ECE 65: Components & Circuits Lab

Lecture 4

Diode introduction

and review of circuit theory

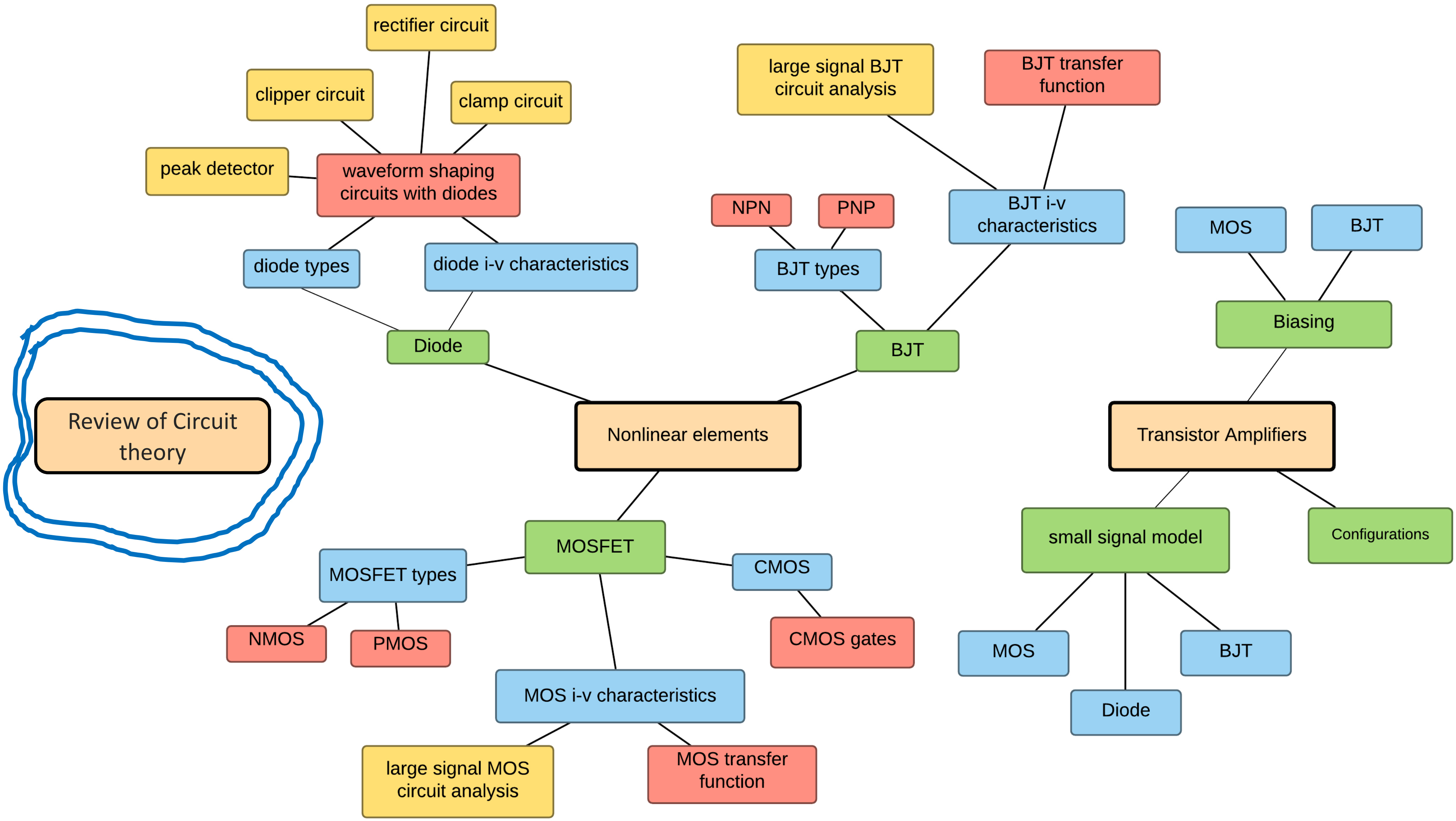
Reference notes: sections 2.1-2.8

Sedra & Smith (7th Ed): sections 4.3-4.4

Saharnaz Baghdadchi

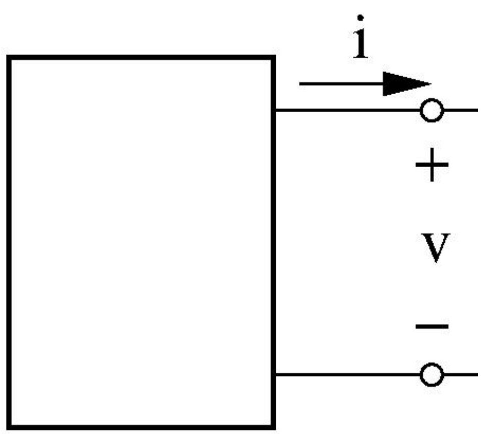
Course map

1. Review of Circuit theory



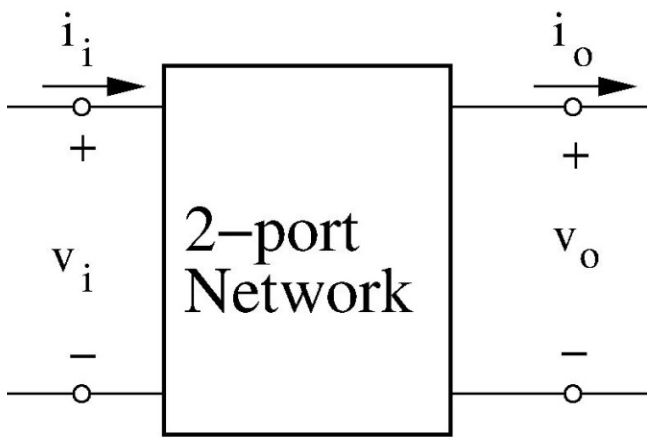
We will analyze many <u>functional circuits</u>

