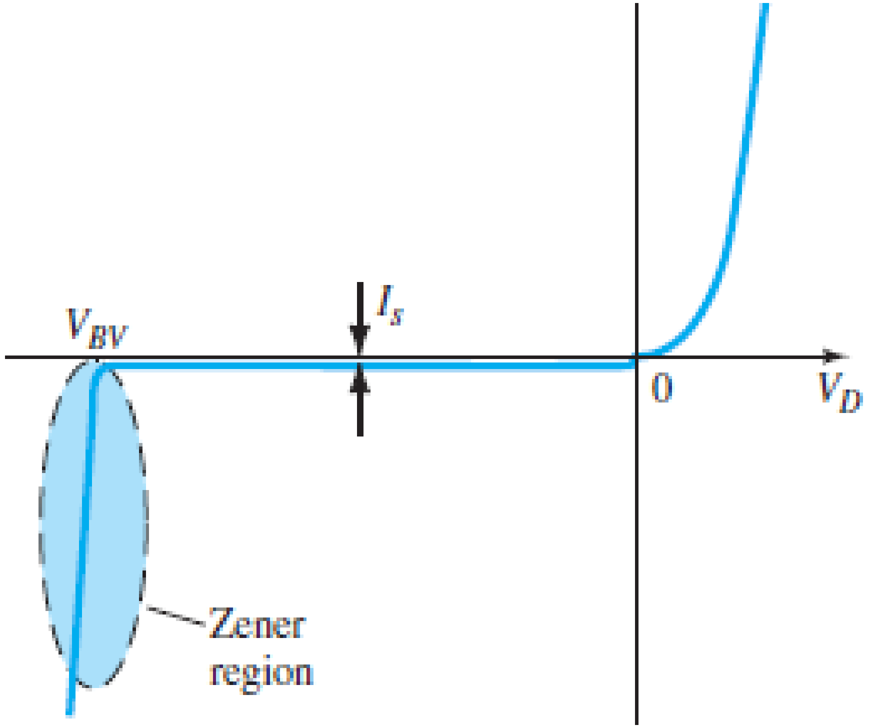


Fig. 5: Breakdown region.

Diode Resistance

- As the operating point of a diode moves from one region to another the resistance of the diode will also change due to the nonlinear shape of the characteristic curve.
- **DC or Static Resistance**
  - The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating point on the characteristic curve that will not change with time.
  - The resistance of the diode at the operating point can be found by the following equation.

$$R_D = \frac{V_D}{I_D}$$

- **AC or Dynamic Resistance**
  - The dc resistance of a diode is independent of the shape of the characteristic in the region surrounding the point of interest.
  - A straight-line drawn tangent to the curve through the *Q* -point as shown in Fig. 6.
  - It will define a particular change in voltage and current that can be used to determine the *ac* or dynamic resistance for this region of the diode characteristics

$$r_d = \frac{\Delta V_d}{\Delta I_d}$$

Where, Δ signifies a finite change in the quantity.

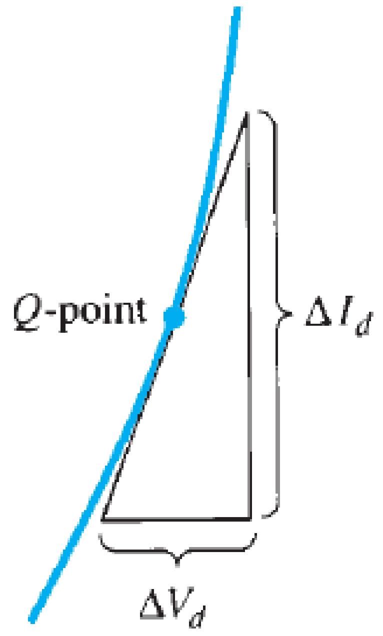


Fig.6: Determining the ac resistance at a Q-point.

- The lower the Q-point of operation (smaller current or lower voltage), the higher is the ac resistance.

Diode Models

- An equivalent circuit/model is a combination of elements properly chosen to best represent the actual terminal characteristics of a device or system in a particular operating region.
- Once the equivalent circuit is defined, the device symbol can be removed from a schematic and the equivalent circuit inserted in its place.
- The various models used to represent diode are:
  - Piece Wise Equivalent Circuit
  - Simplified Equivalent Circuit
  - Ideal Equivalent Circuit

Piece Wise Linear Model

- In this technique , the ideal diode is included to establish that there is only one direction of conduction through the device.
- A reverse-bias condition will result in the open-circuit state for the device.
- It can be obvious from Fig.7 that the straight-line segments do not result in an exact duplication of the actual characteristics especially in the knee region.

