ENEE236 & 241

Analog Electronics

L2 Semiconductor Diodes

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Diode Operating Conditions

A diode has three operating conditions:

- No bias
- Reverse bias
- Forward bias

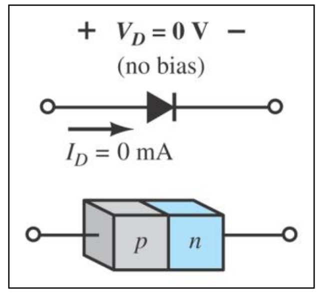
Diode Operating Conditions

No Bias

No external voltage is applied: $V_D = 0$ V

There is no diode current: $I_D = 0$ A

Only a modest depletion region exists



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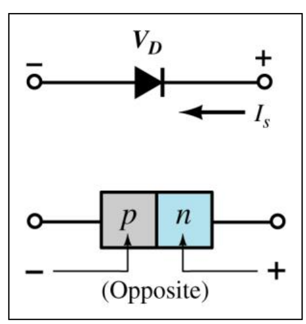
Diode Operating Conditions

Reverse Bias

External voltage is applied across the *p-n* junction in the opposite polarity of the *p*- and *n*-type materials.

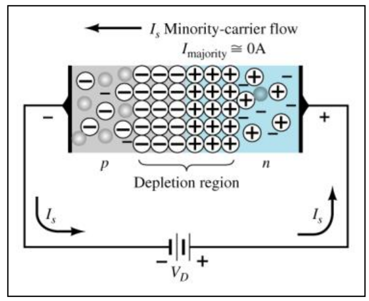


Diode Operating Conditions

Reverse Bias

The reverse voltage causes the depletion region to widen.

The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.



The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.

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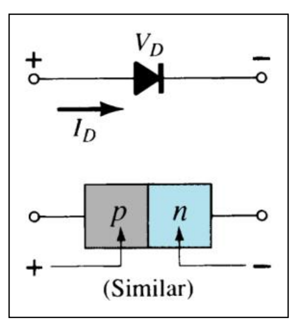
Diode Operating Conditions

Forward Bias

External voltage is applied across the *p*-*n* junction in the same polarity as the *p*- and *n*-type materials.



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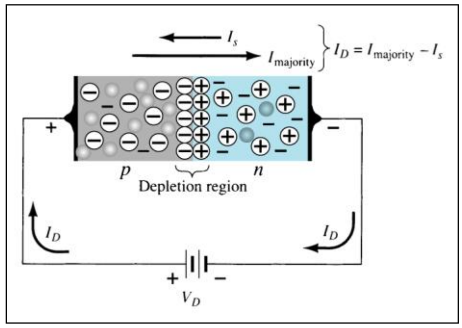
Diode Operating Conditions

Forward Bias

The forward voltage causes the depletion region to narrow.

The electrons and holes are pushed toward the *p-n* junction.



The electrons and holes have sufficient energy to cross the *p-n* junction.

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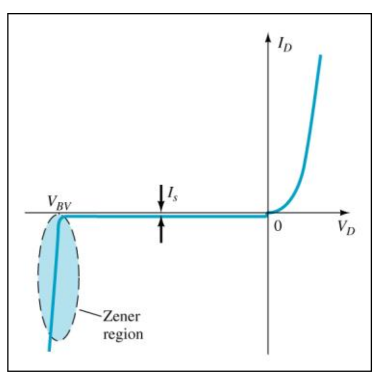
Zener Region

The Zener region is in the diode's reverse-bias region.

At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.
The maximum reverse voltage that won't take a diode into the zener region is called the **peak inverse voltage** or **peak reverse voltage**.

The voltage that causes a diode to enter the zener region of operation is called the **zener voltage (V_Z).**



Forward Bias Voltage

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the p-n junction. This energy comes from the external voltage applied across the diode.

The forward bias voltage required for a:

gallium arsenide diode ≅ 1.2 V

silicon diode ≅ 0.7 V

germanium diode ≅ 0.3 V

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Temperature Effects

As temperature increases it adds energy to the diode.

