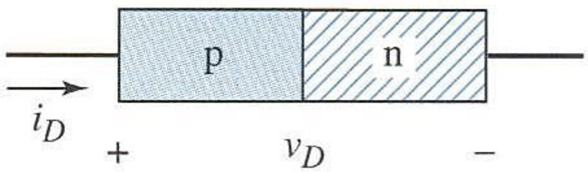
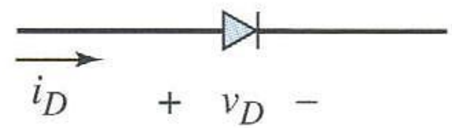
PN Junction Diode

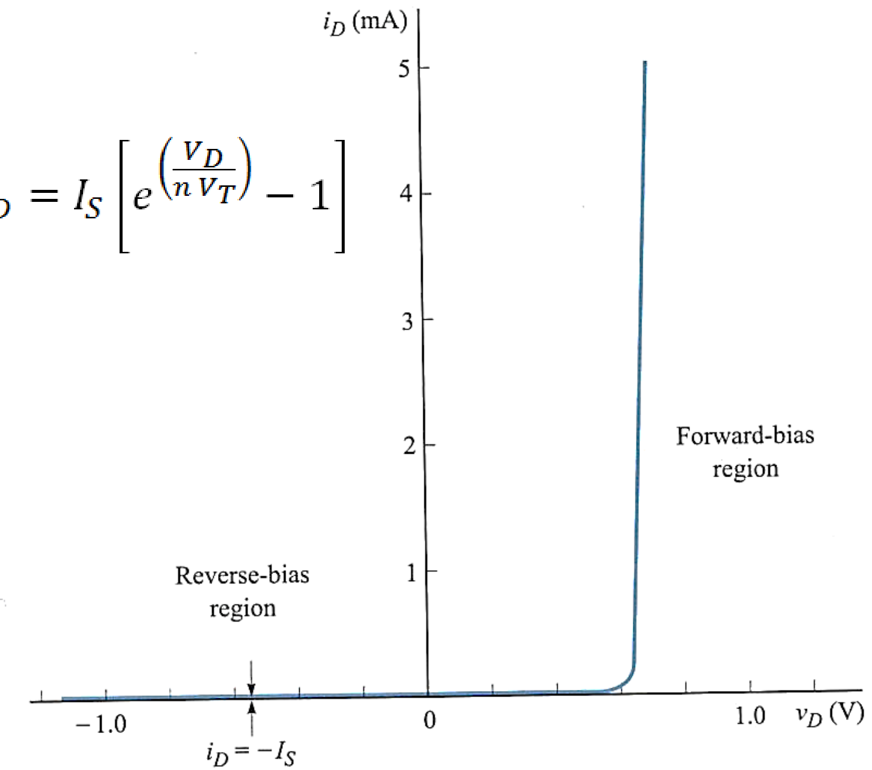
- The basic PN junction diode circuit symbol, and conventional current direction and voltage polarity.





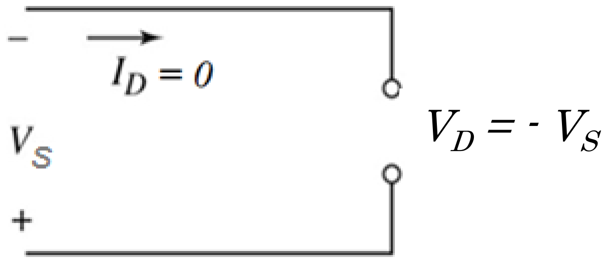
- The graphs shows the ideal I-V characteristics of a PN junction diode.
- The diode current is an exponential function of diode voltage in the forward-bias region.
- The current is very nearly zero in the reverse-bias region.

