Introduction to Diode and Diode Logic Gates

Lecture 7

Course No: CSE 251

Course Title: Electronic Devices and Circuits

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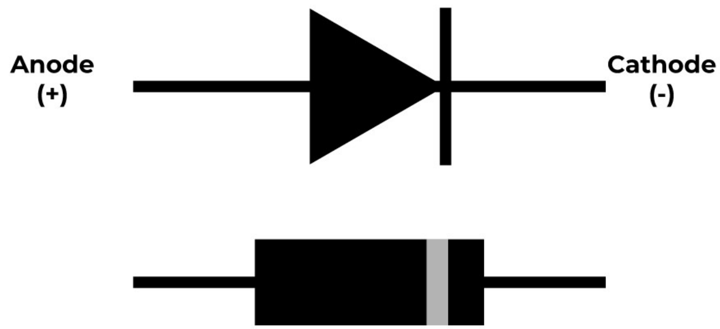
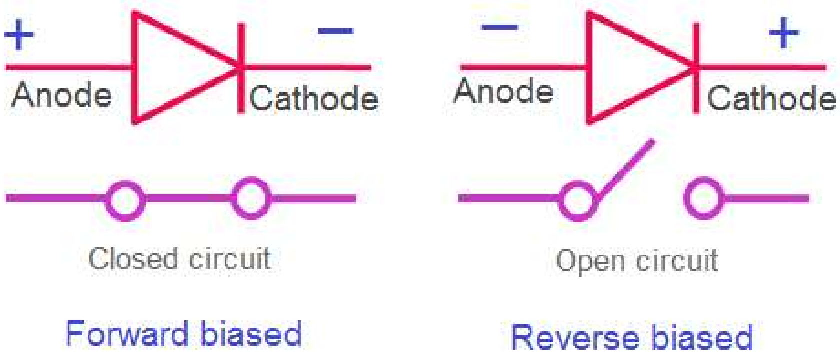
Introduction to Diode



- A two terminal Non-linear device. The two terminals are: Anode (+) and Cathode(-)
- The voltage difference between the terminals is expressed as, Vd= $V_{anode} - V_{cathode}$
- The working principle of a diode can be expressed with an “Electronic Valve”. It only allows the current to flow in one direction (From Anode to Cathode). This means the diode is “ON”/ in Forward Bias only when Vd is positive ($V_{anode} > V_{cathode}$). This property makes it suitable as a “Rectifier”

https://www.geeksforgeeks.org/diode/

Ideal diode model and IV characteristics



In the Ideal diode model, the following conditions are assumed:

i. $V_{anode}>V_{cathode}$:

-The Diode will be ON - It will act as a “Short circuit”

ii. $V_{anode}<V_{cathode}$:

-The Diode will be OFF

- It will act as a “Open circuit”

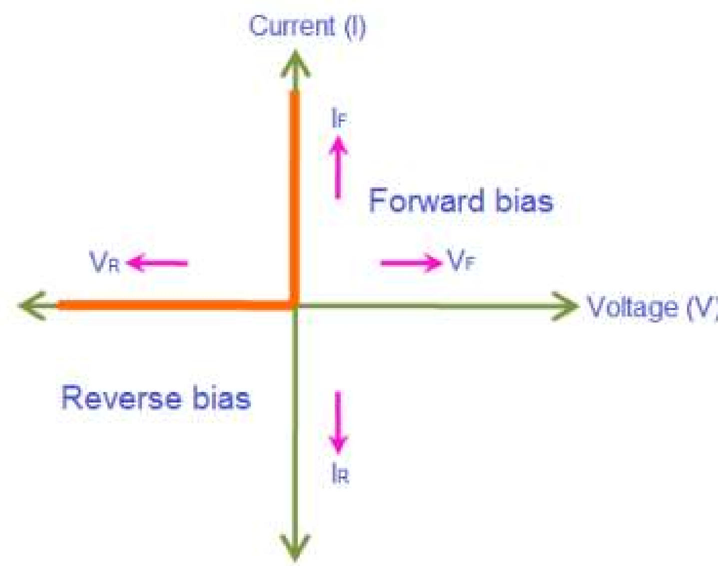


Fig: V-I characteristics of ideal diode

Open circuit→ I-V: x axis

Short Circuit→ I-V: y axis

Real Diode I-V

In the Real diode model, the following conditi
are assumed:

i. Vd>Vthreshold:

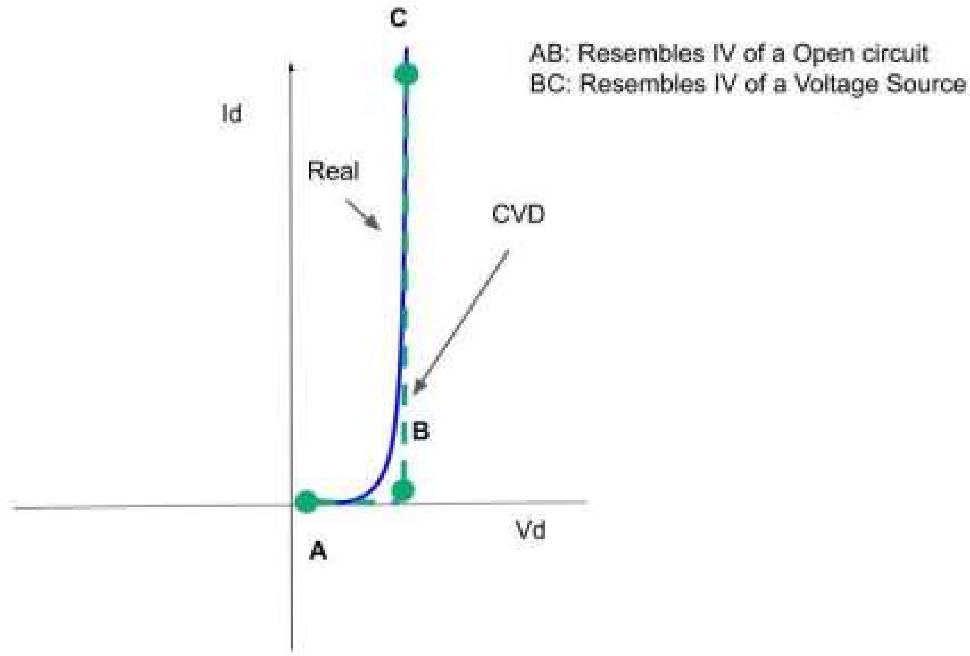
-The Diode will be ON

- It will act as a **“Constant Voltage Source”**

ii. Vd< Vthreshold:

