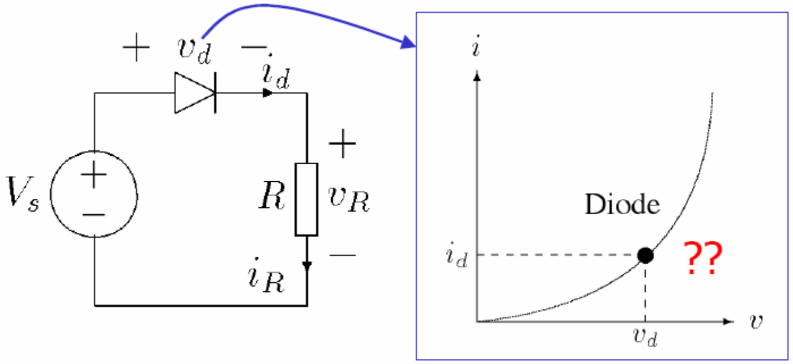
Diode Circuits Analysis

- **Graphical Method**
  - The intersection of the diode and the resistor current equations is calculated
  - 👍 Gives good understanding to the circuit operation
  - 👎 Time consuming
  - 👎 Not suitable for large circuits
- **Analytical Method**
  - Both diode and resistor current equations are solved simultaneously or iteratively
  - 👍 Faster than graphical method
  - 👍 More accurate
  - 👎 Time consuming
  - 👎 Not suitable for large circuits
- **Diode Models**
  - Piecewise-linear diode model is used to replace the diode
  - 👍 Least time consuming method
  - 👍 Suitable for larger circuits
  - 👎 Accuracy depends on the used model



A simple diode circuit.

Diode Current Equation

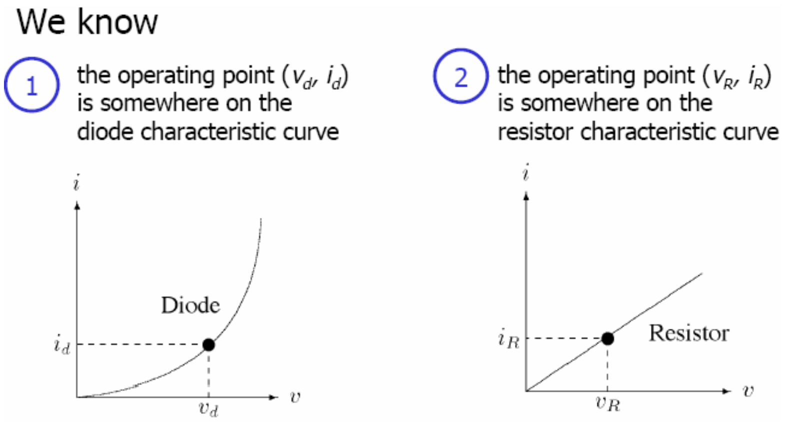
$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

Resistor Current Equation

$$I_R = \frac{V_S - V_D}{R}$$

Graphical Method

Step 1 : Locating the Operating Points

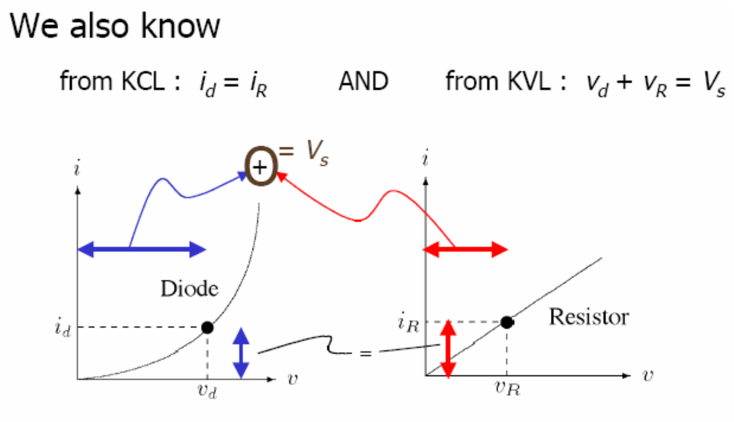


We know

① the operating point (v_d, i_d) is somewhere on the diode characteristic curve

② the operating point (v_R, i_R) is somewhere on the resistor characteristic curve