Two-terminal Networks



Function is defined by the iv equation

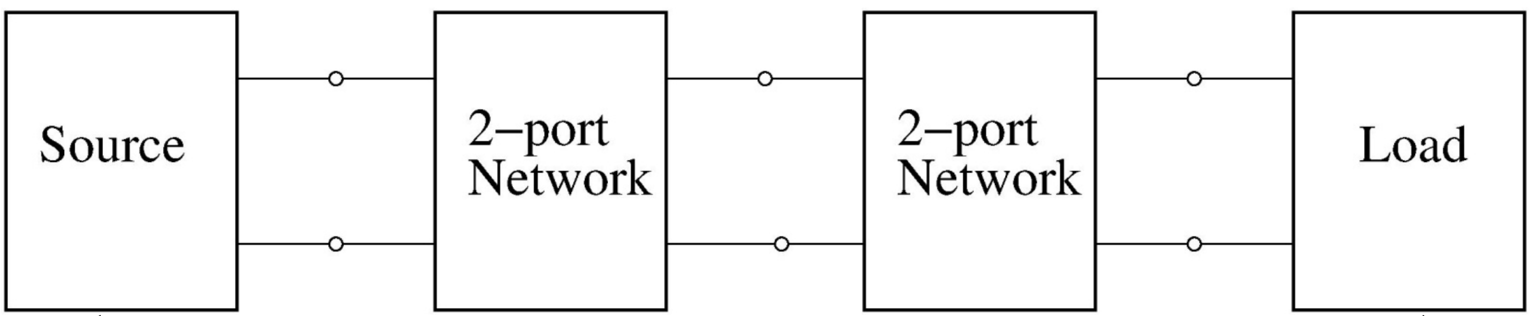
Two-port Networks



Function is defined by the transfer function (e.g., v_o in terms of v_i)

A typical analog circuit contains a load and a source (two-terminal networks) and several two-port networks

We divide the circuit into building blocks to simplify analysis and design



Two-terminal network containing an independent source

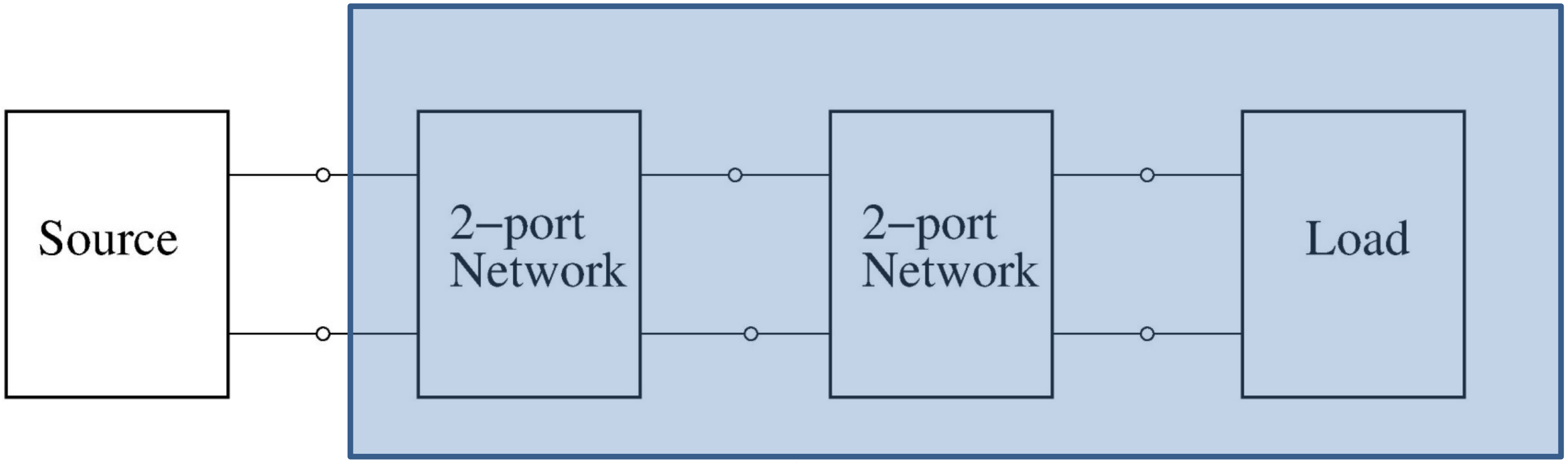
Two-terminal network containing NO independent source

In linear circuits:

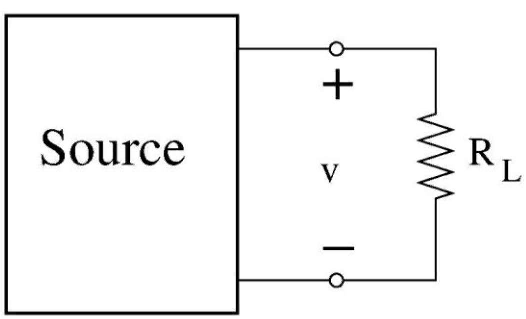
Any two-terminal network can be replaced by its Thevenin equivalent circuit.

If a two-terminal network does not include an “independent source” it will be reduced to a single “impedance” (even if it includes dependent sources).