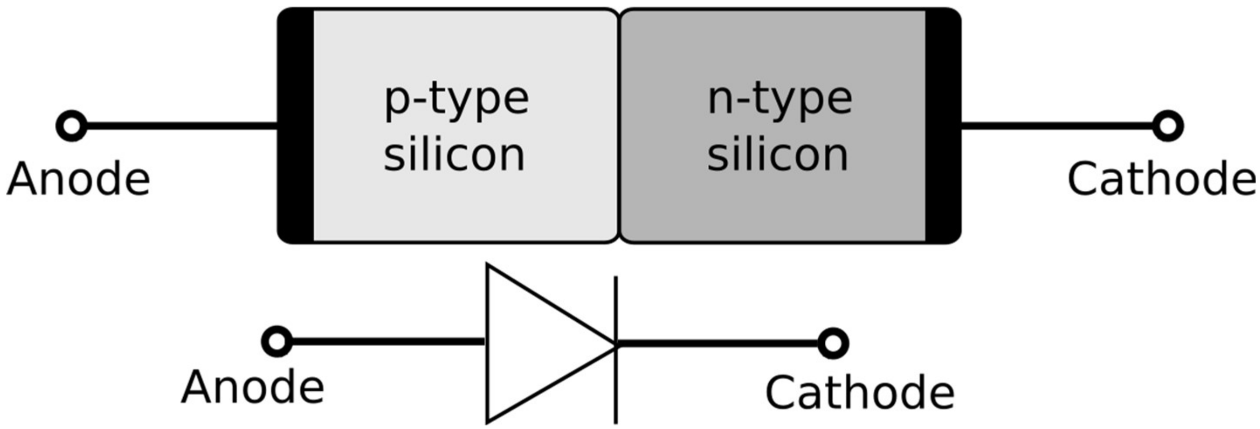
-The Diode will be OFF

- It will act as a **“Open circuit”**



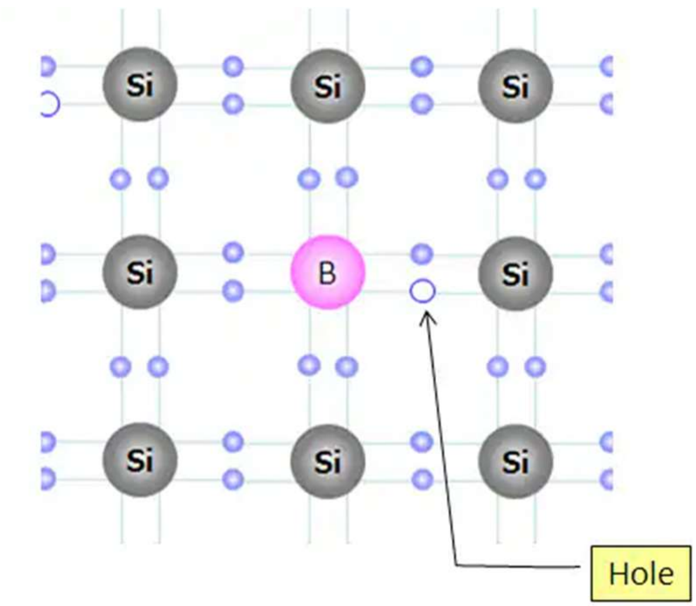
Open circuit→ I-V: x axis
Constant Voltage Source→ I-V: parallel to y axis

p-n junction Diode

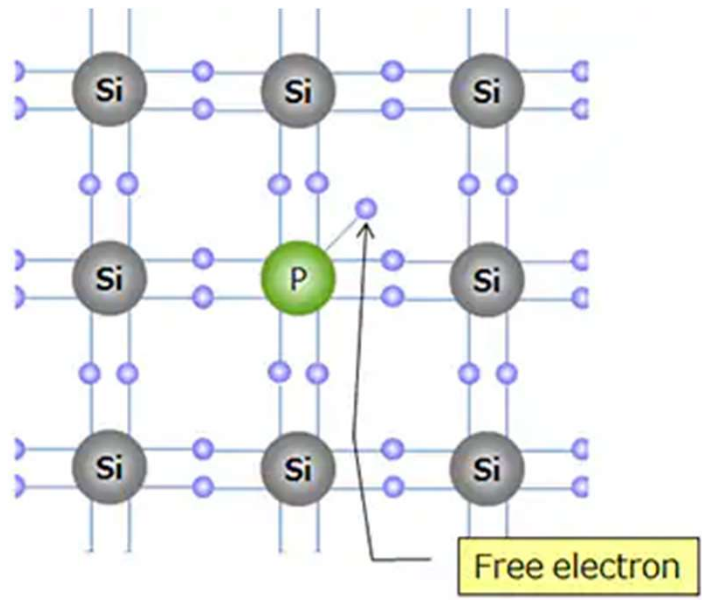


P-type semiconductor: When an intrinsic or pure semiconductor material (Like, Silicon (Si) and Germanium (Ge)) doped with acceptor impurities atom (Trivalent atoms, like Boron (B), Gallium (G), Aluminium(Al))
N-type semiconductor: When pure semiconductor doped with donor impurities (Pentavalent atoms, like Phosphorus (P), Arsenic (As), Antimony (Sb))