$$I_D = I_S\left[e^{\left(\frac{V_D}{n\,V_T}\right)} - 1\right]$$

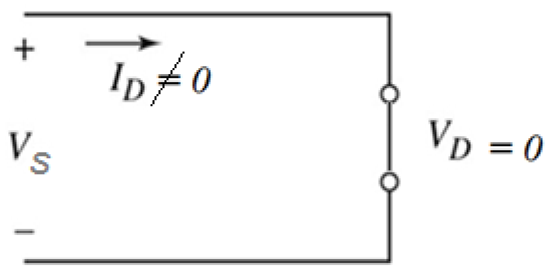


Analysis of PN Junction Diode in a Circuit

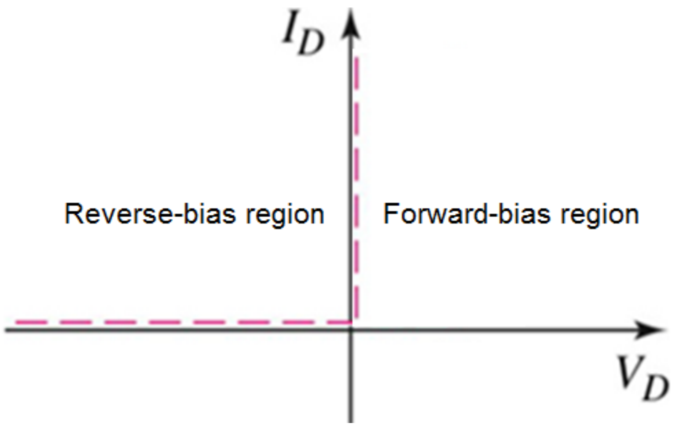
CIRCUIT REPRESENTATION OF DIODE – Model 1 (Ideal Diode)



Reverse-bias

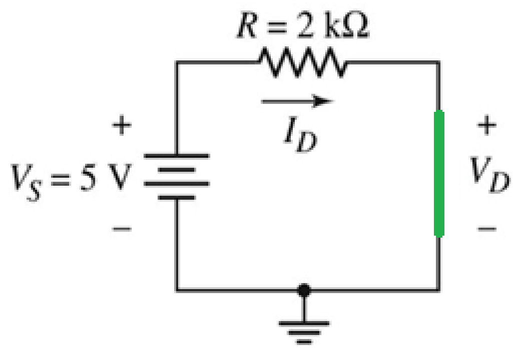


Forward-bias



I-V characteristics of ideal model

EXAMPLE: Determine the diode voltage and current in the circuit using ideal model for a silicon diode. Also determine the power dissipated in the diode.



The diode forward current

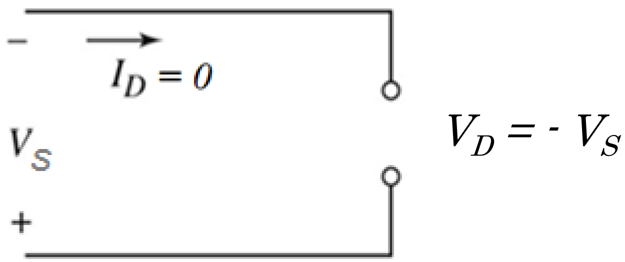
$$I_D = \frac{V_S}{R} = \frac{5\ V}{2\ K\Omega} = 2.5\ mA$$

Voltage drop across diode $V_D = 0\ V$

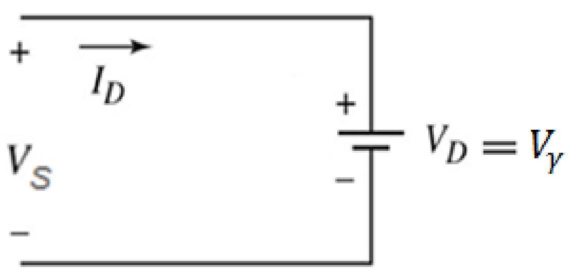
Power dissipation in the diode

$$P_D = V_D \times I_D = 0\ W$$

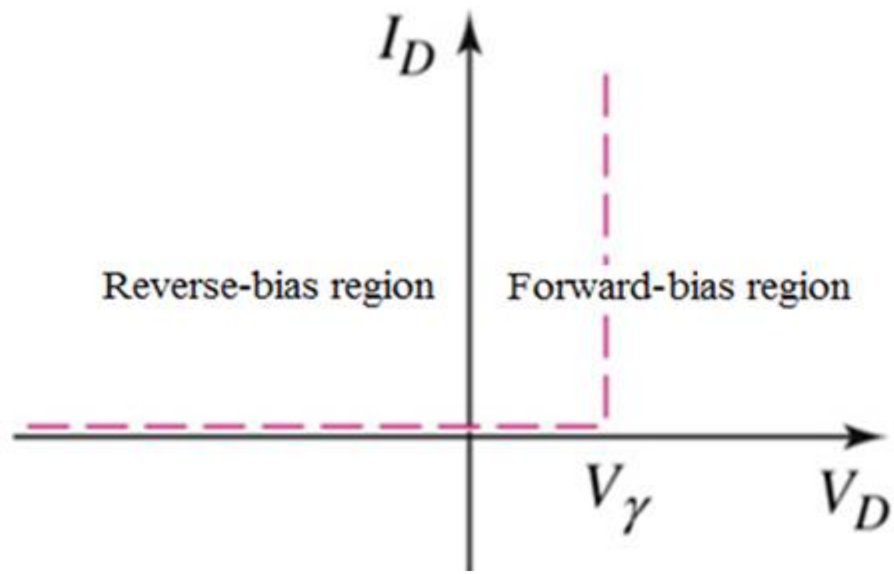
CIRCUIT REPRESENTATION OF DIODE – Model 2 (Piecewise Linear Model)