It reduces the required forward bias voltage for forward-bias conduction.

It increases the amount of reverse current in the reverse-bias condition.

It increases maximum reverse bias avalanche voltage.

Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.

Resistance Levels

Semiconductors react differently to DC and AC currents.

There are three types of resistance:

DC (static) resistance

AC (dynamic) resistance

Average AC resistance

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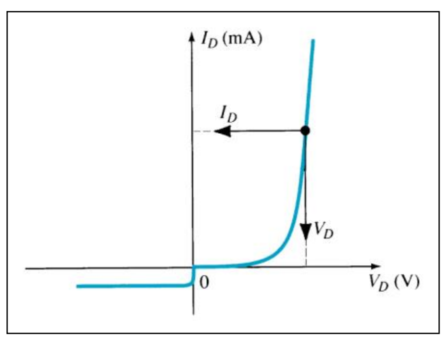
DC (Static) Resistance

For a specific applied DC voltage (V_D) the diode has a specific current (I_D) and a specific resistance (R_D).

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



AC (Dynamic) Resistance

In the forward bias region: $r'_d = \frac{26\,\text{mV}}{I_D}$

The resistance depends on the amount of current (I_D) in the diode.

The voltage across the diode is fairly constant (26 mV for 25°C).

In the reverse bias region: $r'_d = \infty$

The resistance is effectively infinite. The diode acts like an open.

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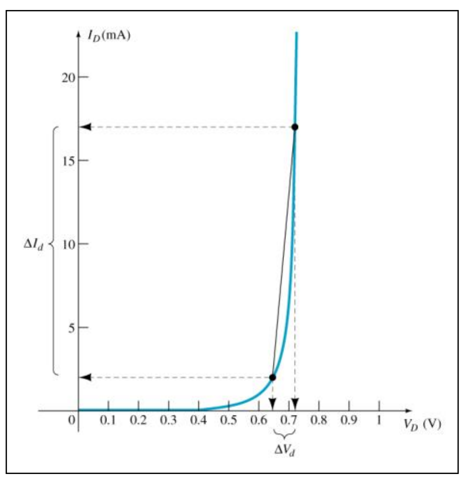
Average AC Resistance

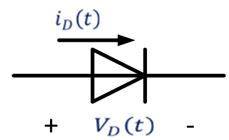
$$r_{av} = \frac{\Delta V_d}{\Delta I_d}\bigg|_{pt.\ to\ pt.}$$

AC resistance can be calculated using the current and voltage values for two points on the diode characteristic curve.



Diode Equation

$$i_D(t) = I_S(e^{\frac{V_D(t)}{\eta V_T}} - 1)$$



Is: Revers saturation current

$Is = 10^{-12}, 10^{-14}$ A

η : eta

$$\eta = \begin{cases} 1 \; for \; Ge \\ 2 \; for \; Si \; (small \; current) \\ 1 \; for \; Si \; (large \; current) \end{cases}$$

V_T= Thermal Voltage

$V_T = \frac{T}{11600}$;T in kelvin

At Room Temp. T=300k

∴ V_T = 25.69 mv at Room Temp.

- The equation is a non linear equation

∴ The Diode is non linear Device

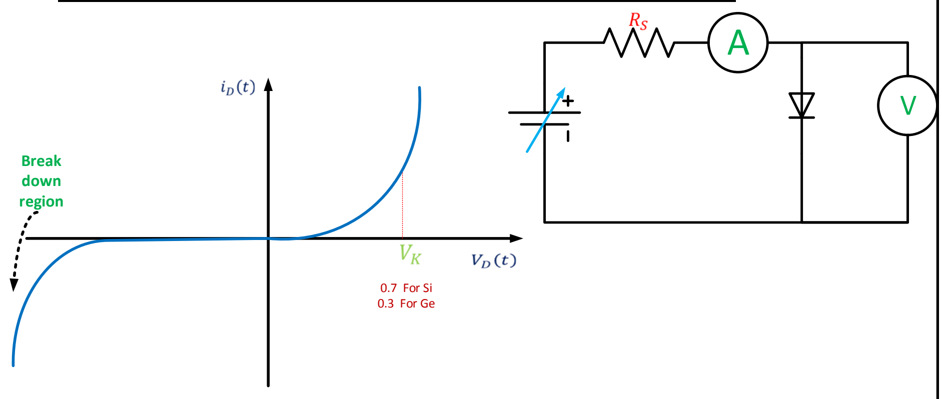
$$i_D(t) = I_S(e^{\frac{V_D(t)}{\eta V_T}} - 1)$$