p, n type semiconductor



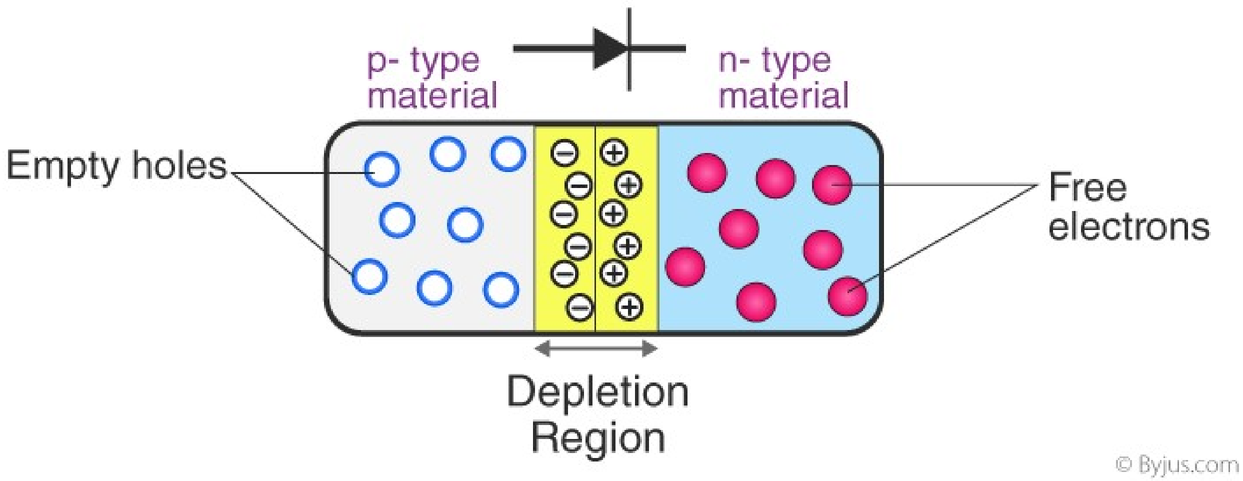
p- type



n- type

https://toshiba.semicon-storage.com/ap-en/semiconductor/knowledge/e-learning/discrete/chap1/chap1-4.html

p-n junction



Threshold voltage- for silicon about 0.7V
- for germanium about 0.3V.

https://byjus.com/physics/p-n-junction/

Shockley Diode Equation

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

k = 1.38 × 10^{-23} J/K is Boltzmann's constant and q = 1.60 × 10^{-19} C is the magnitude of the electrical charge of an electron. At a
temperature of 300 K, we have $V_T \cong 26\,\mathrm{mV}$

$$i_D = I_s\left[\exp\left(\frac{v_D}{nV_T}\right) - 1\right] \qquad V_T = \frac{kT}{q}$$

Where V_T is Thermal Voltage

Where I_S is reverse saturation current

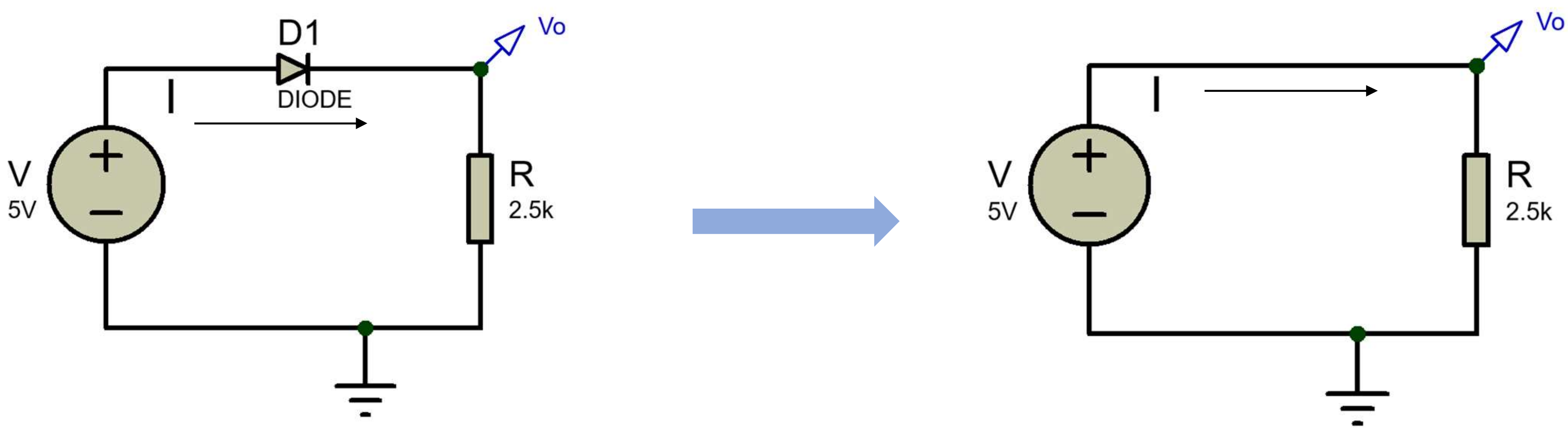
I_D and V_D are the diode current and voltage, respectively

q is the charge on the electron

n is the ideality factor:

Example Problems (Ideal Diode)

Example 1:

