CSE251: Electronic Devices and Circuits

Diodes - 2

Prepared By:

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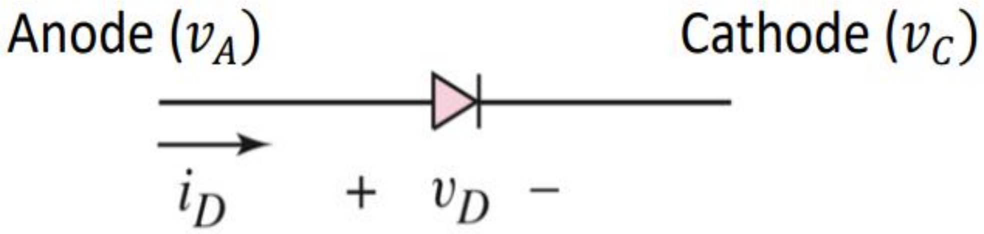
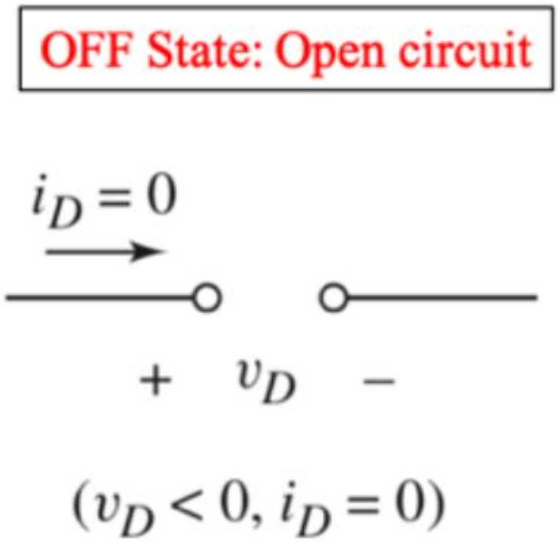
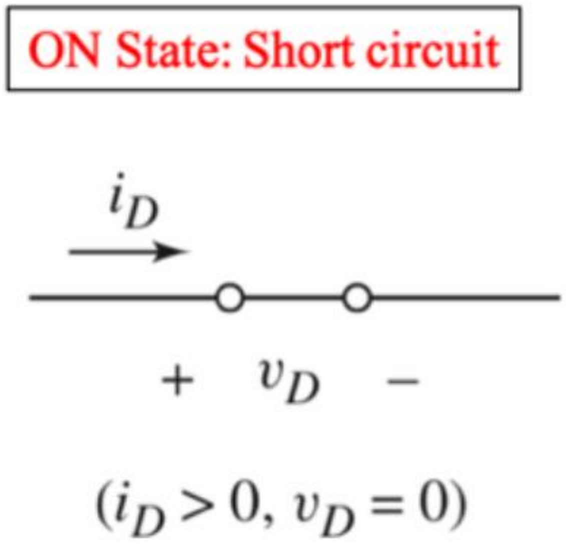
Topics Covered