Source only sees a load resistor

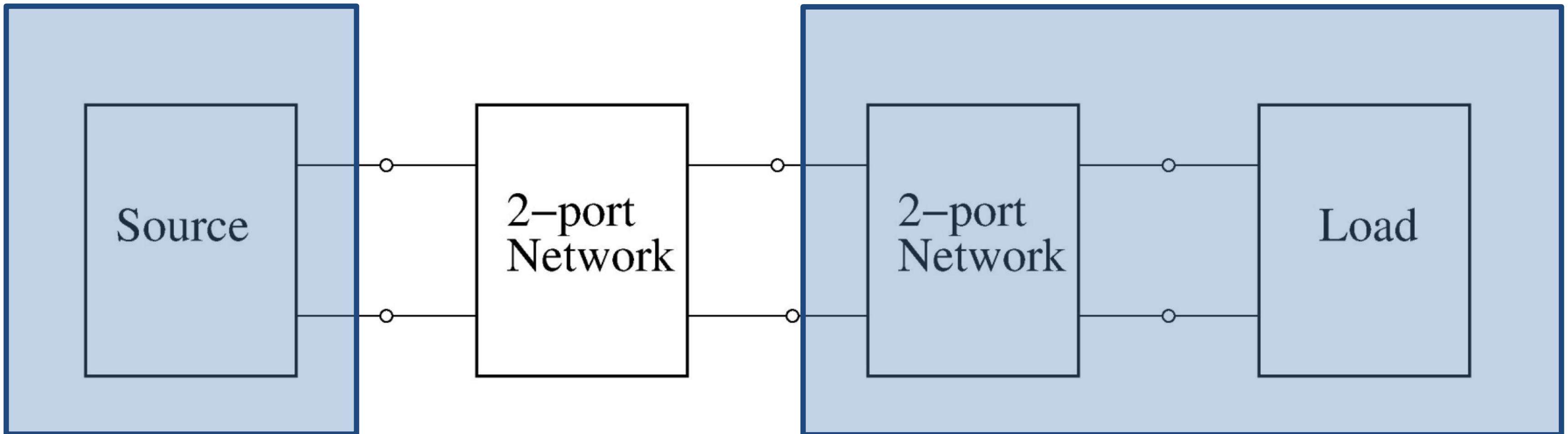


A two-terminal network containing NO independent source



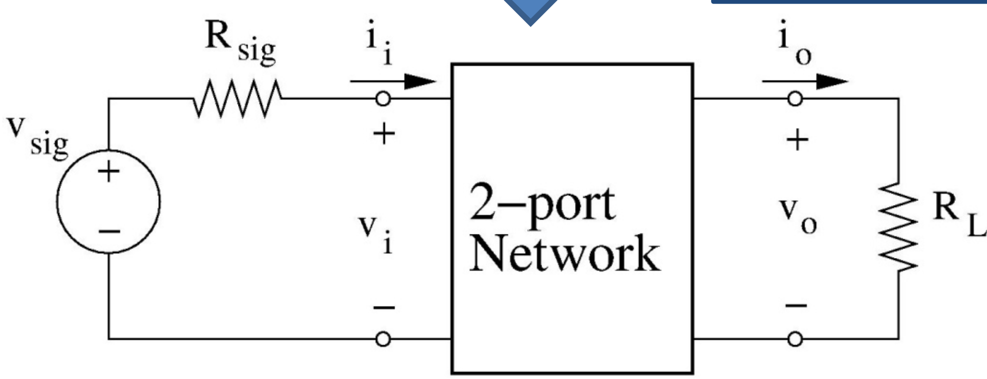
For a linear source, we only find the Thevenin parameters of the source.

Two-port network



A two-terminal network containing an independent source

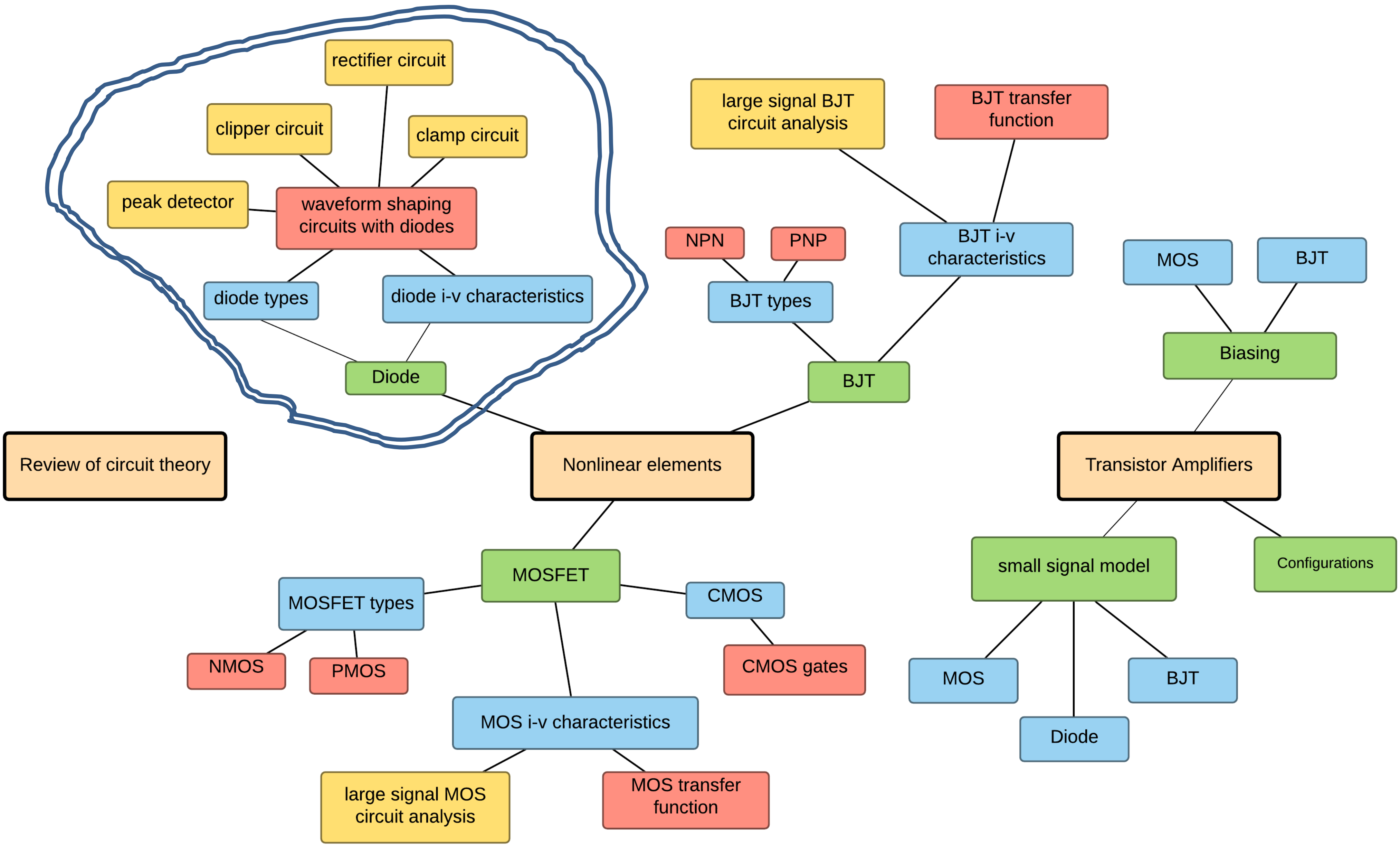
A two-terminal network containing no independent source