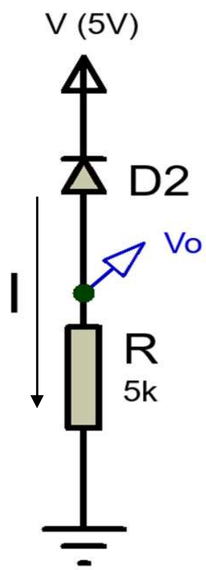


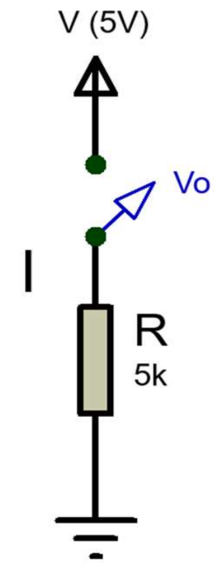
V_{anode}= 5V
Diode is on→ replace with short circuit (**Ideal Diode Model**)

Vo= V= 5V
I= Vo/R= 5V/2.5kΩ= 2 mA

Example Problems (Ideal Diode)

Example 2:



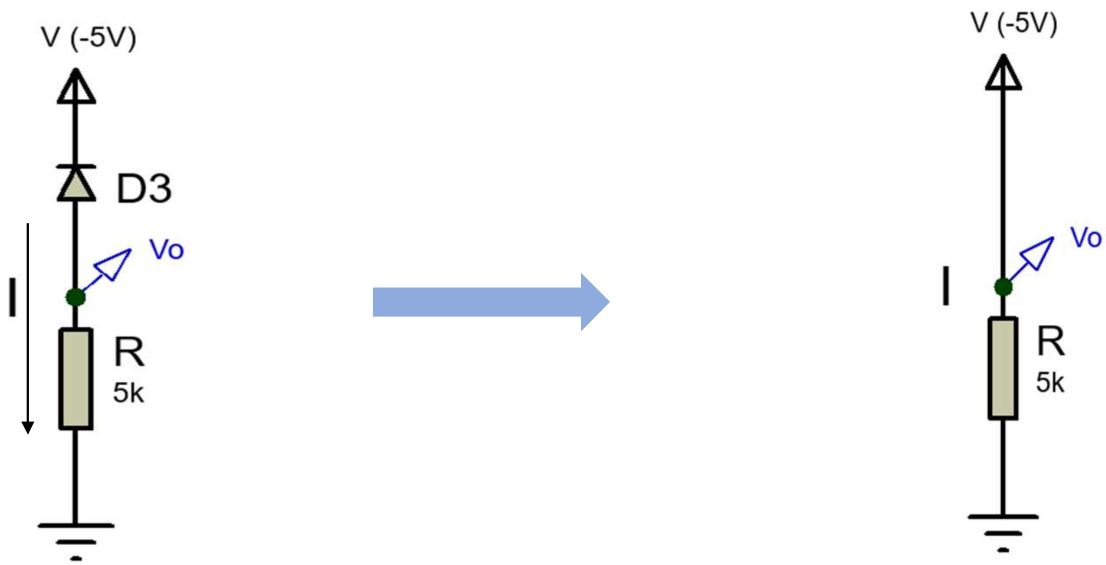


$V_{cathode}$= 5V
Diode is off→ replace with open circuit (Ideal Diode Model)

As the circuit is open, I= 0 mA
Vo= 0V

Example Problems (Ideal Diode)

Example 3:



$V_{cathode}$= -5V
Diode is on→ replace with short circuit (Ideal Diode Model)

Vo= -5V
I= Vo/R= -5V/5kΩ= -1 mA

Logical Operations with Diode (OR)

Logic Truth Table

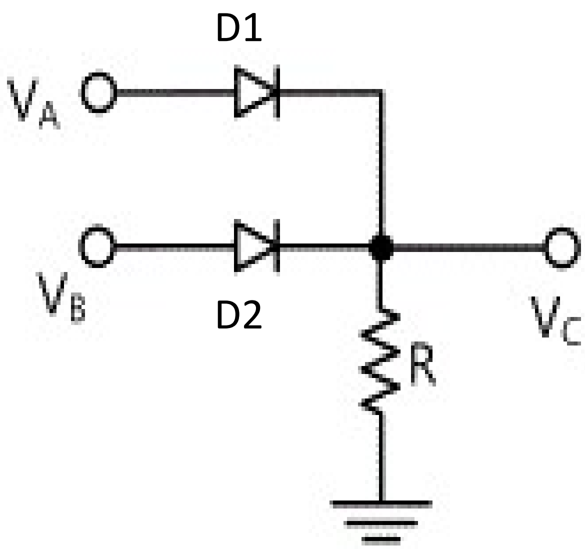
INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	1
1	0	1
1	1	1

Voltage Truth Table

INPUTS		OUTPUT
X	Y	Z
0 V	0 V	0 V
0 V	5 V	5 V
5 V	0 V	5 V
5 V	5 V	5 V

	Low/False	High/True
Logic Levels:	0	1
Corresponding voltage levels:	0V	5V

Logical Operations with Diode (OR)



V_A	V_B	V_C
0	0	0
0	5	5
5	0	5
5	5	5

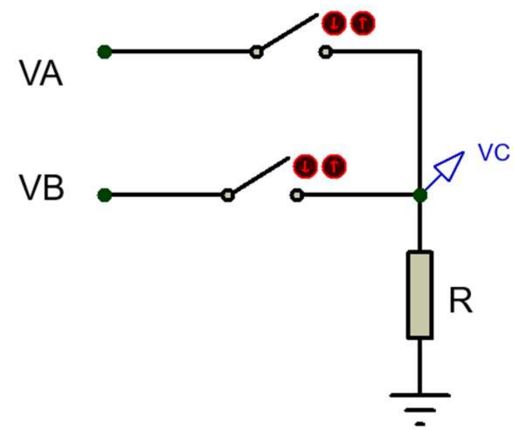
R is a **Pull Down Resistor** which pulls down the voltage of V_C from floating condition to 0V.