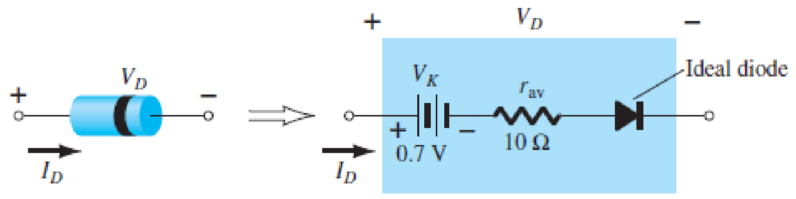


Fig.7: Components of the piecewise-linear equivalent circuit.

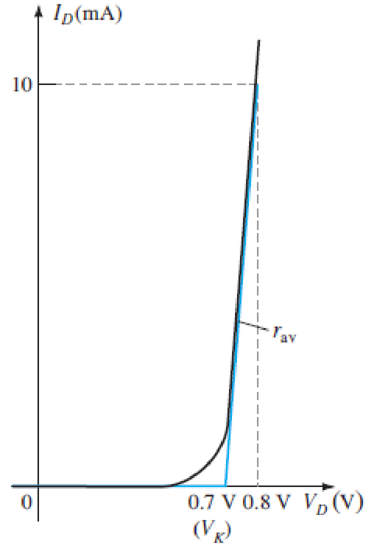
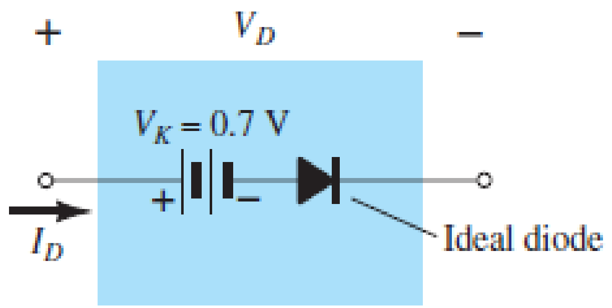


Fig. 8: Defining the piecewise-linear equivalent circuit using straight-line segments

Simplified Equivalent Circuit

- For most applications, the resistance *r* av is sufficiently small to be ignored in comparison to the other elements of the network.
- The reduced equivalent circuit appears in the shown in fig.9.
- It states that a forward biased silicon diode in an electronic system under dc conditions has a drop of 0.7V.



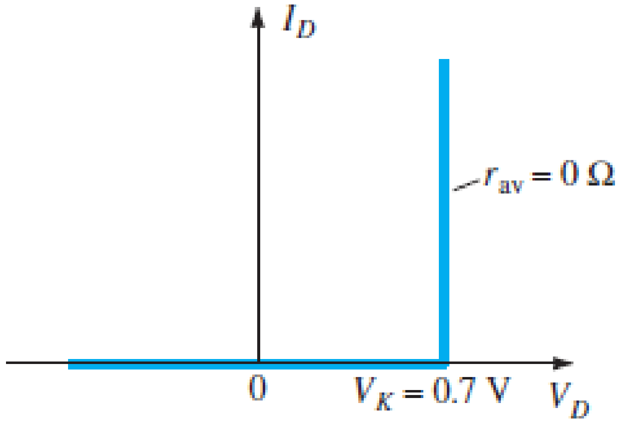


Fig.9: Simplified equivalent circuit for the silicon semiconductor diode.

Ideal Equivalent Circuit

- In this case the equivalent circuit will be reduced to that of an ideal diode as shown in Fig. 10 with its characteristics.