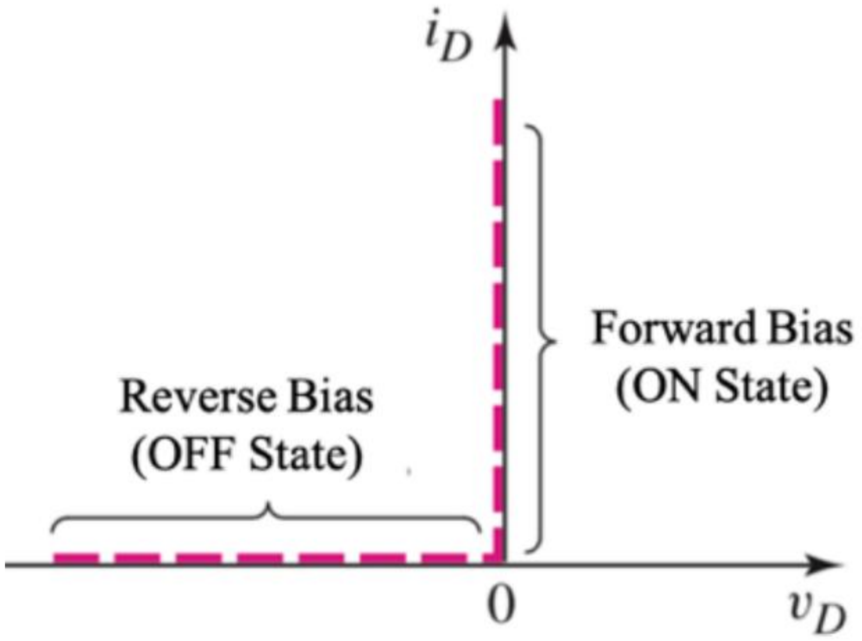
- **Diode Logic OR operation**
- **Diode Logic AND operation**
- **Diode Logic circuits and operation**
- Exponential Converter
- Logarithmic Converter
- Multiplier
- Divider

Review: Ideal Diode Model





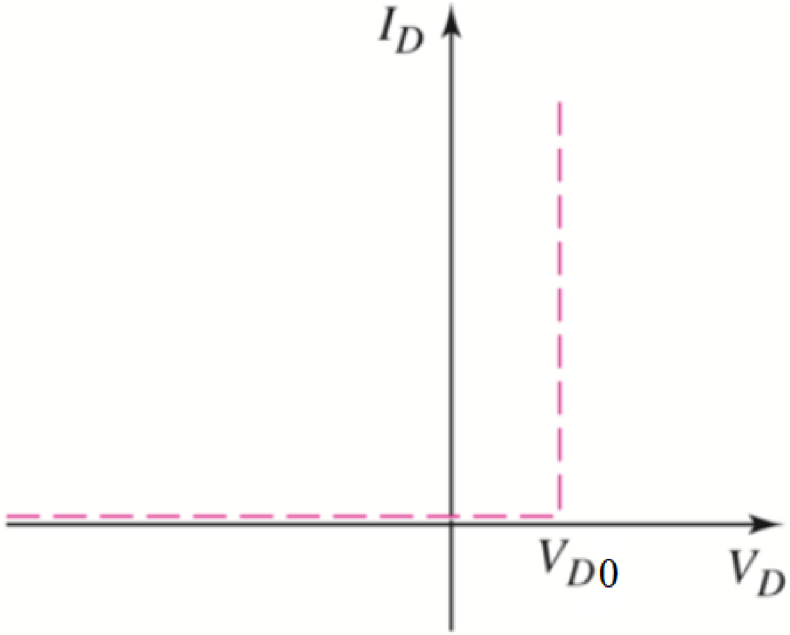




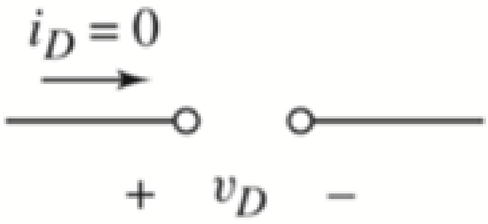
From Microelectronics: Circuit Analysis and Design by Donald A. Neamen: Chapter 2. 4th edition. Published by the McGraw-Hill Companies, Inc. Used for educational purposes only.