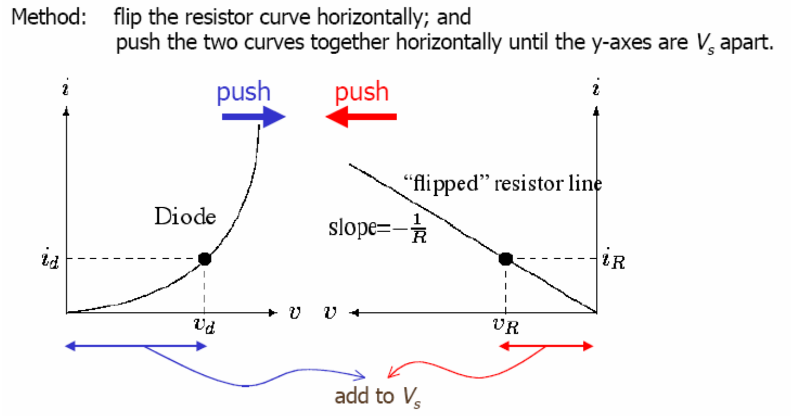
Step 2 : KVL & KCL Constraints



We also know

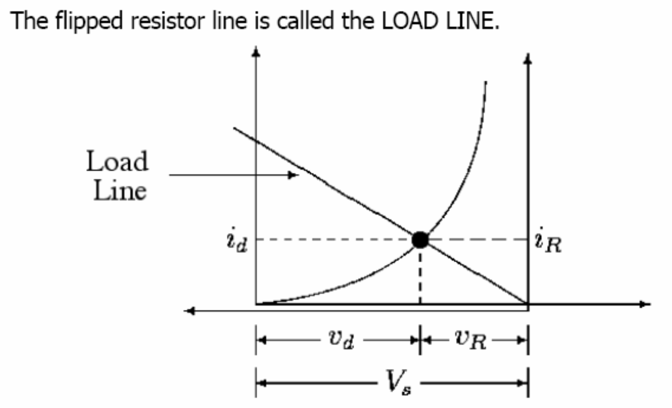
from KCL : $i_d = i_R$ AND from KVL : $v_d + v_R = V_s$

Step 3 : Enforcing KVL & KCL



Method: flip the resistor curve horizontally; and push the two curves together horizontally until the y-axes are V_s apart.

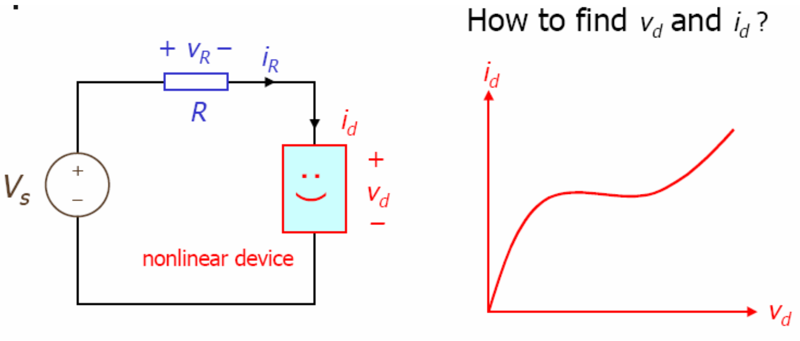
Solution



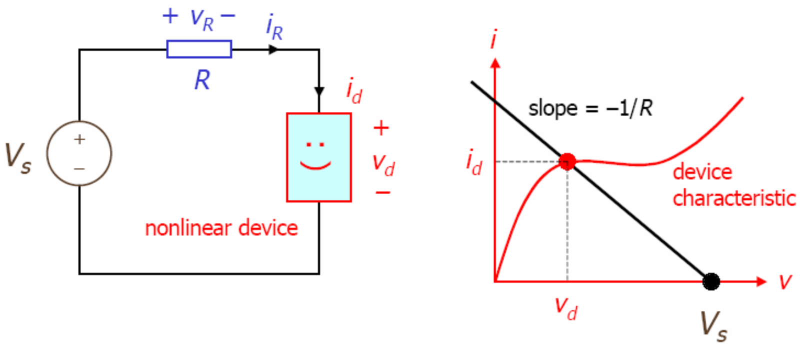
The flipped resistor line is called the LOAD LINE.