- For positive $V_D(t)$, $i_D(t) = I_S(e^{\frac{V_D(t)}{\eta V_T}})$

- **For negative $V_D(t)$**

$$i_D(t) = -I_S$$

Diode V-I Characteristic curve



Approaches to Diode Circuit Analysis

The rectifier diode is a non linear device .

There are essentially three basic approaches to the solution of such problem :

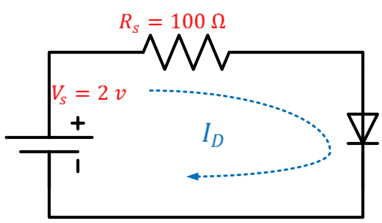
1- The use of non linear mathematics

2- The use of graphical techniques

3- The use of equivalent circuit (models)

1)The use of non linear mathematic (shown , but not required)

- For the circuit shown, find I_D and V_D



Silicon:
η=1.1
I_S= 10^{-14} A

- KVL : V_S=$R_S I_D$+ V_D

$$I_D = I_S(e^{\frac{V_D}{\eta V_T}} - 1)$$

- Since the diode is forward biased , we could approximate

$$I_D = I_S(e^{\frac{V_D}{\eta V_T}})$$

- Solving for $V_D = \eta\, V_T \ln\frac{I_D}{I_S}$

∴We have two equations and two unknowns

V_S=$R_S I_D$+V_D......................1
$V_D = \eta\, V_T \ln\frac{I_D}{I_S}$ 2

∴ V_S=$R_S I_D$ + $\eta\, V_T \ln\frac{I_D}{I_S}$

- **non linear equation**

Iterative Analysis

$I_D = \frac{V_S - V_D}{R_S}$

$V_D = \eta V_T \ln\frac{I_D}{I_S}$

1) Let $V_D = 0.7$v

$I_D = \frac{2-0.7}{0.1k} = 13$ mA

$V_D = 0.7882392$v The error is large

2) Let $V_D = 0.7882392$v

$I_D = 12.117608$ mA

$V_D = 0.7862529$v The error is small

3) Let $V_D = 0.7862529$v

$I_D = 12.137471$ mA

$V_D = 0.7862991$ V The error getting smaller

4) Let $V_D = 0.7862991$ V

$V_D = 0.786298066$ V

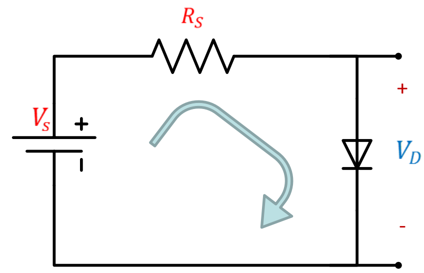
$I_D = 12.137009$mA

$I_D = 12.137$ mA
$V_D = 0.7863$v

2) The use of graphical techniques

$V_S = R_S I_D + V_D$ ……………..1

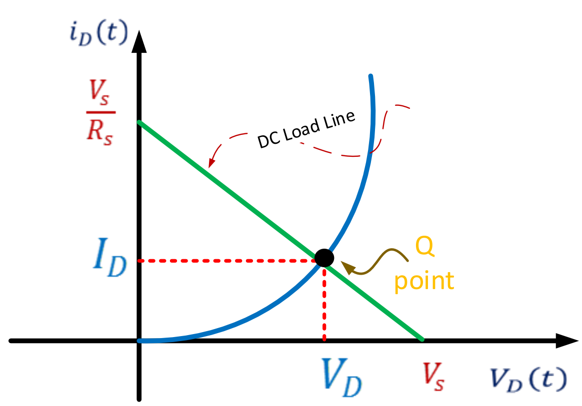
$I_D = I_S \left(e^{\frac{V_D}{\eta V_T}} - 1\right)$ …………2