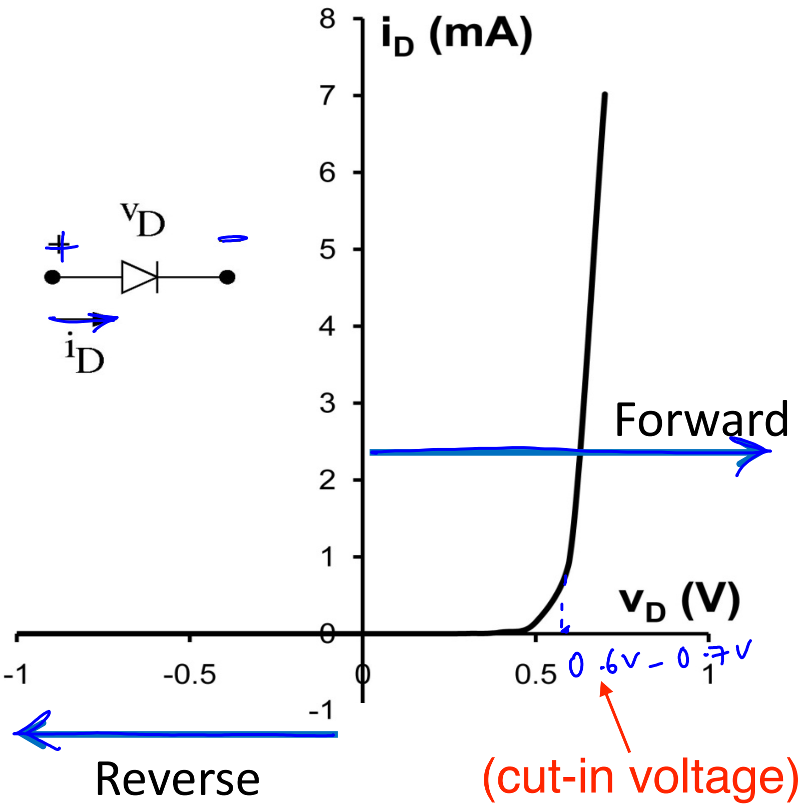
Transfer function of a two-port network can be found by solving the above circuit once.

Course map

2. Diodes



The iv characteristics of a silicon junction diode



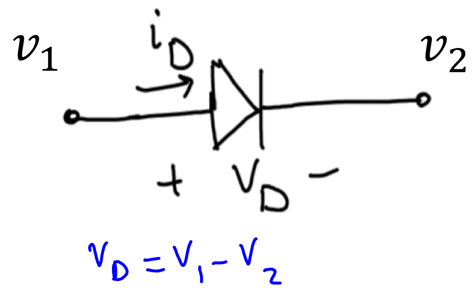
When the diode conducts,
$i_D \gg I_S$ and:

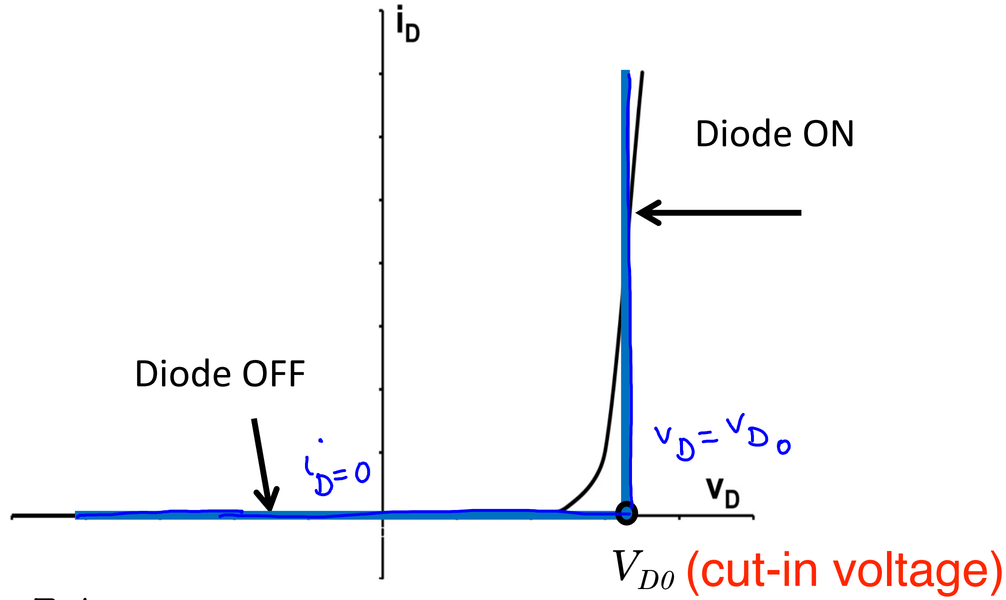
$$\boxed{i_D = I_S\, e^{v_D/V_T}}$$

I_S : Saturation Current
(10^{-9} to 10^{-18} A)

V_T : Thermal voltage = 26mV at room temp.