Graphical Method (cont.)

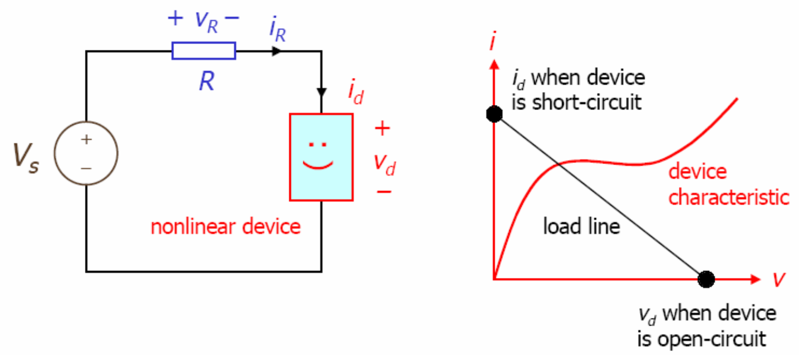
General Problem



Basic Load Line Construction

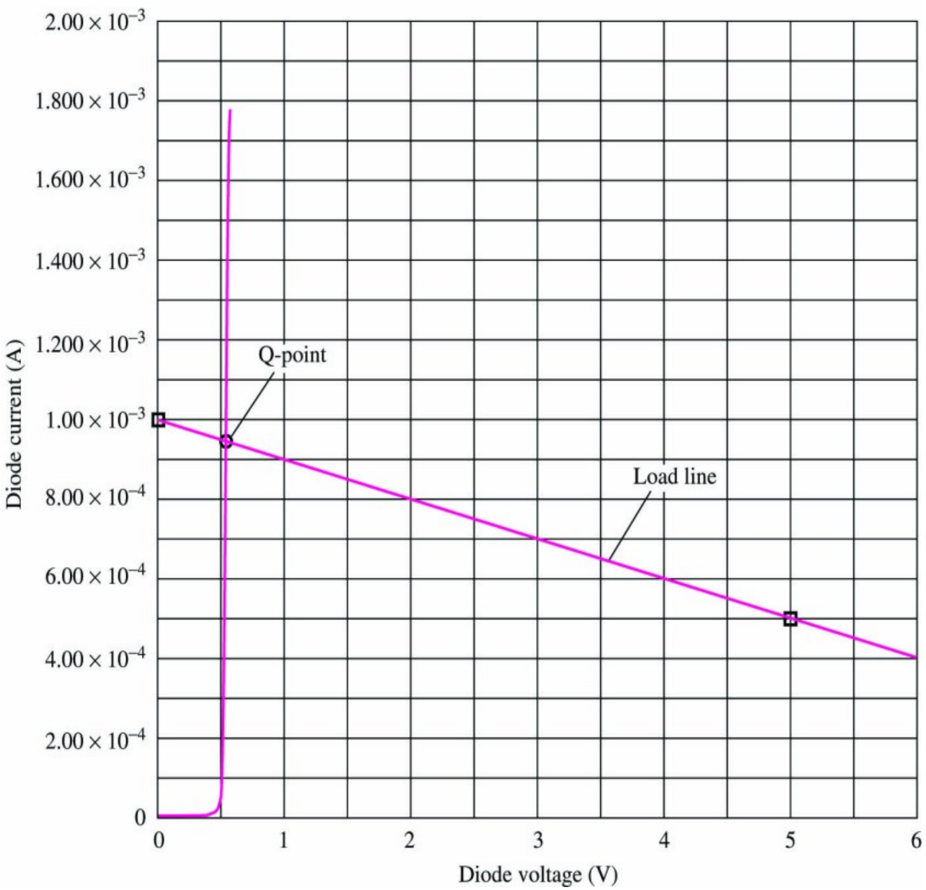


Alternative Construction



- Gives good understanding to the circuit operation
- Not suitable for large circuits