- Using equation 1

$I_D = -\frac{1}{R_S} V_D - \frac{V_S}{R_S}$

Drawing the two equations

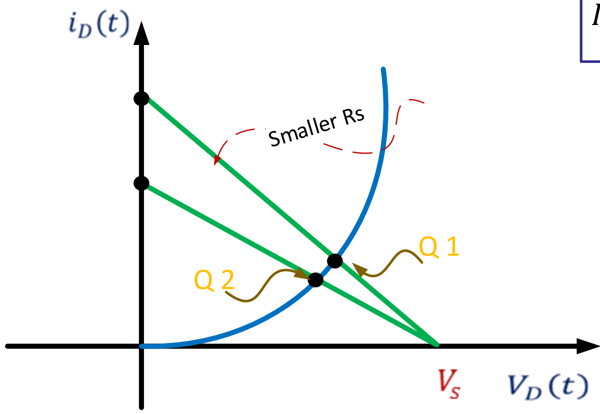


$I_D = -\frac{1}{R_S} V_D - \frac{V_S}{R_S}$

- $Q_{point} = (I_{DQ}, V_{DQ}) = Q_{uiescent\ point}$

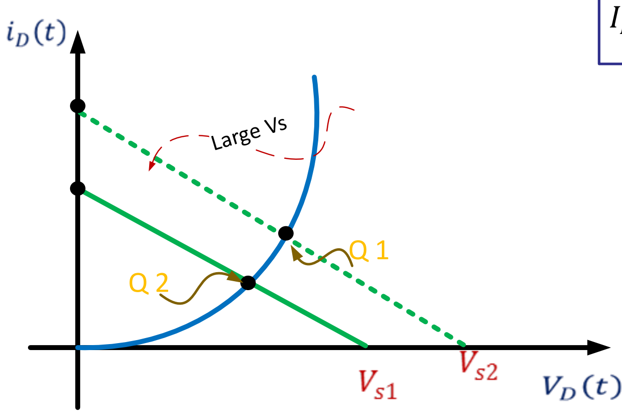
The effect of Rs on the Qpoint

$I_D = -\frac{1}{R_S} V_D - \frac{V_S}{R_S}$



The effect of Vs on Qpoint

$I_D = -\frac{1}{R_S} V_D - \frac{V_S}{R_S}$



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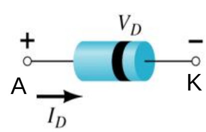
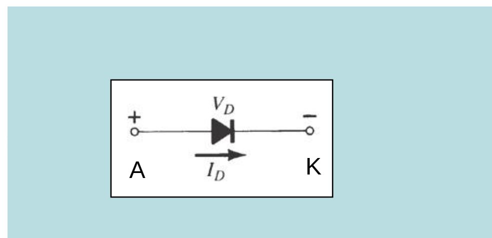
Diode (Models)

1) **Ideal Diode Model**
2) **Simplified/piecewise/ knee model**
3) **Complete diode model**





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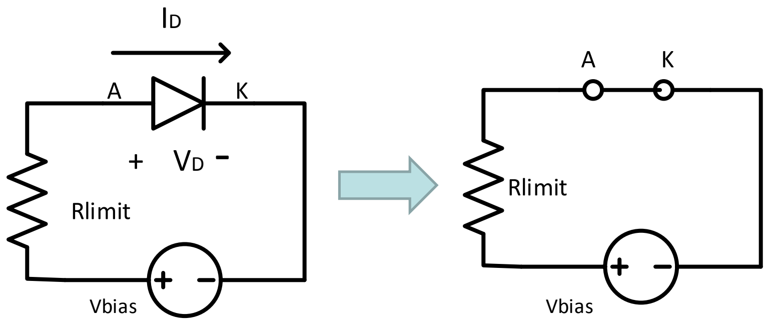
Ideal Diode Model