Reverse-bias $(V_S < V_\gamma)$

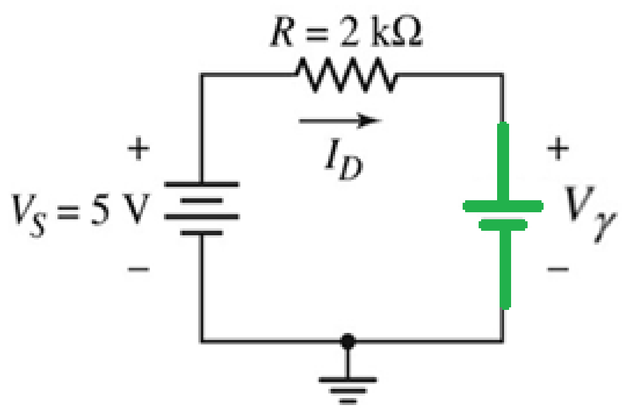


Forward-bias $(V_S \geq V_\gamma)$



I-V characteristics of constant voltage model

EXAMPLE: Determine the diode voltage and current in the circuit (using constant voltage model) for a silicon diode. Also determine the power dissipated in the diode. Consider the cut-in voltage $V_\gamma = 0.65$ V.



The diode forward current

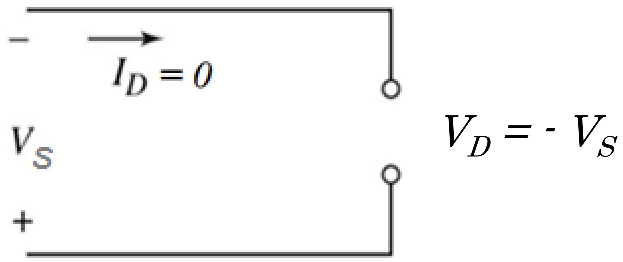
$$I_D = \frac{V_S - V_\gamma}{R} = \frac{(5 - 0.65)V}{2\ K\Omega} = 2.175\ mA$$