Modeling the real diode

1. Ideal diode model
2. **Constant voltage drop (CVD) model**
3. CVD+R model

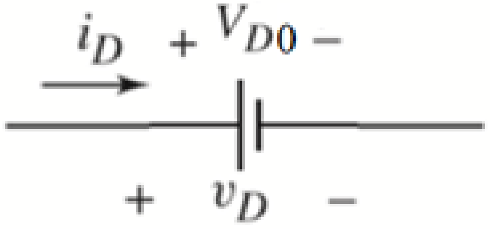


OFF State: Open circuit



$(v_D < V_{D0}, i_D = 0)$

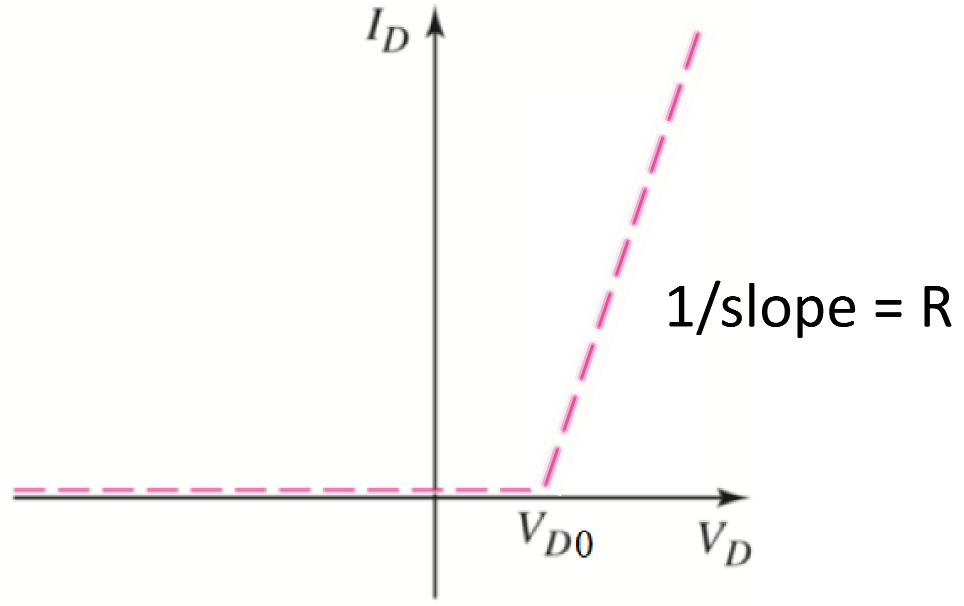
ON State: Voltage source

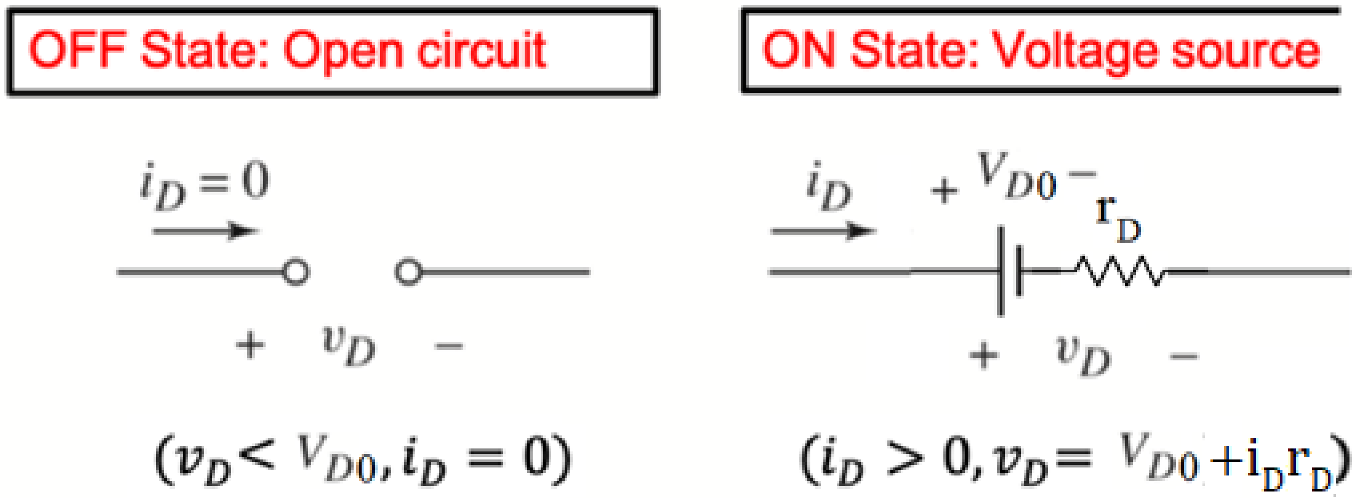


$(i_D > 0, v_D = V_{D0})$

Modeling the real diode

1. Ideal diode model
2. Constant voltage drop (CVD) model
3. **CVD+R model**





Digital Representation

- Binary → Two states (0/False, 1/True)
- Binary variables in circuit, need to use two states of device/parameters