- 1) if the diode is forward biased ==> diode is replaced by short circuit



$V_D=0$
$I_D=Vbias/Rlimit$

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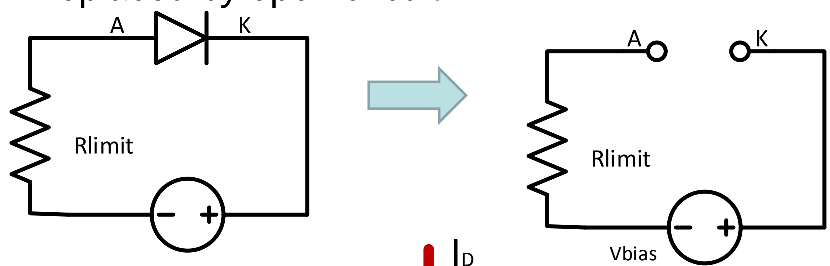
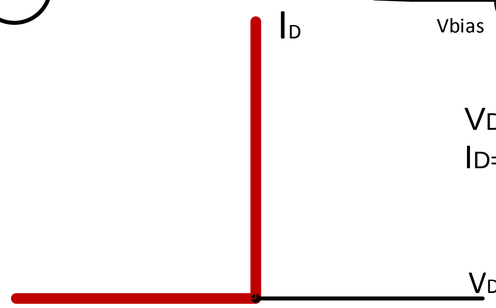
Ideal Diode Model

- 2) if the diode is Reverse biased ==> diode is replaced by open circuit





V_D=Vbias
I_D=0

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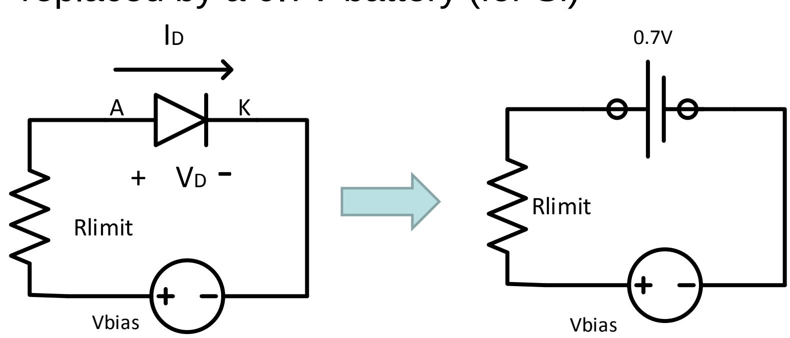
Simplified / knee model

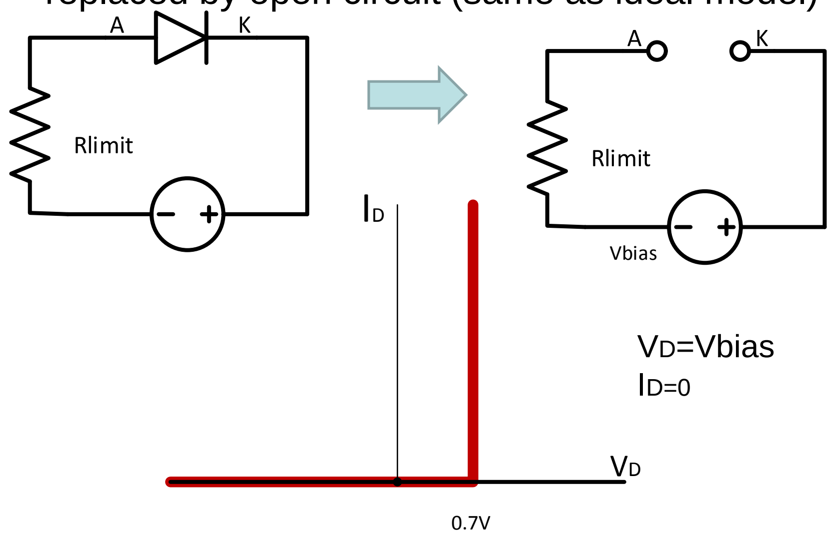
- 1) if the diode is forward biased ==> diode is replaced by a 0.7V battery (for Si)