Voltage drop across diode $V_D = V_\gamma = 0.65\ V$

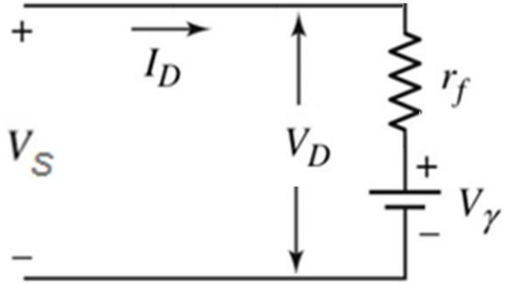
Power dissipation in the diode

$$P_D = V_D \times I_D = 0.65\ V \times 2.175\ mA \cong 1.414\ mW$$

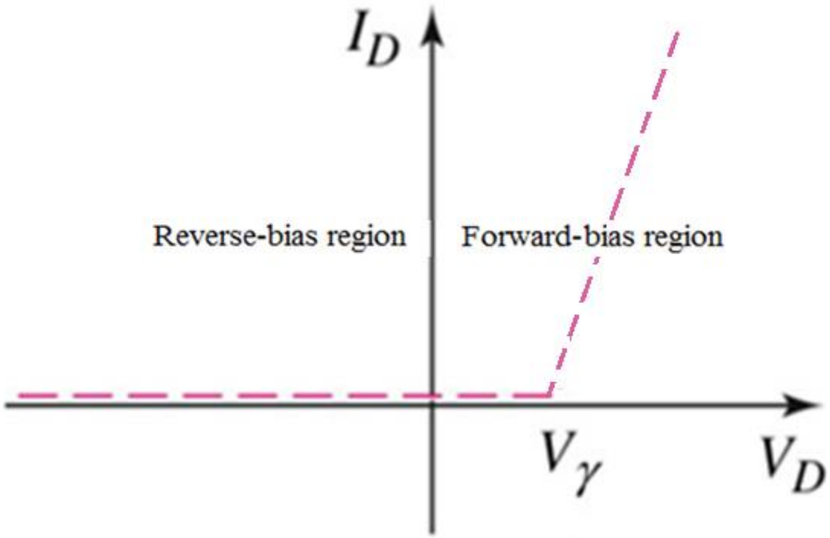
CIRCUIT REPRESENTATION OF DIODE – Model 3 (Piecewise Linear Model)



Reverse-bias $(V_S < V_\gamma)$

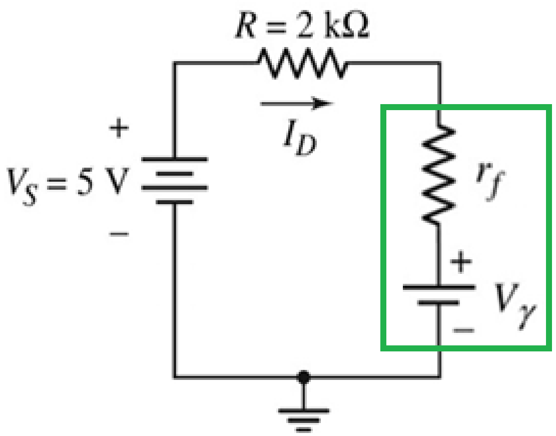


Forward-bias $(V_S \geq V_\gamma)$



I-V characteristics of piecewise model
$(r_f \neq 0)$

EXAMPLE: Determine the diode voltage and current in the circuit using piecewise linear model for a silicon diode. Also determine the power dissipated in the diode. Consider the cut-in voltage $V_\gamma = 0.65$ V and the diode DC forward resistance, $r_f = 15\ \Omega$.



The diode forward current

$$I_D = \frac{V_S - V_\gamma}{R + r_f} = \frac{(5 - 0.65)V}{2.015\ K\Omega} \cong 2.159\ mA$$

Voltage drop across diode

$$V_D = V_\gamma + I_D r_f = (0.65 + \ 2.159 \times 10^{-3} \times 15)V$$

Or, $V_D = 0.682\ V$

Power dissipation in the diode

$$P_D = V_D \times I_D = \ 0.682 \text{ x } 2.159 \text{ mA} = 1.472 \text{ mW}$$

Why do you need to use these models?

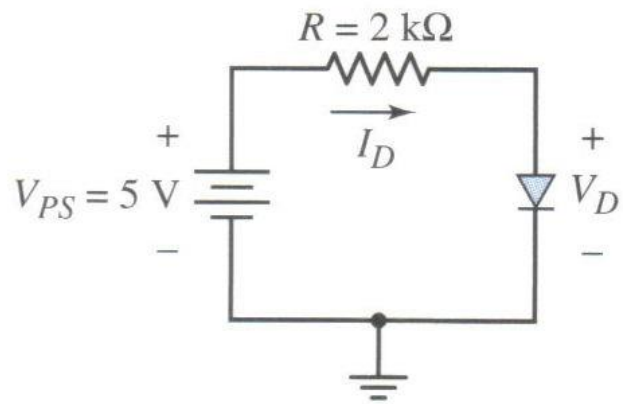
Diode Circuits: Direct Approach

$$I_D = I_S\left[e^{\left(\frac{V_D}{n\,V_T}\right)} - 1\right]$$

Question

Determine the diode voltage and current for the circuit.

Consider $I_S = 10^{-13}$ A.