Graphical Method (Example)



Problem: Find Q-point
Given data: V_s=10 V, R=10kΩ.
Analysis:

To define the load line we use,
V_D= 0
V_D= 5 V, I_D =0.5 mA

These points and the resulting load line are plotted.Q-point is given by the intersection of the load line and the diode characteristic:

Q-point = (0.95 mA, 0.6 V)

Analytical Method

Example:

$I_s=10^{-15}$ A, n=1, $V_s=5$ V, R=1K

Step 1:

Assume $V_D=V_{Do}=0.7V$

$I_{D1}=(V_s-V_{Do})/R=4.3$ m.A

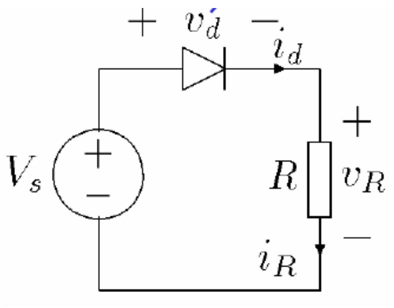
$V_{D1}=0.025\ln(I_{D1}/I_s)=0.7272$ V

Step 2:

$I_{D2}=(V_s-V_{D1})/R=4.2728$ m.A
$V_{D2}=0.025\ln(I_{D2}/I_s)=0.7271$ V

Exact Value:

$I_D=4.2729$ m.A, $V_D=0.7271$ V

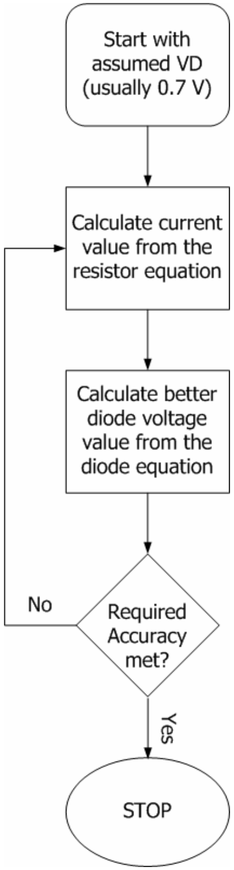


Diode Current Equation

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

Resistor Current Equation

$$I_R = \frac{V_S - V_D}{R}$$



Start with assumed VD (usually 0.7 V)

Calculate current value from the resistor equation

Calculate better diode voltage value from the diode equation

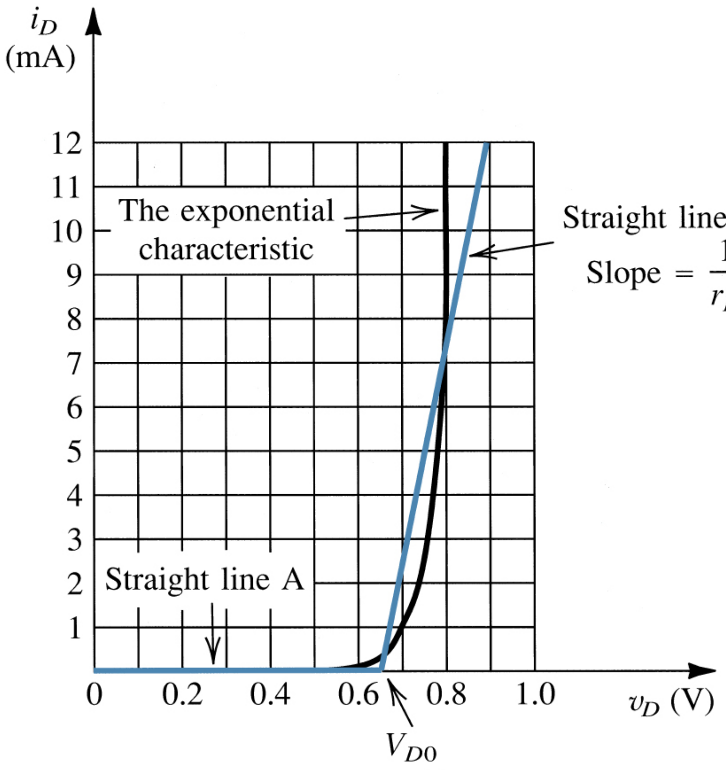
Required Accuracy met?