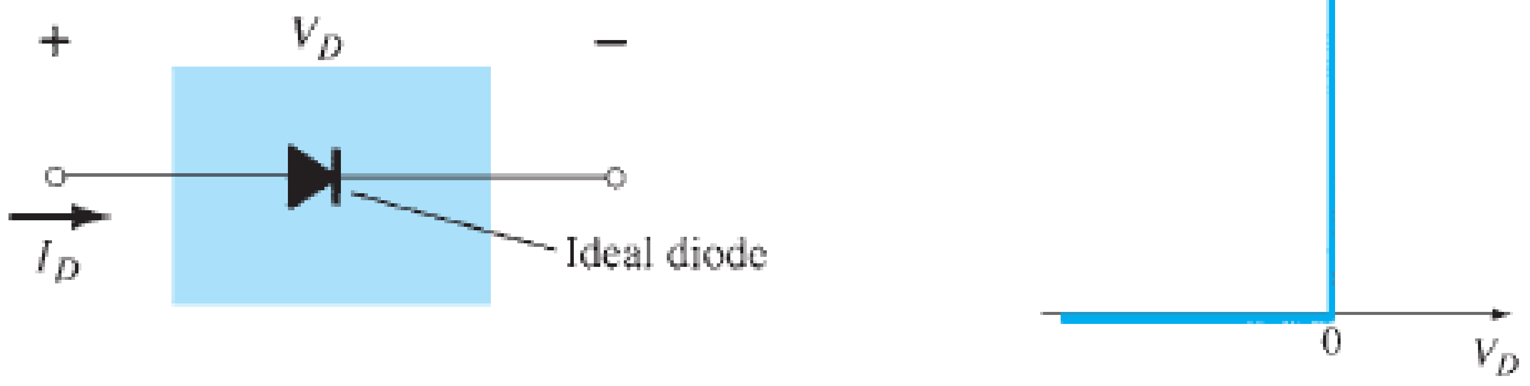
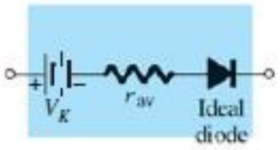
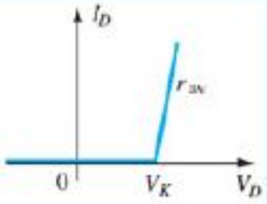
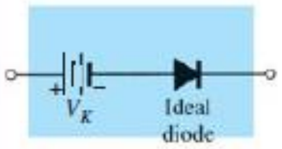
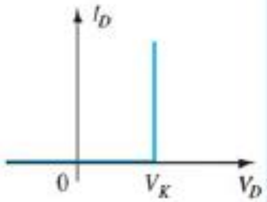
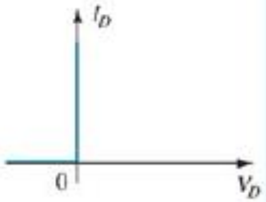


Fig.10: Ideal diode and its characteristics.

- **Table 1 : Diode Equivalent Circuits (Models)**

Type	Conditions	Model	Characteristics
Piecewise-linear model			
Simplified model	$R_{network} \gg r_{av}$		
Ideal device	$R_{network} \gg r_{av}$ $E_{network} \gg V_K$		

Example

Q. For the series diode configuration of Fig. 11 , determine V_D , V_R , and I_D using the following models: (Given $r_{AV} = 10\Omega$)

(a) Piece wise linear Model

(b) Constant Voltage drop Model

(c) Ideal Diode Model

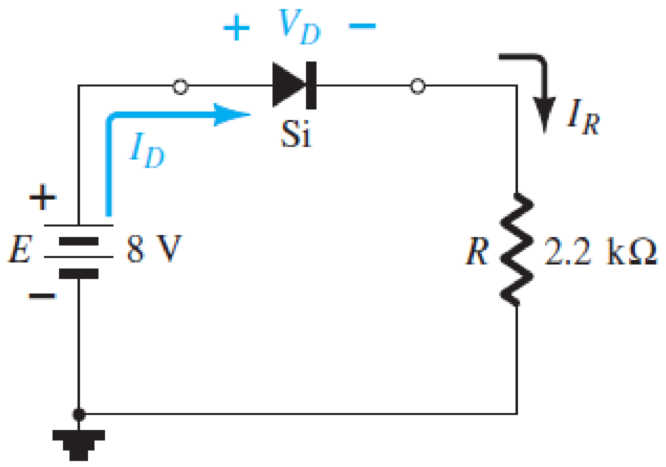


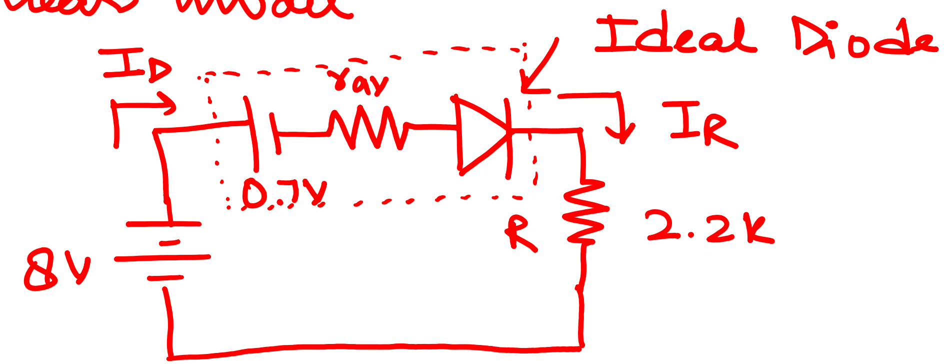
Fig.11

Solution :- (a) Using Piecewise linear model

$I_D = I_R = I$

$\boxed{V_D = 0.7}$

$r_{av} = 10\Omega$ (Given)