$V_{PS} = I_D R + V_D$

$5 = (2 \times 10^3)\,(10^{-3})\,[\,e^{(VD / 0.026)} - 1\,] + V_D$

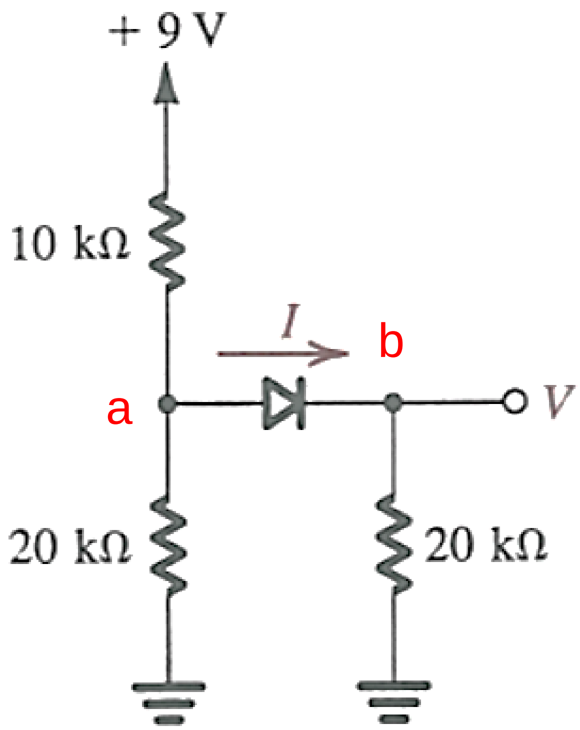
$V_D = 0.619$ V

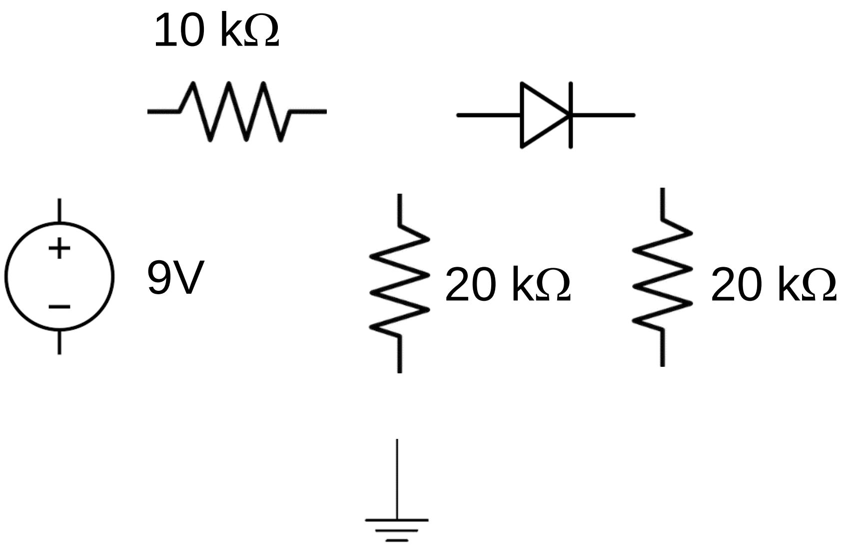
ITERATION METHOD

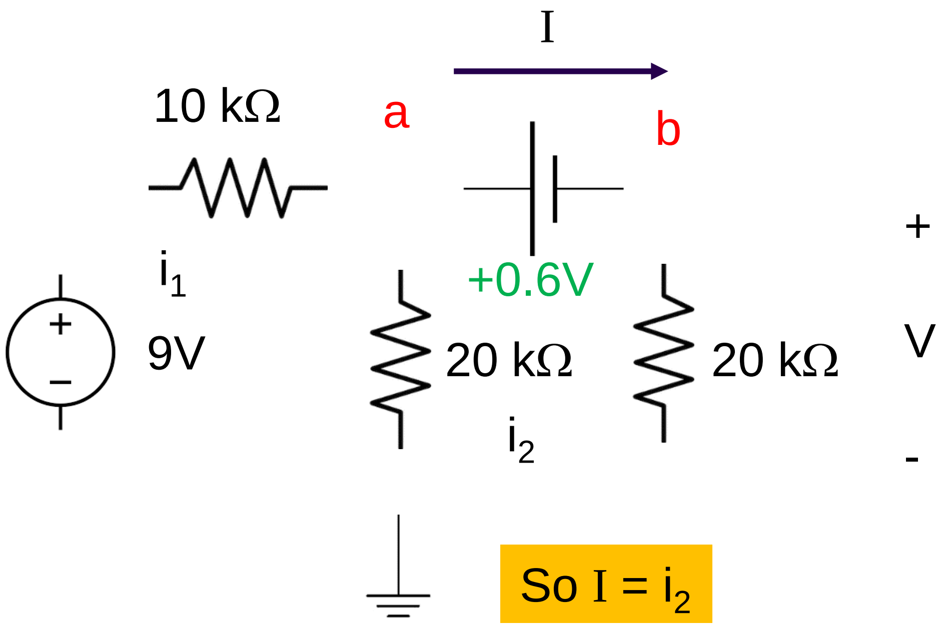
And $I_D = 2.19$ mA

	IDEAL MODEL	PIECEWISE LINEAR MODEL 2	PIECEWISE LINEAR MODEL 3	DIRECT APPROACH
Diode voltage V_D	0V	0.65 V	0.652 V	0.619 V
Diode current I_D	2.5 mA	2.175 mA	2.159 mA	2.19 mA

Calculate the values of the voltage V and the current, I,
Given that $V_\gamma = 0.6$ V