Case 1: V_A= 0V, V_B= 0V

Both D1 and D2 are off as V_{anode}<$V_{cathode}$

Replace D1 and D2 with open circuits.

So, V_C= 0V



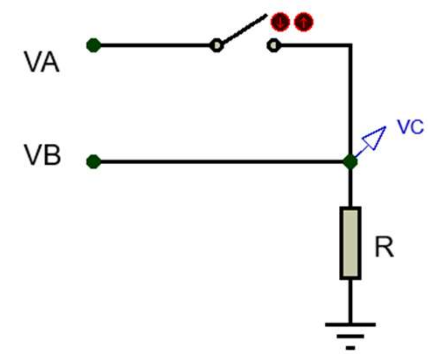
Logical Operations with Diode (OR)

Case 2: V_A= 0V, V_B= 5V

D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit.

So, V_C= V_B= 5V

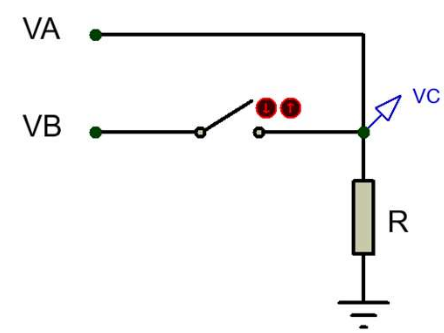


Case 3: V_A= 5V, V_B= 0V

D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit.

So, V_C= V_A= 5V

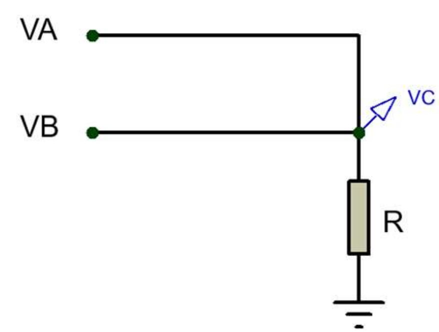


Case 1: V_A= 5V, V_B= 5V

Both D1 and D2 are on

Replace D1 and D2 with short circuits.

So, V_C= V_A= V_B= 5V



Logical Operations with Diode (AND)

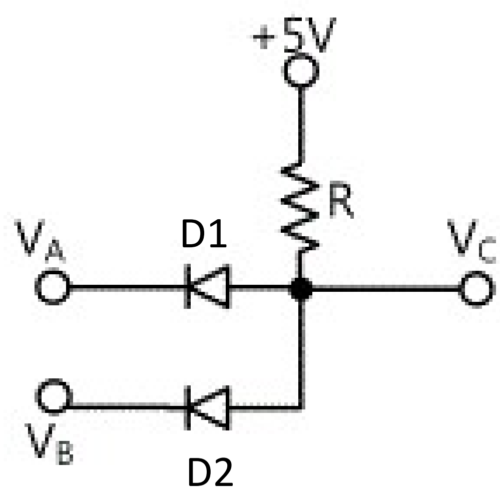
Logic Truth Table

INPUTS		OUTPUT
X	Y	Z
0	0	0
0	1	0
1	0	0
1	1	1

Voltage Truth Table

INPUTS		OUTPUT
X	Y	Z
0 V	0 V	0 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	5 V

Logical Operations with Diode (AND)



V_A	V_B	V_C
0	0	0
0	5	0
5	0	0
5	5	5

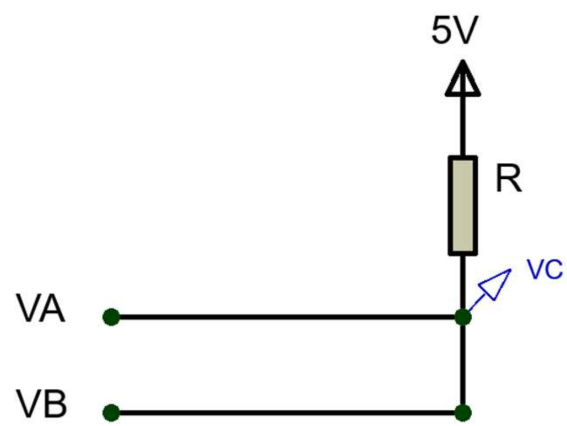
R is a **Pull Up Resistor** which pulls up the voltage of V_C from floating condition to 5V.

Case 1: V_A= 0V, V_B= 0V

Both D1 and D2 are on as V_{anode}>$V_{cathode}$

Replace D1 and D2 with short circuits.

So, , V_C= V_A= V_B= 0V



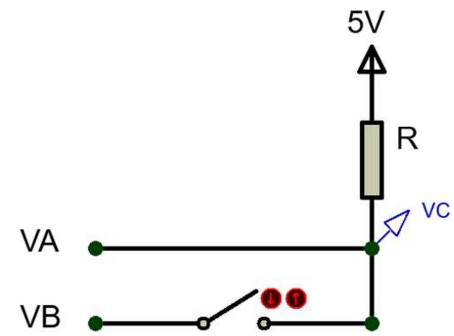
Logical Operations with Diode (AND)

Case 2: V_A= 0V, V_B= 5V

D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit.

So, V_C= V_A= 0V

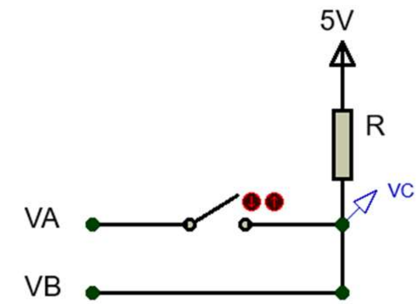


Case 3: V_A= 5V, V_B= 0V

D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit.