Diode piecewise-linear model:





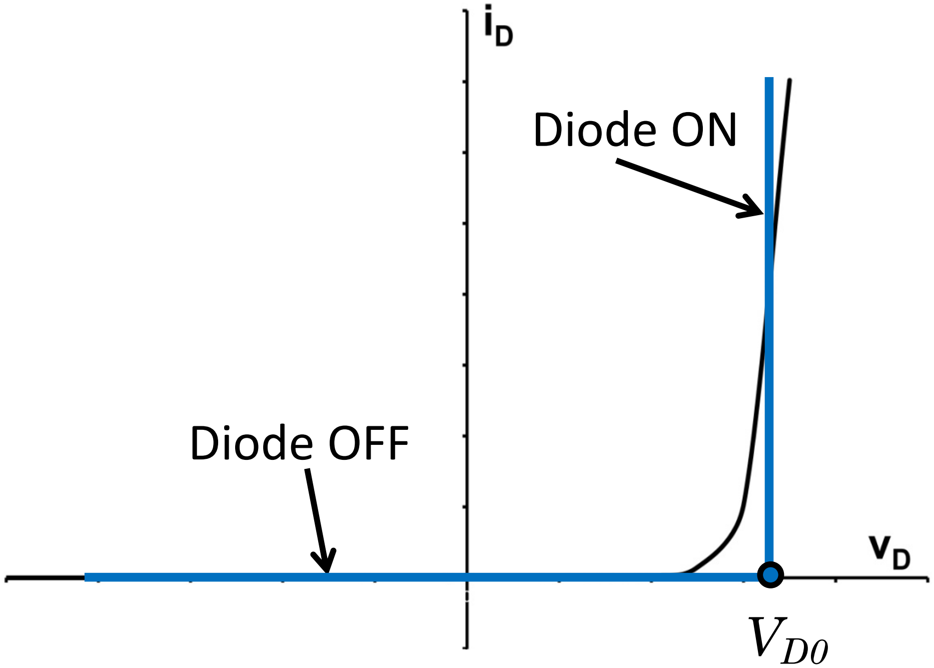
Assume Si Diode with $v_{D_0} = 0.7V$

(A) When $v_1 - v_2 < 0$ → diode is reverse-biased ⇒ $i_D = 0$

(B) When $0 < v_1 - v_2 < 0.7$ → diode is forward-biased, but it is not ON, yet ⇒ $i_D = 0$

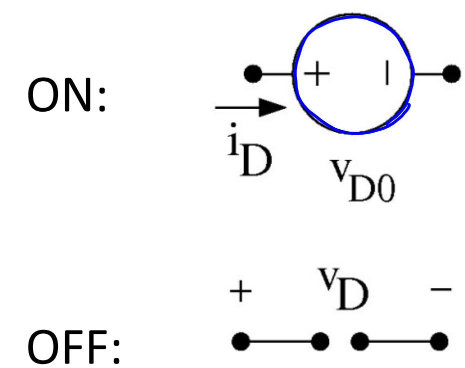
(C) When $v_1 - v_2 = 0.7$ → diode is forward biased and it's ON ⇒ $i_D \geq 0$ & $v_D = v_{D_0} = 0.7$

Diode piecewise-linear model:



Constant Voltage drop Model:

Circuit Models:

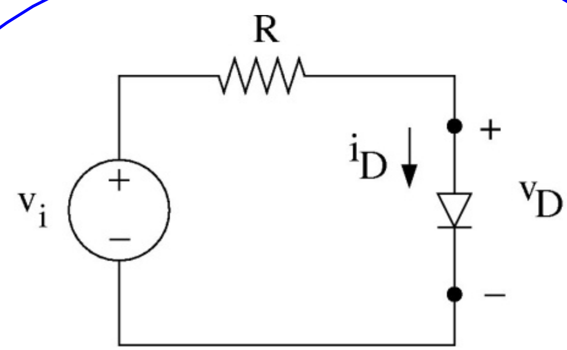


Diode ON: $v_D = V_{D0}$ and $i_D \geq 0$

Diode OFF: $i_D = 0$ and $v_D < V_{D0}$

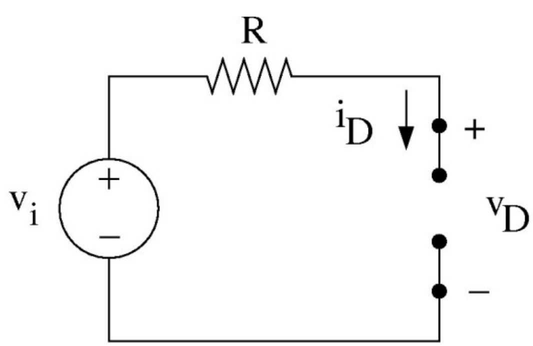
(cut-in voltage) $V_{D0} = 0.6 - 0.7\ V$ for Si

Diode circuit models:



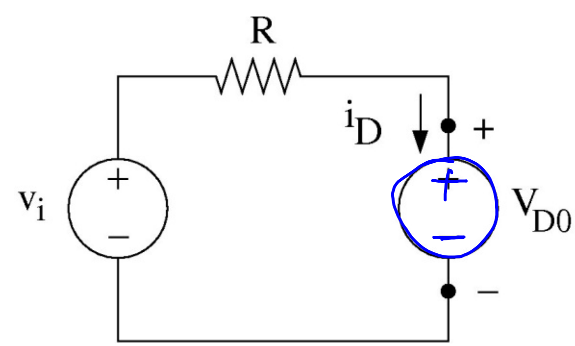
When Diode is OFF:

$i_D = 0$ and $v_D < V_{D0}$



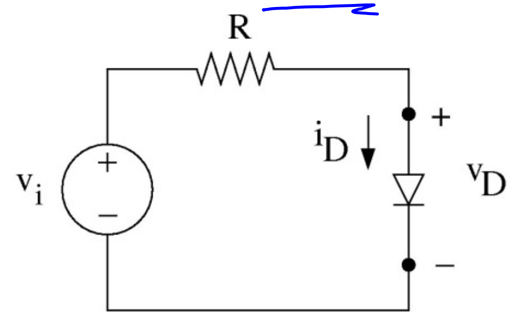
When Diode is ON:

$i_D \geq 0$ and $v_D = V_{D0}$



Example 1:

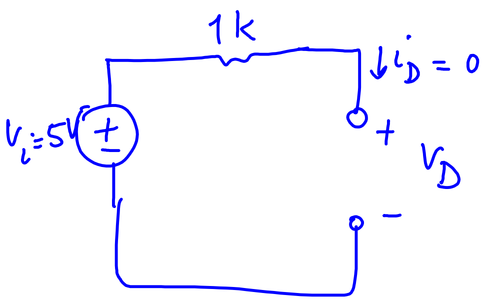
Find i_D and v_D for R = 1k, $V_i = 5$ V, and Si Diode ($V_{D0} = 0.7$ V).



Solution with diode circuit models:

Assume Diode is off

$\boxed{i_D = 0, \quad V_D < V_{D_0}}$

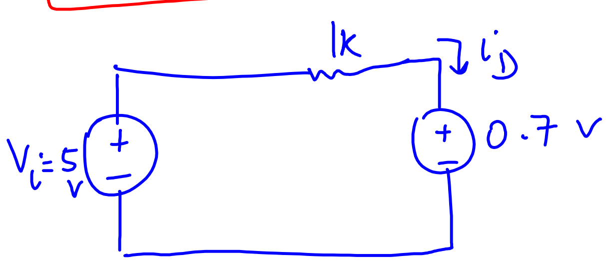


$V_i = 1k \times i_D + V_D$

$V_i = V_D = 5V > 0.7$ → Assumption was wrong.

Assume Diode is ON

$\boxed{i_D > 0}, \quad V_D = V_{D_0}$



$V_i = 1k \times i_D + 0.7V$

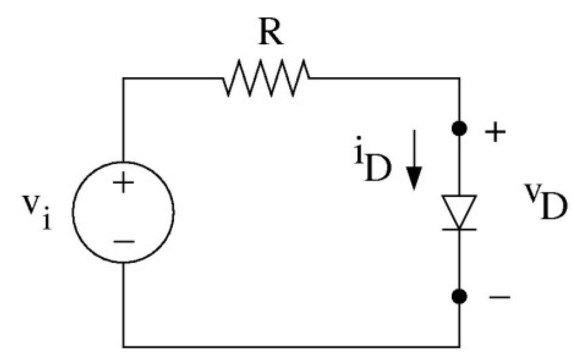
$\rightarrow i_D = \dfrac{5 - 0.7}{1k} = \underline{4.3 \text{ mA} > 0}$

The diode is ON.

Example 2 :

For what range of V_i the diode will be ON and for what range it will be OFF?

Find i_D and v_D for each range.



When diode is ON : $i_D \geq 0$, $V_D = V_{D_0}$

$V_i = R\, i_D + V_D = R\, i_D + 0.7$

$i_D = \frac{V_i - 0.7}{R} \geq 0 \longrightarrow V_i \geq 0.7\,V$

$\boxed{\text{For } v_i \geq 0.7\,V \text{, diode is ON, } V_D = V_{D_0},\ i_D \geq 0}$

when the diode is off : $i_D = 0$, $V_D < V_{D_0}$

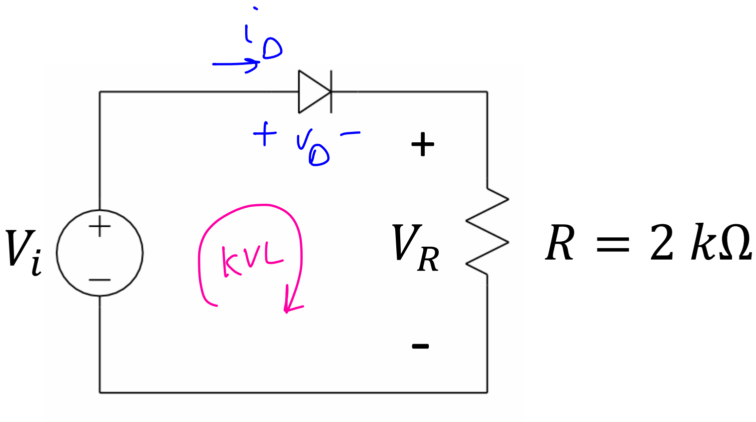
$V_i = R\, i_D + V_D \longrightarrow V_i = V_D$, $V_D < V_{D_0} \longrightarrow V_i < V_{D_0}$

$\boxed{\text{For } v_i < V_{D_0} \text{, diode is off, } i_D = 0,\ V_D < V_{D_0}}$

Lecture 4 reading quiz

In this diode circuit, what is the value of V_R for $V_i = 5\ V$ and $V_i = -5\ V$?