No

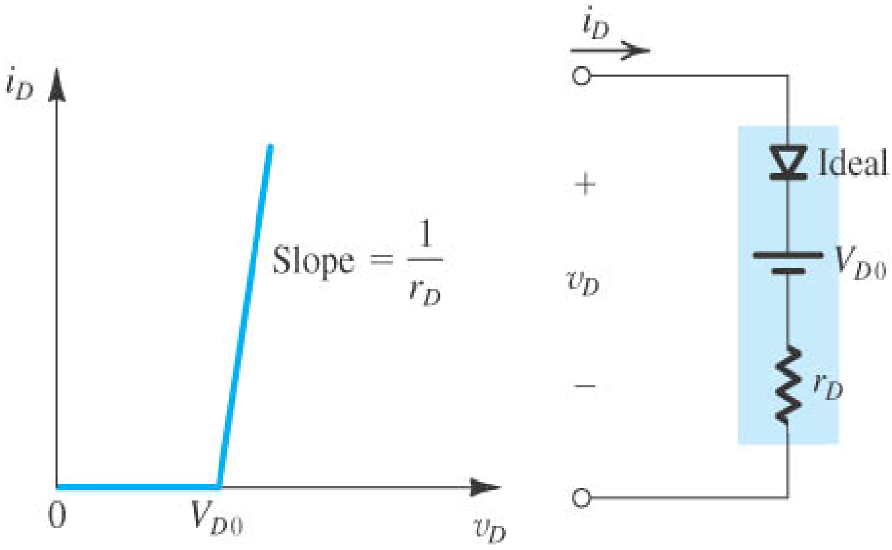
Yes

STOP

Diode Models

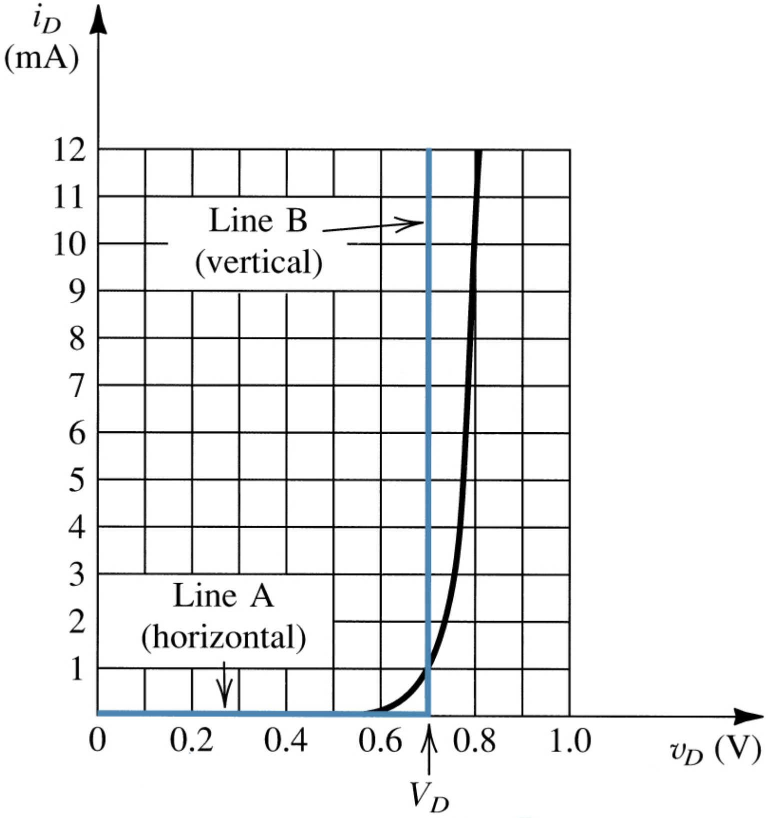


Approximating the diode forward characteristic with two straight lines.