So, V_C= V_B= 0V

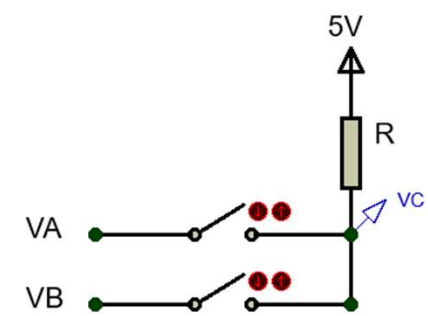


Case 1: V_A= 5V, V_B= 5V

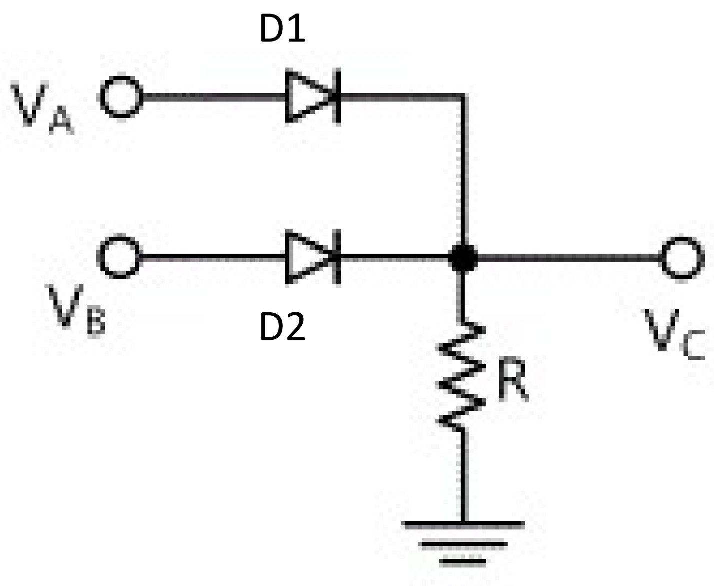
Both D1 and D2 are off

Replace D1 and D2 with open circuits.

So, V_C= 5V



Effect of input Voltage Variation in Logic Gates (OR)



If V_A= 4V and V_B= 5V, what is the value of output V_C?

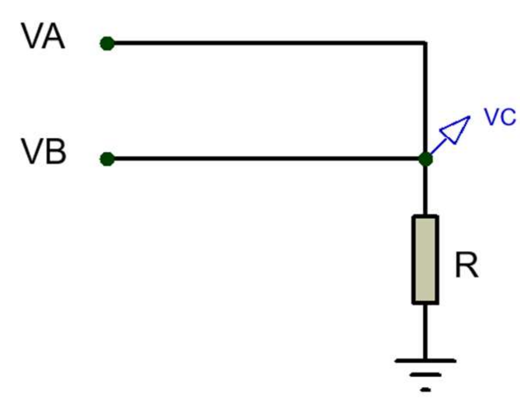
Case 1: Assuming both D1 and D2 are on

Replace D1 and D2 with short circuits.

So, V_C is short with both V_A and V_B

Can V_C be 4V and 5V at the same time???

So this assumption is wrong!



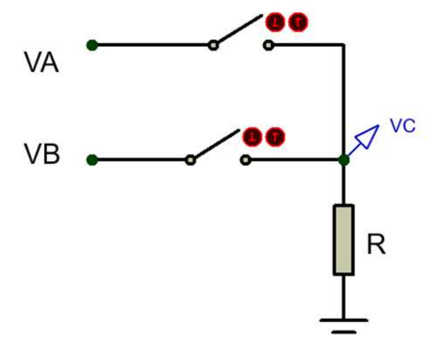
Effect of input Voltage Variation in Logic Gates (OR)

Case 2: Assuming both D1 and D2 are off

Replace D1 and D2 with open circuits. So, V_C= 0V

But now V_{anode}(4V for D1, 5V for D2)>$V_{cathode}$(0V) for both diode

So this assumption is also wrong!

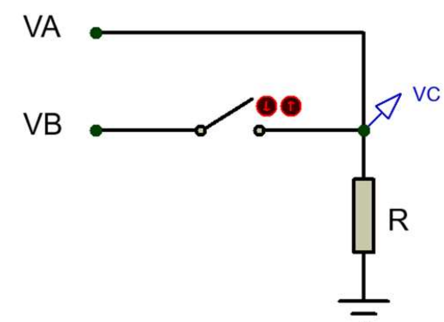


Case 3: Assuming D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit. So, V_C= V_A= 4V

But now for D2, V_{anode}(5V)>$V_{cathode}$(4V). So, D1 should have been ON!

So this assumption is also wrong!

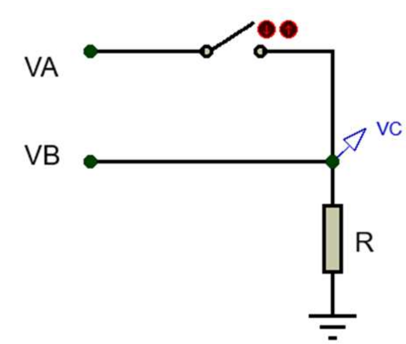


Case 4: Assuming D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit. So, V_C= V_B= 5V