Assume $V_{D0} = 0.7\ V$



when $V_i = 5V$:

Assume the diode is off :

$v_D < V_{D_0}$ and $i_D = 0$

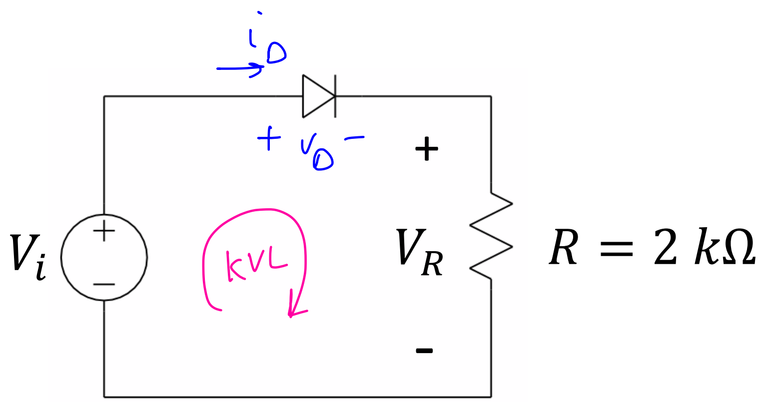
KVL : $-V_i + V_D + R\, i_D = 0 \longrightarrow -V_i + V_D = 0 \longrightarrow V_i = V_D = 5 > V_{D_0}$

$\Rightarrow$ The assumption was wrong.

Lecture 4 reading quiz

In this diode circuit, what is the value of V_R for $V_i = 5\ V$ and $V_i = -5\ V$?

Assume $V_{D0} = 0.7\ V$



when $V_i = 5V$:

Assume the diode is ON :

$V_D = V_{D_0}$ and $i_D \geq 0$

KVL : $-V_i + V_D + R\, i_D = 0 \longrightarrow -V_i + V_{D_0} + 2k\Omega \times i_D = 0$

$\longrightarrow -5V + 0.7V + 2k\Omega \times i_D = 0 \Longrightarrow i_D = 2.15\ mA > 0$

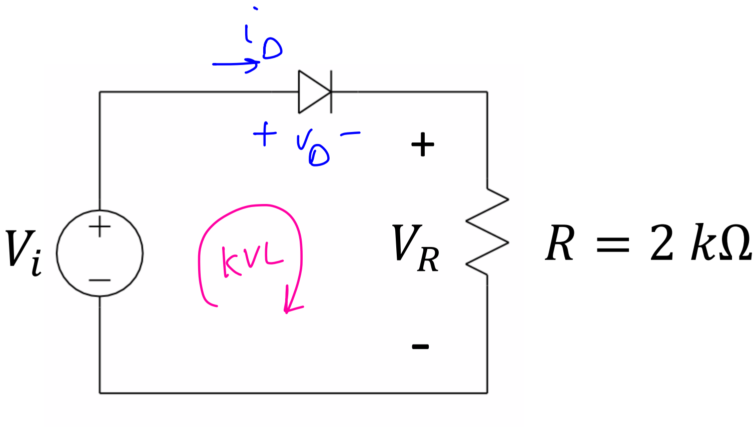
$\Longrightarrow$ The assumption was correct. The diode is ON, $V_D = V_{D_0}$ and $i_D = 2.15\ mA$.

$V_R = 2k\Omega \times 2.15\ mA = 4.3\ V$

Lecture 4 reading quiz

In this diode circuit, what is the value of V_R for $V_i = 5\,V$ and $V_i = -5\,V$?

Assume $V_{D0} = 0.7\,V$



when $V_i = -5V$:

Assume the diode is off :

$v_D < V_{D_0}$ and $i_D = 0$

KVL : $-V_i + V_D + R\,i_D = 0 \longrightarrow -V_i + V_D = 0 \longrightarrow V_i = V_D = -5V < V_{D_0}$

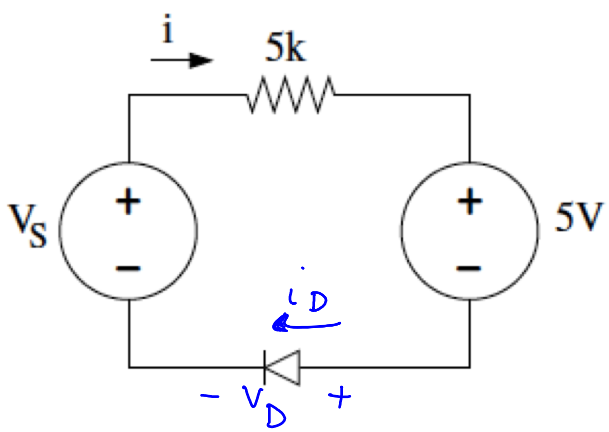
$\Rightarrow$ The assumption was correct. The diode is off. $i_D = 0$ and $V_D = -5V$.

$V_R = 2k\Omega \times i_D = 0\ V$

Clicker question 1.

For what range of v_s , will the diode in the following circuit be ON??