V_D=0.7 V
I_D=(Vbias-0.7)/Rlimit

Simplified/ knee model

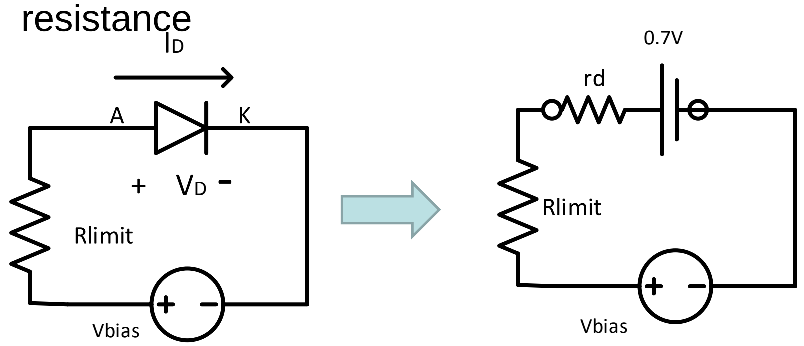
- 2) if the diode is Reverse biased ==> diode is replaced by open circuit (same as ideal model)



V_D=Vbias
I_D=0

Complete Diode model

- 1) if the diode is forward biased ==> diode is replaced by a 0.7V battery and forward dynamic resistance



$V_D = 0.7 + I_D.\ rd$
$I_D = (Vbias - 0.7)/(Rlimit + rd)$

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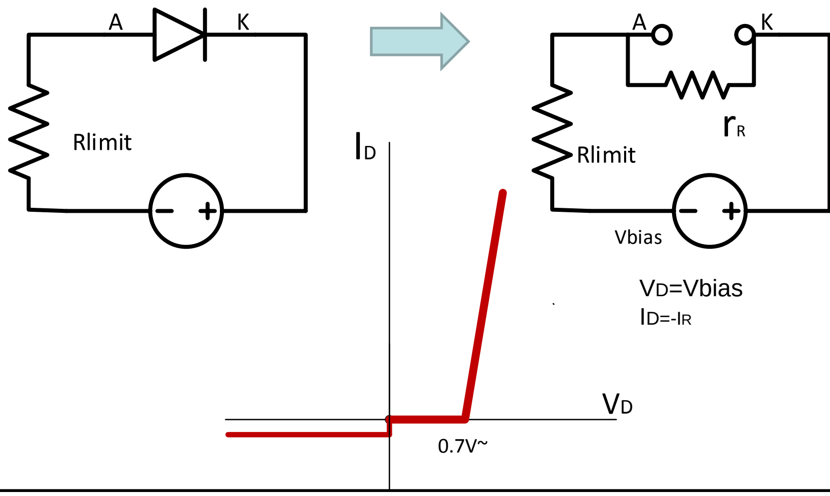
Complete Diode model

- 2) if the diode is Reverse biased ==> diode is replaced by open circuit // to reverse resistance r_R



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Diode Specification Sheets

Diode data sheets contain standard information, making cross-matching of diodes for replacement or design easier.

1. Forward Voltage (V_F) at a specified current and temperature
2. Maximum forward current (I_F) at a specified temperature
3. Reverse saturation current (I_R) at a specified voltage and temperature
4. Reverse voltage rating, PIV or PRV or $V_{(BR)}$, at a specified temperature
5. Maximum power dissipation at a specified temperature
6. Capacitance levels
7. Reverse recovery time, t_{rr}
8. Operating temperature range

Other Types of Diodes

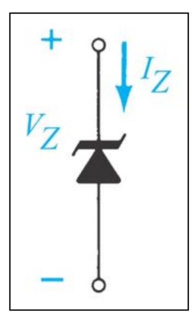
There are several types of diodes besides the standard *p-n* junction diode. Three of the more common are:

Zener diodes

Light-emitting diodes

Zener Diode

A **Zener diode** is one that is designed to safely operate in its zener region; i.e., biased at the Zener voltage (V_Z).