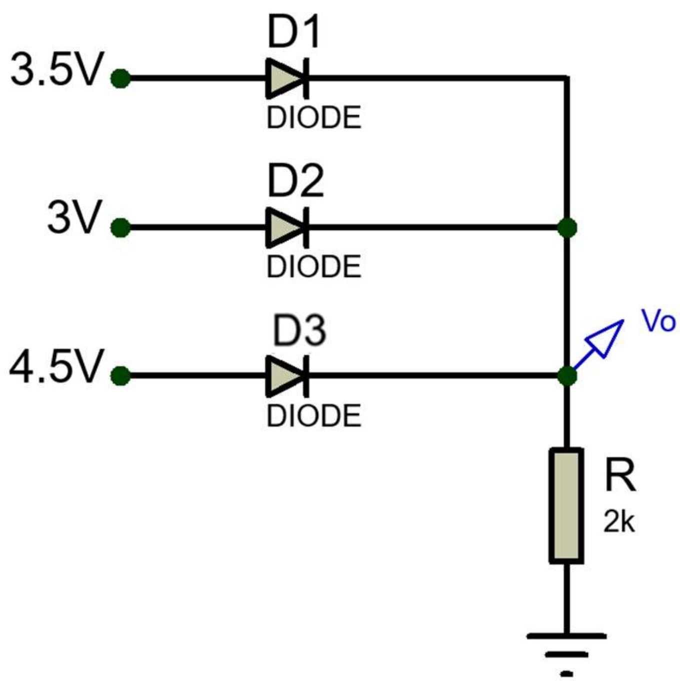
Now for D1, V_{anode}(4V)<$V_{cathode}$(5V). So, D1 should be **OFF!**

So this assumption is **correct!**



Effect of input Voltage Variation in Logic Gates (OR)

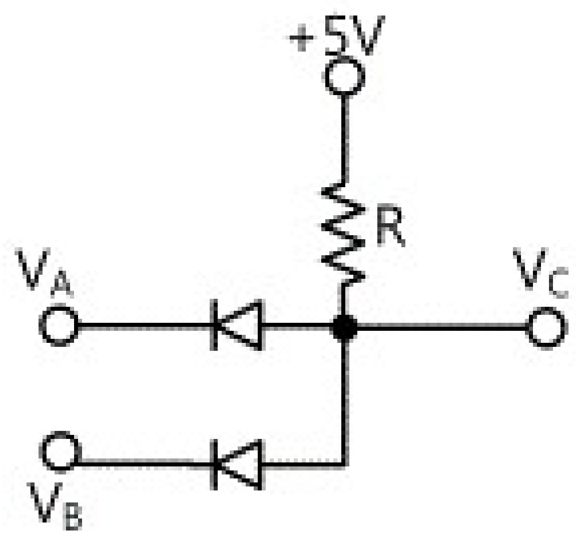
Example 4: Find the value of Vo



D1 and D2 are OFF → Open Circuit
Only D3 is ON → Short Circuit

Vo= 4.5V
Current, I= 4.5V/2kΩ= 2.25 mA

Effect of input Voltage Variation in Logic Gates (AND)



If V_A= 1V and V_B= 2V, what is the value of output V_C?

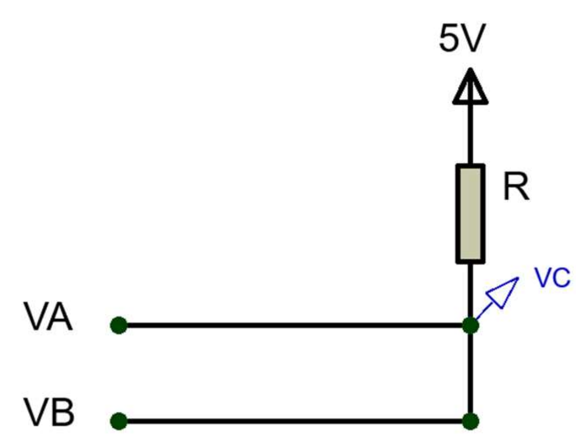
Case 1: Assuming both D1 and D2 are on

Replace D1 and D2 with short circuits.

So, V_C is short with both V_A and V_B

Can V_C be 1V and 2V at the same time???

So this assumption is wrong!



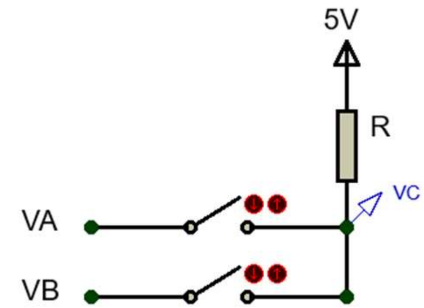
Effect of input Voltage Variation in Logic Gates (AND)

Case 2: Assuming both D1 and D2 are off

Replace D1 and D2 with open circuits. So, V_C= 5V

But now V_{anode}(5V)>$V_{cathode}$(1V for D1 & 2V for D2) for both diode

So this assumption is also wrong!

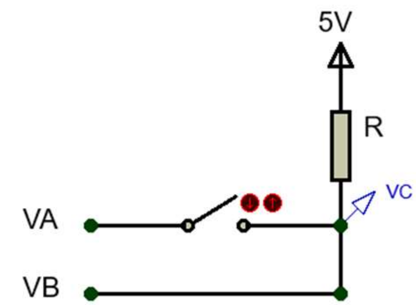


Case 3: Assuming D1 is off and D2 is on

Replace D1 with open circuit and D2 with short circuit. So, V_C= V_B= 2V

But now for D1, V_{anode}(2V)>$V_{cathode}$(1V). So, D1 should have been ON!

So this assumption is also wrong!