(Si diodes with $V_{D0} = 0.7\ V$)



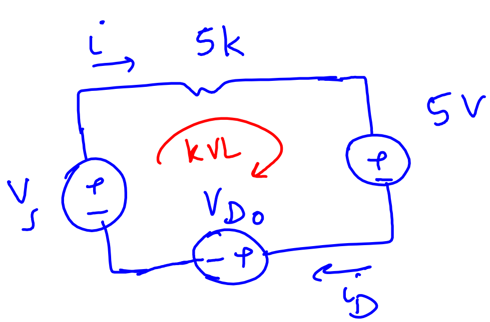
A. $v_s \geqslant 5$ V

B. $v_s \geq 5.7$ V

C. $v_s \geqslant 4.3$ V

Diode ON : $V_D = V_{D_0}$, $\boxed{i_D \geqslant 0}$

replacing the diode with the constant voltage drop model:



KVL : $-V_s + 5k\Omega \times i + 5V + V_{D_0} = 0$

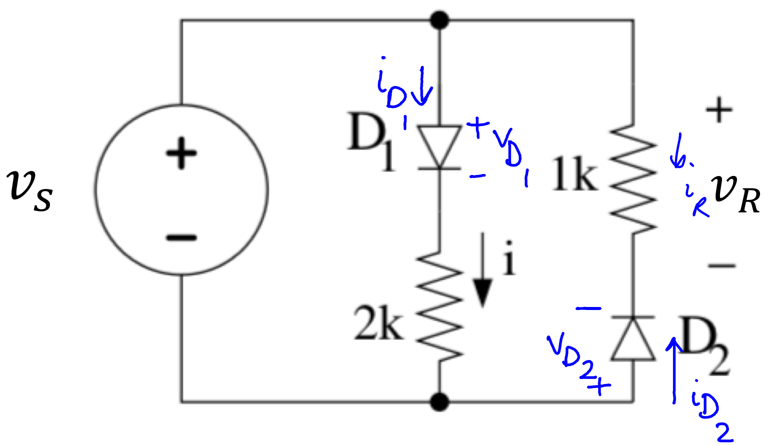
$\Rightarrow i = i_D = \dfrac{V_s - 5.7}{5k\Omega} \geqslant 0$

$\rightarrow V_s \geqslant 5.7V$

Clicker question 3.

Find v_R and i in the below circuit for $v_s = 3V$.

(Assume Si diodes with $V_{D0} = 0.7\ V$)



A. $v_R = 2.3\ V, \quad i = 1.15\ mA$

B. $v_R = 0\ V, \quad i = 1.15\ mA$

C. $v_R = 0.6\ V, \quad i = 0.3\ mA$

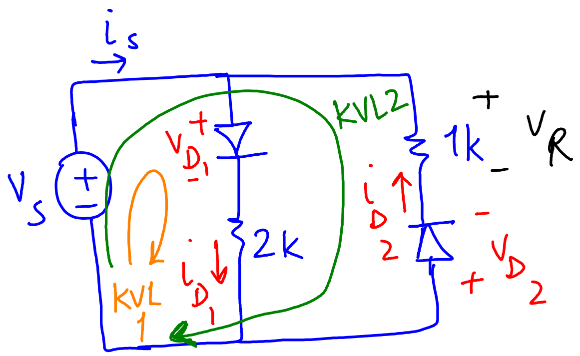
A. $v_R = -2.3\ V, \quad i = 1.15\ mA$

$V_R = 1k\Omega \times i_R$

KCL: $i_R = -i_{D_2}$

$\rightarrow V_R = -1k\Omega \times i_{D_2}$

All the states for D_1 and D_2:



D_1	D_2	
ON	OFF	case 1
OFF	OFF	case 2
ON	ON	case 3
OFF	ON	case 4

Case 1: Assume D_1 is ON and D_2 is OFF

$V_{D_1} = V_{D_0}$ & $i_{D_1} \geq 0$ & $V_{D_2} < V_{D_0}$ & $i_{D_2} = 0$

KVL 1: $-V_s + V_{D_1} + 2k \times i_{D_1} = 0 \longrightarrow -3V + 0.7V + 2k\Omega \times i_{D_1} = 0$

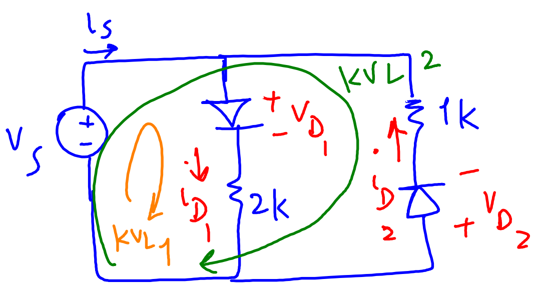
$\longrightarrow i_{D_1} = 1.15\ mA \geq 0$

KVL 2: $-V_s + 1k\Omega \times (-i_{D_2}) - V_{D_2} = 0 \longrightarrow -3V + 0 - V_{D_2} = 0 \longrightarrow V_{D_2} = -3V < 0.7V$

$i_{D_1} \geq 0$ and $V_{D_2} < V_{D_0} \longrightarrow$ the assumption was correct.

$V_R = -1k\Omega \times i_{D_2} = 0\,V \longrightarrow \boxed{V_R = 0\,V}$

Let's show that other cases are not valid.



Case 2: Assume D_1 is OFF and D_2 is OFF

$i_{D_1}=0$ & $V_{D_1} < V_{D_0}$ & $i_{D_2}=0$ & $V_{D_2} < V_{D_0}$

KVL1: $V_S = V_{D_1} + 2k \times i_{D_1} \longrightarrow V_{D_1} = V_S = 3V > V_{D_0} \longrightarrow$ Assumption was wrong

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Case 3: Assume D_1 and D_2 are ON

$V_{D_1} = V_{D_0}$ & $i_{D_1} \geq 0$ & $V_{D_2} = V_{D_0}$ & $i_{D_2} \geq 0$

KVL2: $V_S = -1k\Omega \times i_{D_2} - V_{D_2} \longrightarrow i_{D_2} = \dfrac{-3-0.7}{1k} = -3.7mA < 0 \longrightarrow$ Assumption was wrong

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Case 4: Assume D_1 is OFF and D_2 is ON

$V_{D_1} < V_{D_0}$ & $i_{D_1}=0$ & $V_{D_2} = V_{D_0}$ & $i_{D_2} \geq 0$

KVL1: $V_S = V_{D_1} + 2k \times i_{D_1} \longrightarrow V_{D_1} = V_S = 3V > V_{D_0} \longrightarrow$ Assumption was wrong