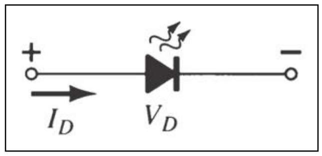


Common zener diode voltage ratings are between 1.8 V and 200 V

The **Zener diode** is used for voltage regulation, details will be discussed later

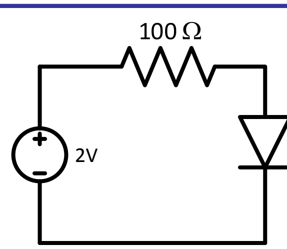
Light-Emitting Diode (LED)

An **LED** emits light when it is forward biased, which can be in the infrared or visible spectrum.



The forward bias voltage is usually in the range of 2 V to 3 V.

Example:



Find the Q-point (I_{DQ} and V_{DQ})

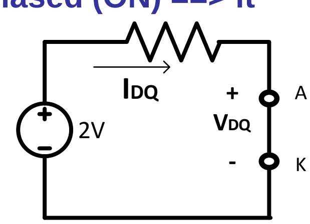
a) Use ideal diode model

b) Use practical diode model

c) Use exact model

Solution

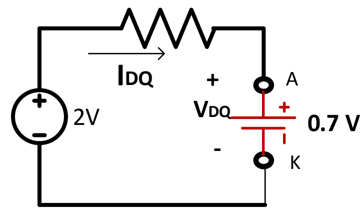
a) Since VA > VK , diode is forward biased (ON) ==> it can be replaced by a short circuit



$V_{DQ}=V_{AK}=0$ V

$I_{DQ}= 2V/100\ \Omega=20$ mA

b) When using practical model , diode is replaced by a 0.7 V battery



V_{DQ}=V_{AK}=0.7 V

I_{DQ}= 2-0.7/100 = 13 mA

c) Exact solution yields

V_{DQ}=V_{AK}=0.786 V

I_{DQ} = 12.14 mA

Note: If applied voltage is much higher than VAK (at least 10 times) , then ideal diode model is recommended

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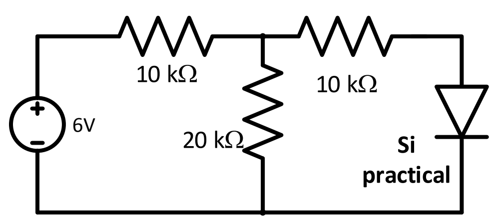
Example:

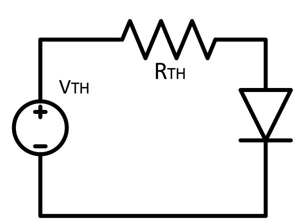
Find the Q-point

(I_{DQ} and V_{DQ})



Solution

It is better to convert the two loop circuit to a single loop circuit by finding Thevenin's equivalent circuit