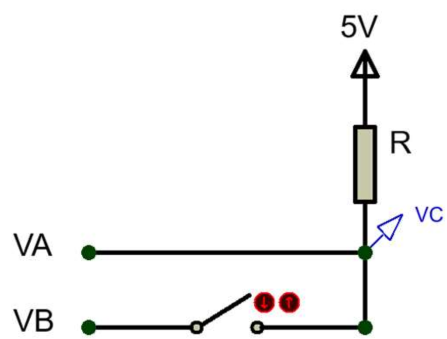


Case 4: Assuming D1 is on and D2 is off

Replace D1 with short circuit and D2 with open circuit. So, V_C= V_A= 1V

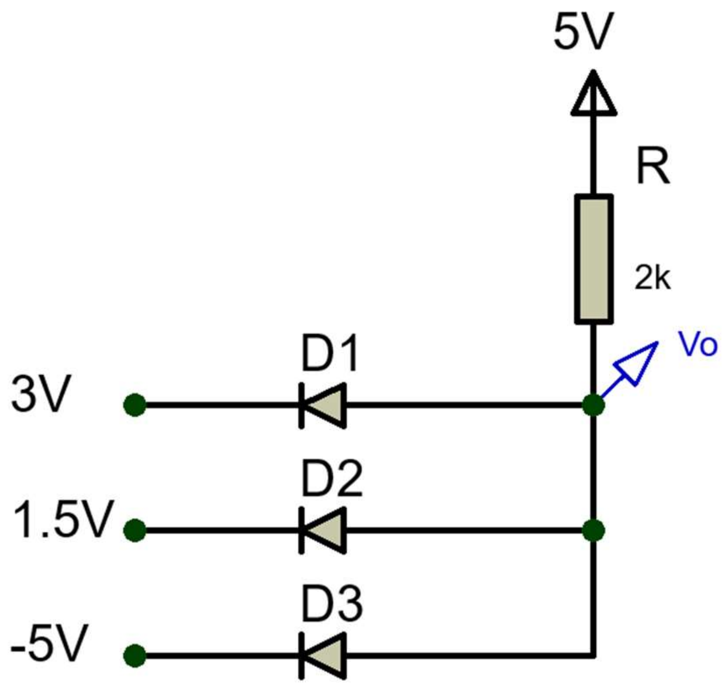
Now for D2, V_{anode}(1V)<$V_{cathode}$(2V). So, D2 should be **OFF!**

So this assumption is **correct!**



Effect of input Voltage Variation in Logic Gates (AND)

Example 5: Find the value of Vo



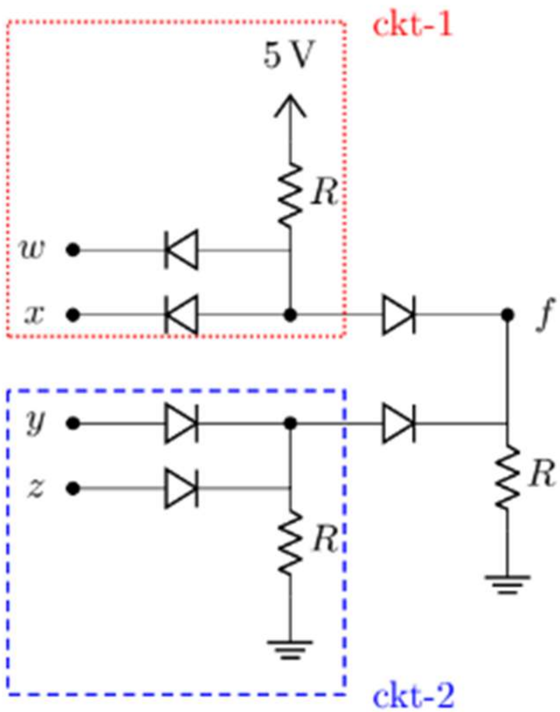
D1 and D2 are OFF → Open Circuit
Only D3 is ON → Short Circuit

Vo= -5V

Current, $I = \frac{5V-(-5\ \ )}{2k\Omega}$ = 5 mA

Example

Assuming w, x, y, z are Boolean variables, analyze the circuits below to find an expression of *"f"* in terms of w, x, y, and z.



$$f = wx + y + z$$

w	x	y	z	f
3.5V	2V	1.5V	1V	

Practice

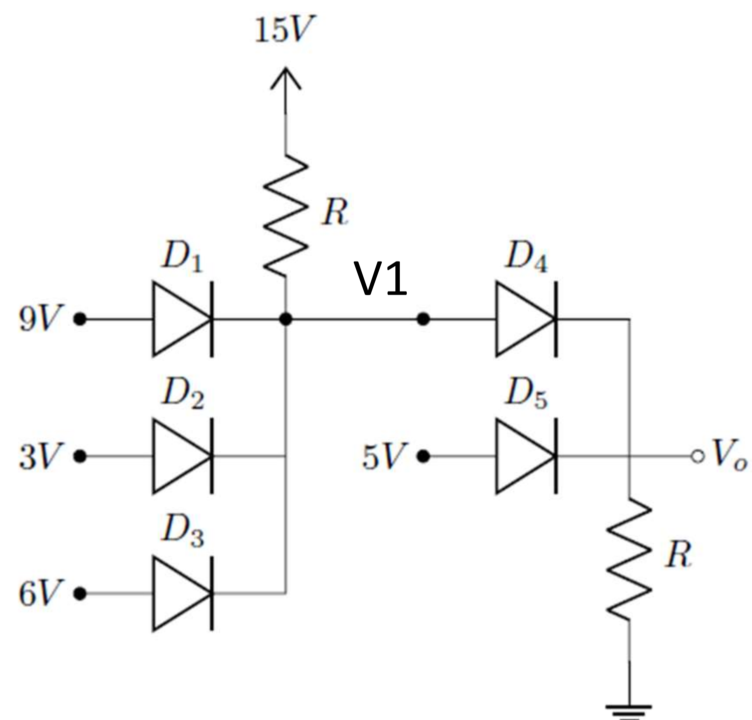
1. Implement $f = wx(y+z)$ with diode logic gates
2. Implement $f = xy+z+w$ with diode logic gates

Example

Determine Vo

Stage 1: AND gate

Stage 2: OR gate



Thank You