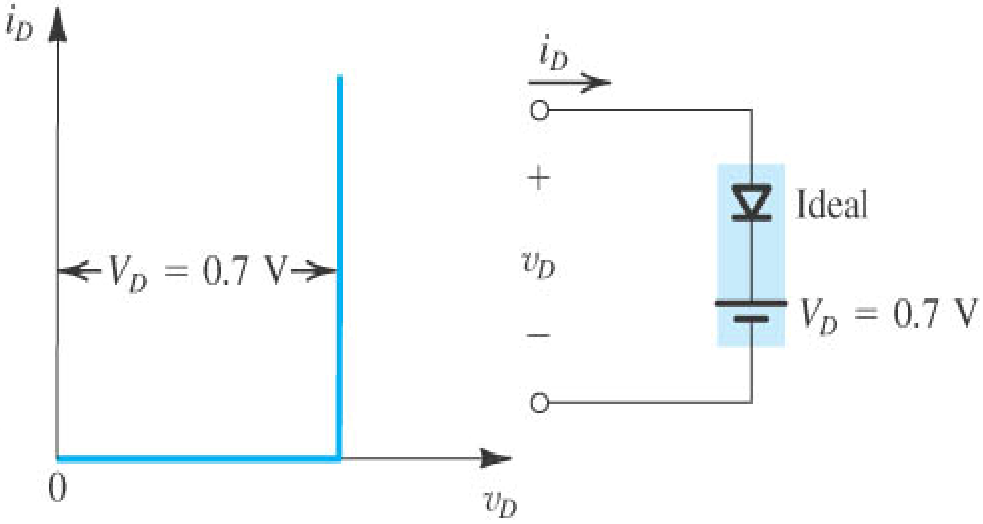


Piecewise-linear model of the diode forward characteristic and its equivalent circuit representation.

Diode Models (cont.)



Development of the constant-voltage-drop model of the diode forward characteristics. A vertical straight line (b) is used to approximate the fast-rising exponential.

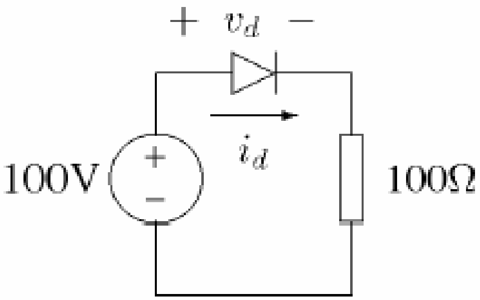


The constant-voltage-drop model of the diode forward characteristic and its equivalent circuit representation.

Also Ideal diode model may be used which means short circuit in the forward direction and open circuit in the reverse direction.

Which Model to Use?

The choice depends on the external voltage magnitudes.

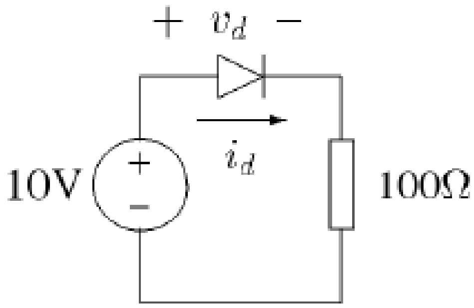


Ideal model:

i_d = 100/100 = 1 A

With 0.7V drop:

i_d = (100–0.7)/100
= 0.997 A

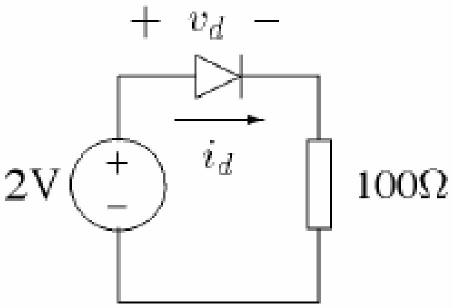


Ideal model:

i_d = 10/100 = 100 mA

With 0.7V drop:

i_d = (10–0.7)/100
= 93 mA



Ideal model:

i_d = 2/100 = 20 mA

With 0.7V drop:

i_d = (2–0.7)/100
= 13 mA

Analysis using Diode Models

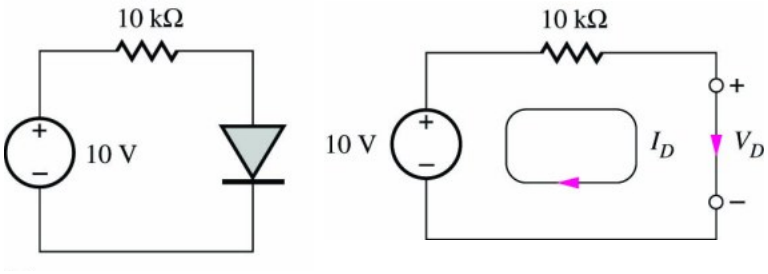
Diode is assumed to be either ON or OFF.

Analysis is conducted as follows:

1. Select diode model.
2. Identify anode and cathode of diode and label v_D and i_D.
3. Guess diode's region of operation from circuit.
4. Analyze circuit using diode model appropriate for assumed operating region.
5. Check results to check consistency with assumptions. (For forward assumption check that $i_D > 0$, for reverse biased check that $v_D < V_{DO}$ or zero for ideal diode model)

Analysis using Ideal Model for Diode: Example

Find the Q-Point (I_D, V_D) for the following diodes assuming ideal diode model.

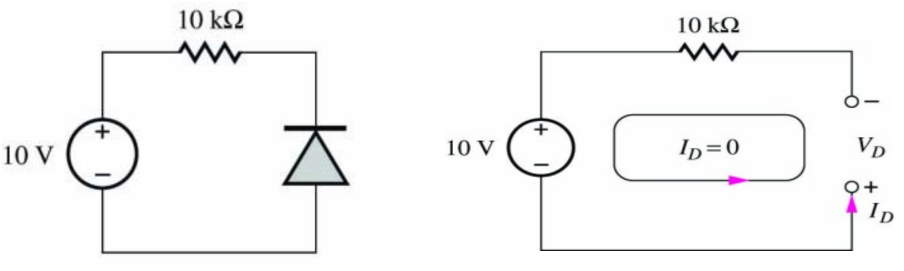


Since source is forcing positive current through diode assume diode is on.

$$I_D = \frac{(10-0)\mathrm{V}}{10\mathrm{k}\Omega} = 1\mathrm{m}A$$

$\because I_D \geq 0$ our assumption is right.

Q-point is(1 mA, 0V)



Since source is forcing current backward through diode assume diode is off. Hence I_D =0 . Loop equation is:

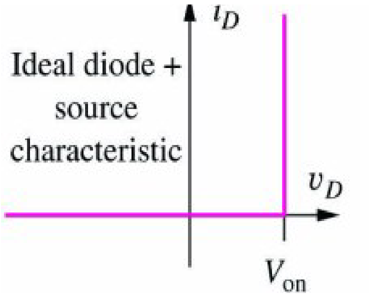
$$10 + V_D + 10^4 I_D = 0$$

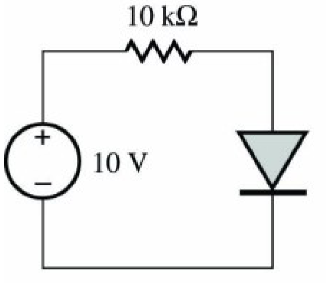
$\therefore V_D = -10\mathrm{V}$ our assumption is right.

Q-point is (0, -10 V)

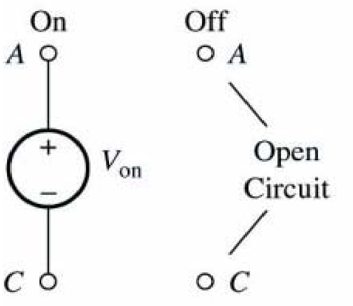
Analysis using Constant Voltage Drop Model for Diode

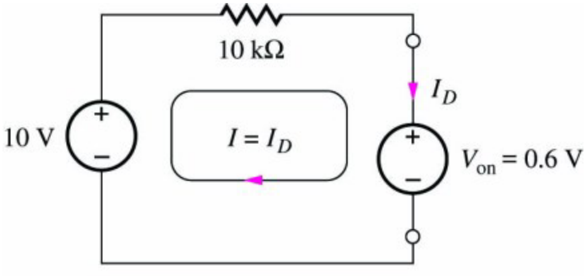
Find the Q-Point (I_D, V_D) for the following diode assuming CVD, with V_{DO}=0.6V.