MESH 1 : $10\, i_1 + 20\,(i_1 - i_2) - 9 = 0$ → $10\, i_1 + 20\, i_1 - 20\, i_2 = 9$ → $30\, i_1 - 20\, i_2 = 9$

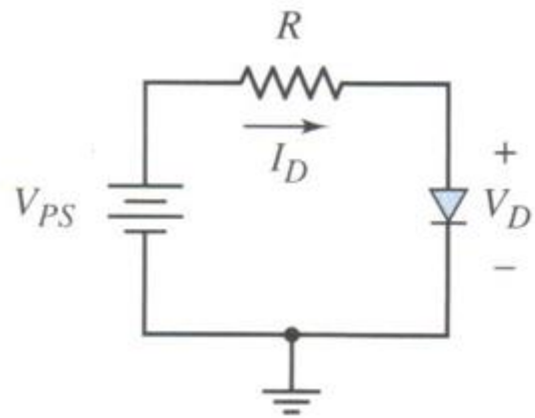
MESH 2 : $0.6 + 20\, i_2 + 20\,(i_2 - i_1) = 0$ → $20\, i_2 + 20\, i_2 - 20\, i_1 = -0.6$ → $40\, i_2 - 20\, i_1 = -0.6$

$60\, i_2 - 30\, i_1 = -0.9$

$40\, i_2 = 8.1$
$i_2 = I = 0.2025$ mA

Use Ohm's law to calculate V
$V = 20\,(i_2) = 4.05$ V

DC Load Line



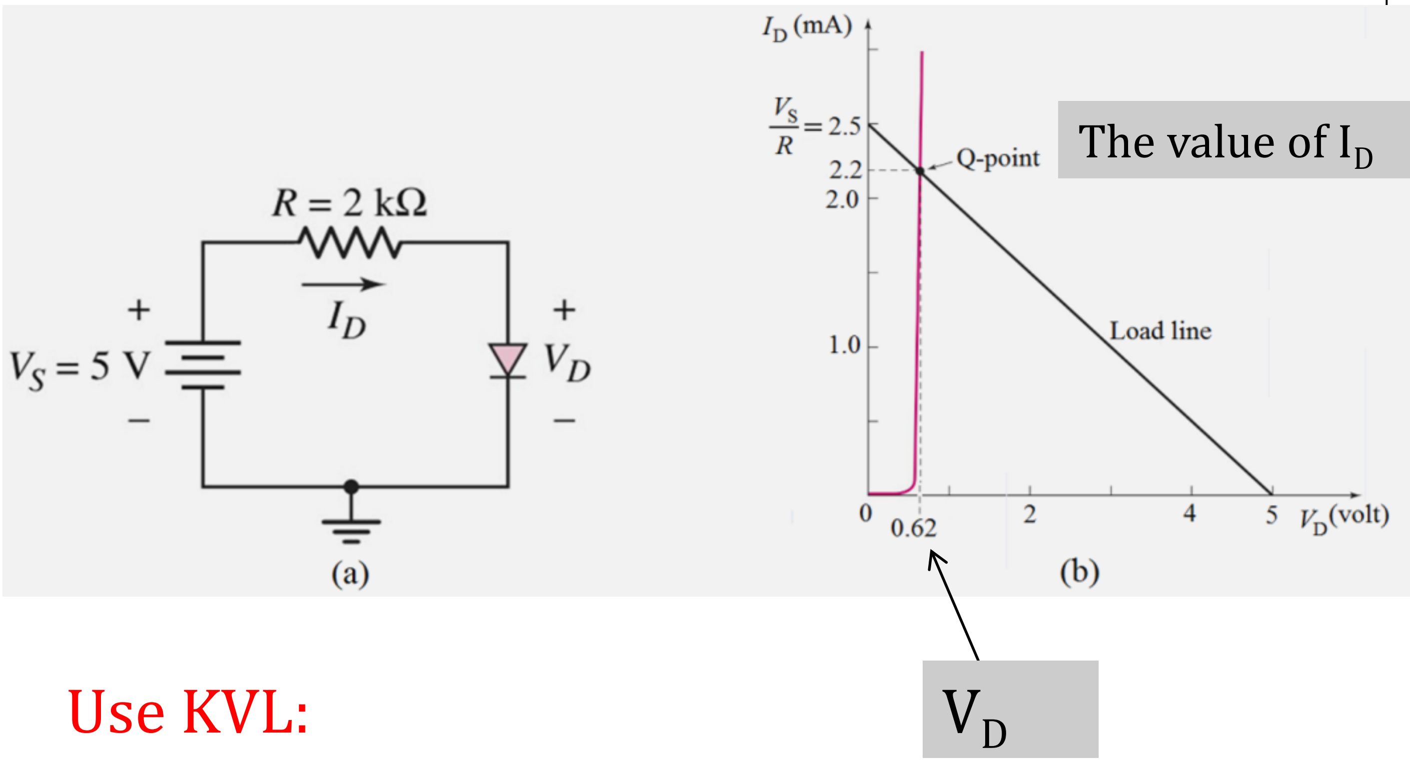
- A linear line equation
- I_D versus V_D
- Obtain the equation using KVL