Voltage	**Current**	**State**
5V → 1 0V → 0		

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

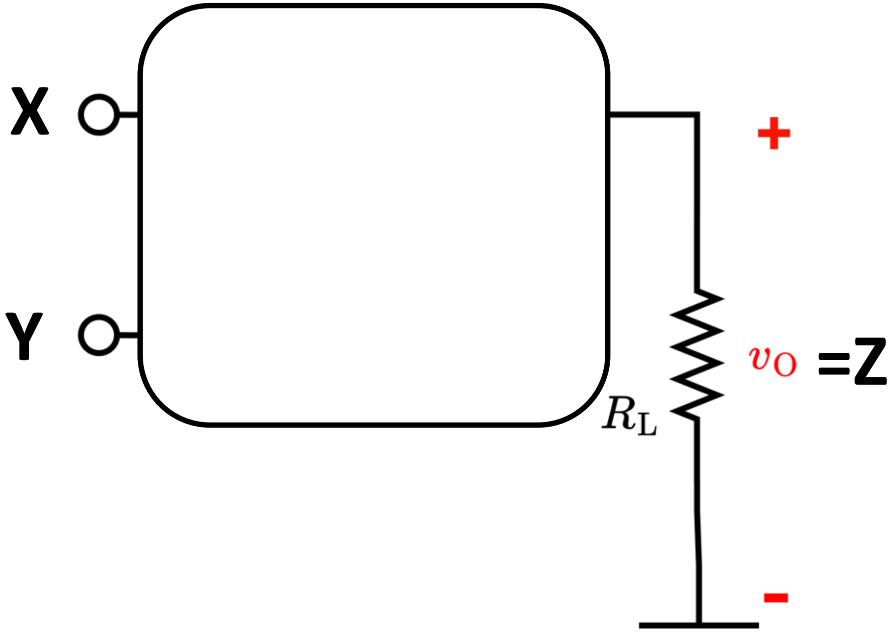
INPUTS		OUTPUT
X	Y	Z
0 V	0 V	0 V
0 V	5 V	5 V
5 V	0 V	5 V
5 V	5 V	5 V

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

Logical Operations with Diode (OR)