V_{TH}=6V. 20k/(20k+10k)=4 V

R_{TH}=(10k+20k//10k)=16.67 kΩ

V_{DQ}=V_{AK}=0.7 V

I_{DQ}= (4-0.7)/16.67 kΩ = 0.198 mA

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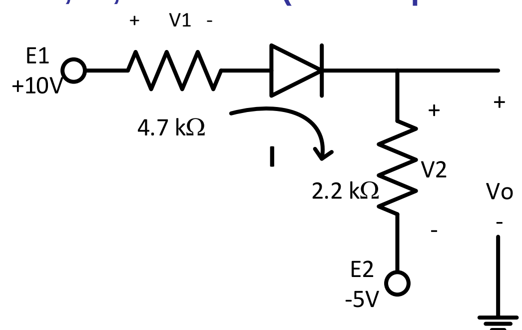
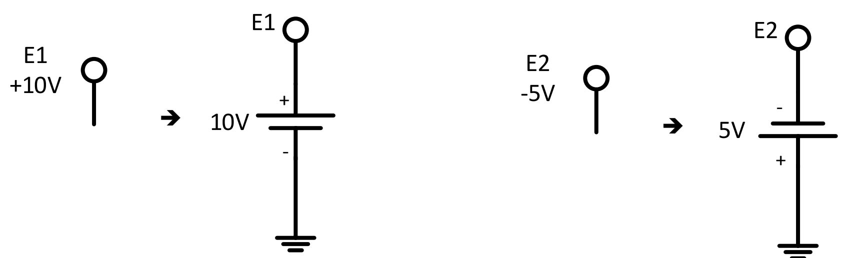
Example: **Find I,V1,V and Vo (use simplified model)**



Solution:



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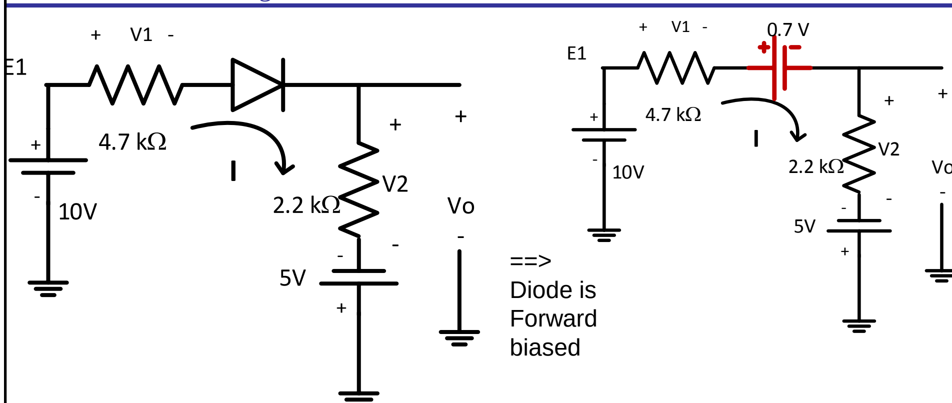

I=(10+5-0.7)V/(4.7+2.2) kΩ
=2.07 mA

V1=I . R1= 9.73 V

Vo= V2- 5 = -0.45 V

V2=I . R2= 4.55 V

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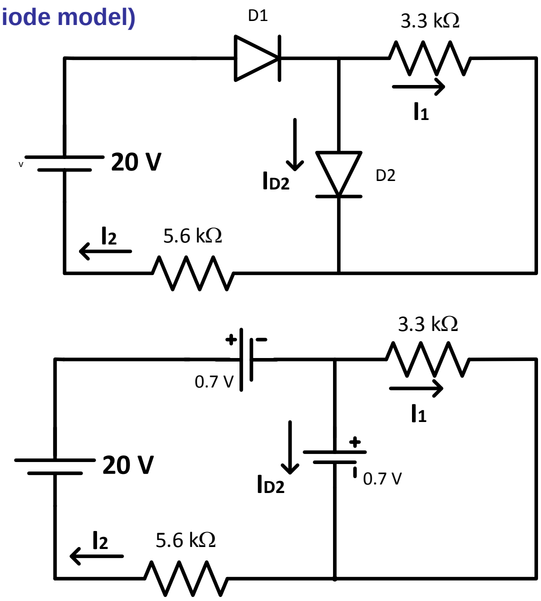
Find I_1, I_2, I_{D2} (use practical diode model)



Solution:

Applied voltage is suitable for forward biasing both diodes

I_1= 0.7 V/3.3 kΩ

=0.212 mA

I_2= (20-0.7-0.7)/5.6 kΩ

=3.32 mA

$I_2=I_1+I_{D2}$

$I_{D2}=I_2-I_1$= 3.32– 0.212

=3.11 mA