The exact relation among the circuit current, voltage and resistance can be expressed by Kirchhoff's voltage law (KVL) as:

$$V_S = I_D R + V_D$$

Or, $$I_D = -\frac{V_D}{R} + \frac{V_S}{R}$$

$$(\ y = mx + c\ )$$



Use KVL:

$$2I_D + V_D - 5 = 0$$

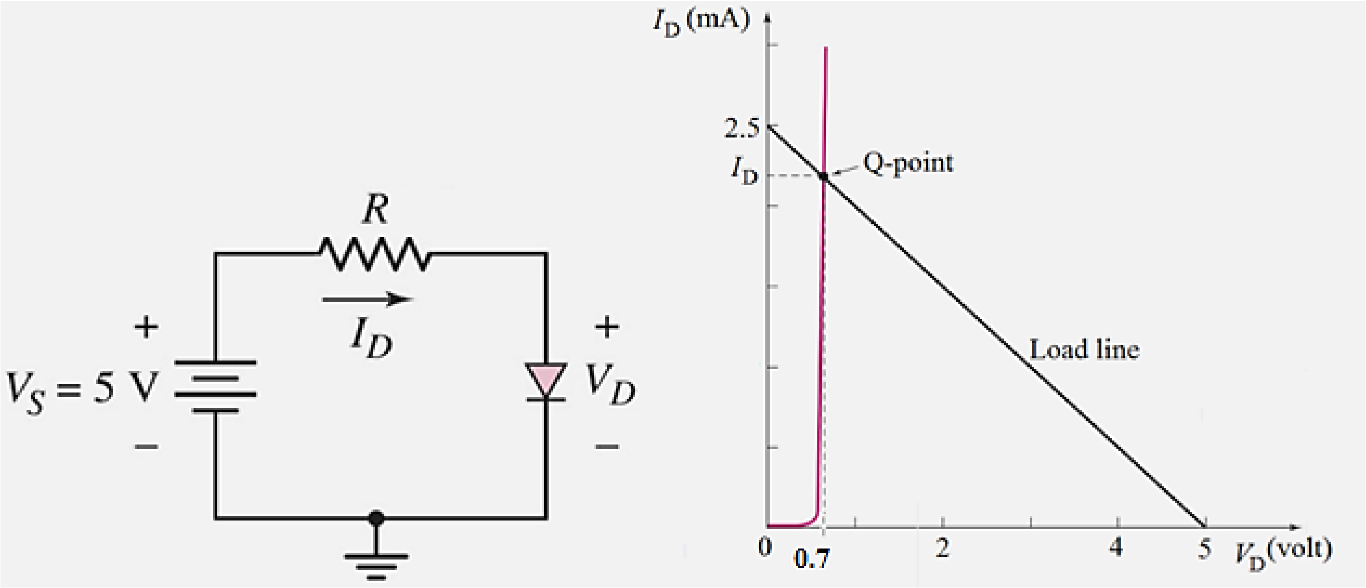
$$I_D = \frac{-V_D + 5}{2} = -\frac{V_D}{2} + 2.5$$