$$8 - 0.7 - I r_{av} - I(2.2k) = 0$$

$$7.3 - I(10 + 2200) = 0$$

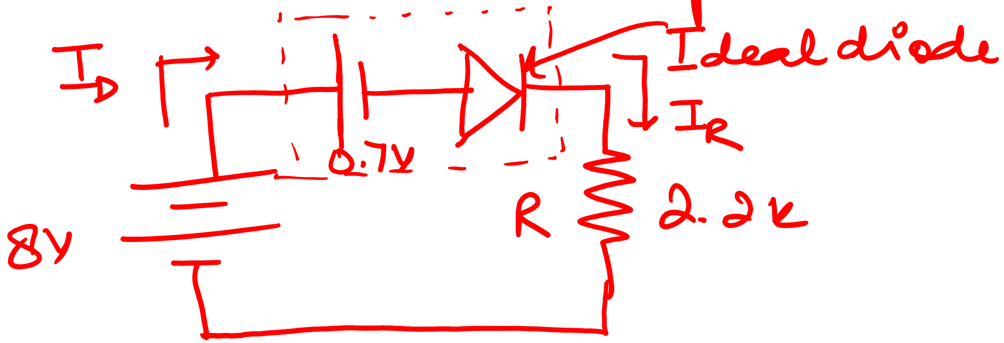
$$I = \frac{7.3}{2210} = 0.00330 = 3.30 mA$$

$\boxed{I_D = 3.30 mA}$

$$V_R = I \times R = 3.30 \times 2.2 = 7.26V$$

$\boxed{V_R = 7.26V}$

(b) Using Simplified Equivalent Circuit / Constant Voltage Drop Model



$$\boxed{V_D = 0.7V}$$

$$I_D = I_R = I$$

$$8 - 0.7 - IR = 0$$

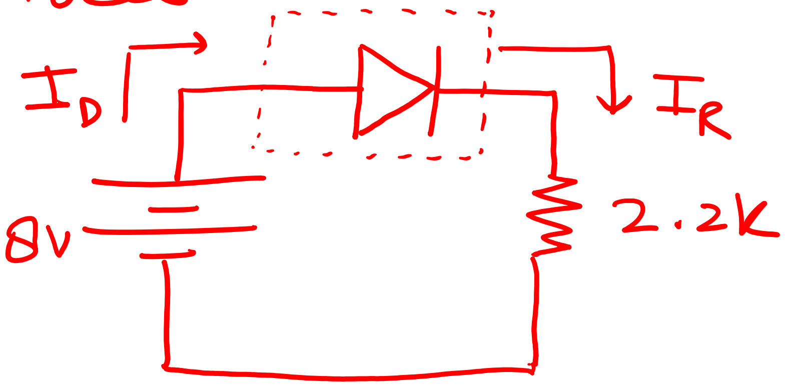
$$I = \frac{7.3}{2.2} = 3.32mA$$

$$\boxed{I_D = 3.32mA}$$

$$V_R = I.R = 3.32 \times 2.2 = 7.30V$$

$$\boxed{V_R = 7.30V}$$

(c) Using Ideal Diode Model



$$\boxed{V_D = 0}$$

$$I_D = I_R = I$$

$$8 - I.(2.2) = 0$$

$$I = \frac{8}{2.2} = 3.64 mA$$

$$\boxed{I_D = 3.64 mA}$$

$$V_R = I.R = 3.64 \times 2.2 = 8V$$

$$\boxed{V_R = 8V}$$

Problems

Q.1 Determine the thermal voltage for a diode at a temperature of 20.Also, find the diode current if I_S = 40 nA, n =2 and the applied bias voltage is 0.5 V.

Q.2 Given a diode current of 8 mA and n = 1, find I_S if the applied voltage is 0.5 V and the temperature is room temperature (25°C).

Q.3 Given a diode current of 6 mA, V_T = 26 mV, n =1, and I_S=1 nA, find the applied voltage V_D.

Q.4 Determine the static or dc resistance of the commercially available diode of Fig. 1.15 at a forward current of 4 mA.