Analysis:
Since 10V source is forcing positive current through diode assume diode is on.





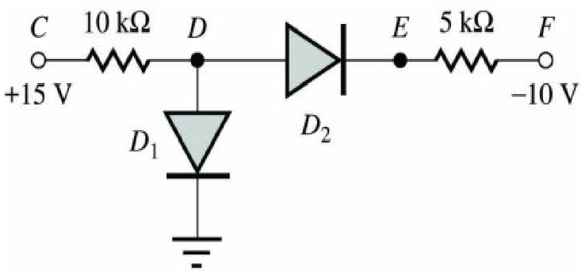
$$I_D = \frac{(10 - V_{on})\text{V}}{10\text{k}\Omega}$$

$$= \frac{(10 - 0.6)\text{V}}{10\text{k}\Omega} = 0.94\text{mA}$$

$v_D = V_{on}$ for $i_D > 0$ and
$i_D = 0$ for $v_D < V_{on}$.

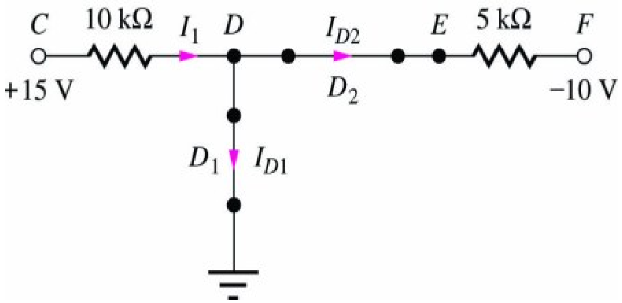
Two-Diode Circuit Analysis

Find the Q-Point (I_D, V_D) for the following diodes assuming ideal diode model.



Analysis: Since 15V source is forcing positive current through D_1 and D_2 and -10V source is forcing positive current through D_2, assume both diodes are on.

Since voltage at node *D* is zero due to short circuit of ideal diode D_1,



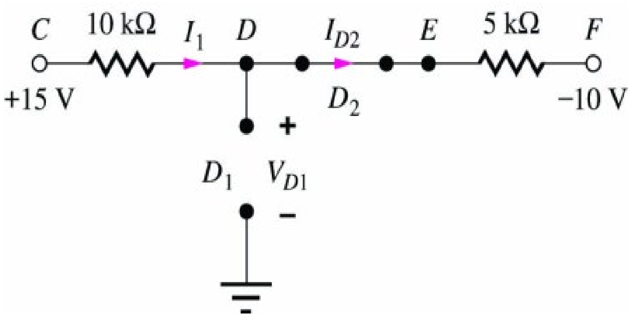
$$I_1 = \frac{(15-0)\text{V}}{10\text{k}\Omega} = 1.50\text{mA} \quad I_{D2} = \frac{0-(-10)\text{V}}{5\text{k}\Omega} = 2.00\text{mA}$$

$$I_1 = I_{D1} + I_{D2} \qquad \therefore I_{D1} = 1.5 - 2 = -0.50\text{mA}$$

Q-points are (-0.5 mA, 0 V) and (2.0 mA, 0 V)

But, I_{D1} <0 is not allowed by diode, so try again.

Two-Diode Circuit Analysis (cont.)



Since current in D_2 but that in D_1 is invalid, the second guess is D_1 off and D_2 on.

Since current in D_1 is zero, $I_{D2} = I_1$,

$$15 - 10{,}000 I_1 - 5{,}000 I_{D2} - (-10) = 0$$

$$\therefore I_1 = \frac{25\text{V}}{15{,}000\Omega} = 1.67\text{mA}$$

$$V_{D1} = 15 - 10{,}000 I_1 = 15 - 16.7 = -1.67\text{V}$$

Q-points are D_1 : (0 mA, -1.67 V):off

D_2 : (1.67 mA, 0 V) :on