ID = (-0.62/2) + 2.5

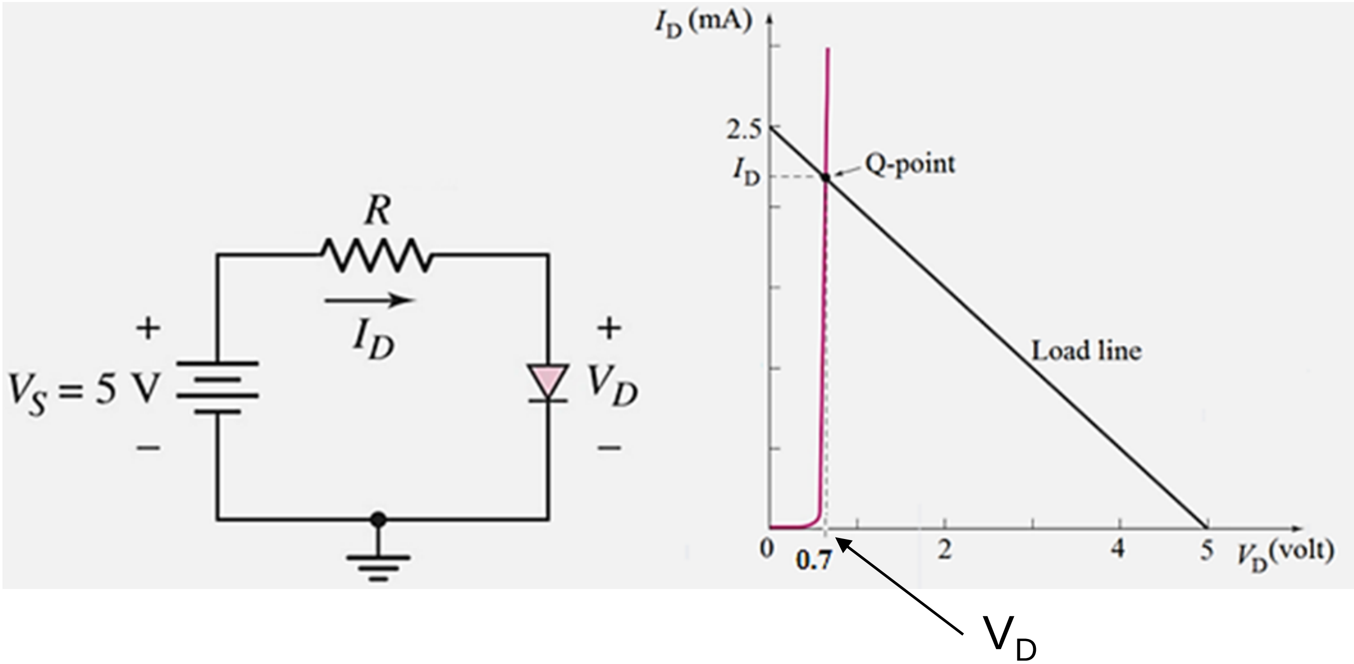
ID = -0.31+2.5 = 2.19 mA

EXAMPLE

A diode circuit and its load line are as shown in the figure below



Design the circuit when the diode is operating in forward bias condition. Determine the diode current I_D and diode forward resistance r_f in the circuit using a piecewise linear model. Consider the cut-in voltage of the diode, $V\gamma = 0.65$V.



$I_DR + V_D - 5 = 0$
$I_D = -V_D/R + 5/R$ ← $y = mx + C$
$5/R = 2.5$ mA
$R =$ **$2\ k\Omega$**

at $V_D = 0.7V$
$I_D = (5 - 0.7) / 2 =$ **2.15 mA**

Now, $V_D = V\gamma + I_D\, r_f$
$0.7 = 0.65 + 2.15\, r_f$
$r_f = 0.05 / 2.15$ mA $=$ **23. 3 Ω**