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



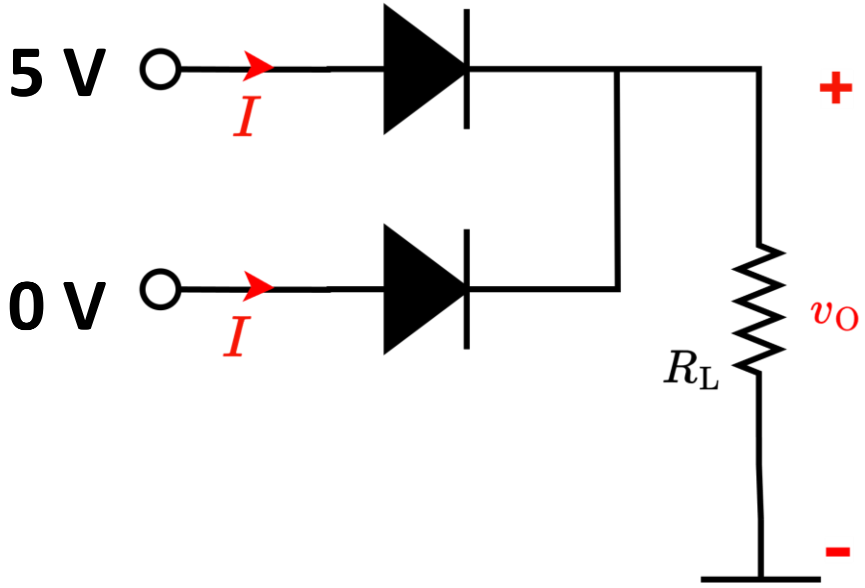
PULL DOWN NETWORK

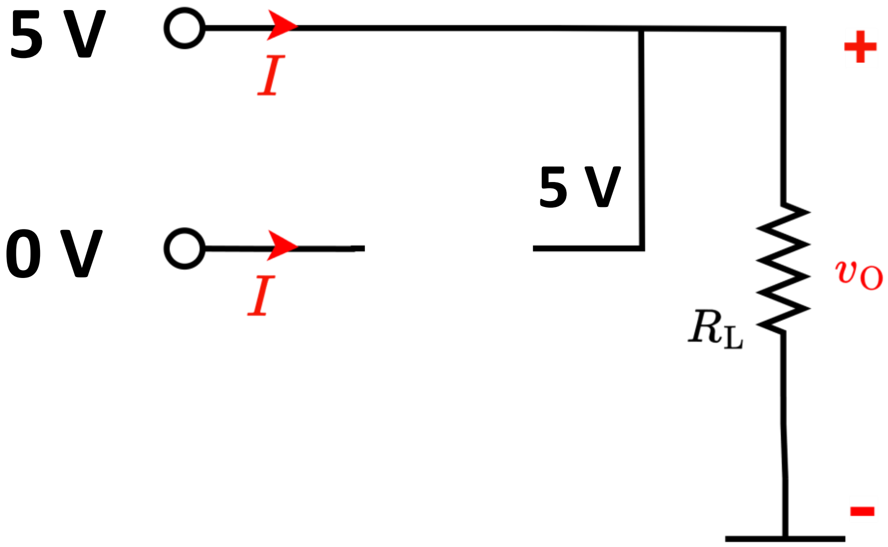
When all inputs are completely disconnected, v_O is pulled down to **GND**

Degrades the HIGHEST output voltage

Logical Operations with Diode (OR)

Ideal diode

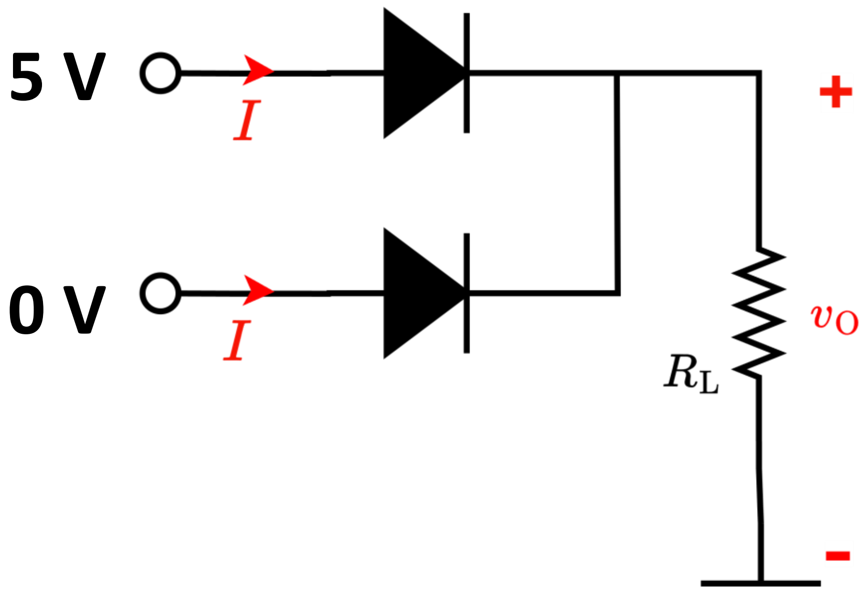


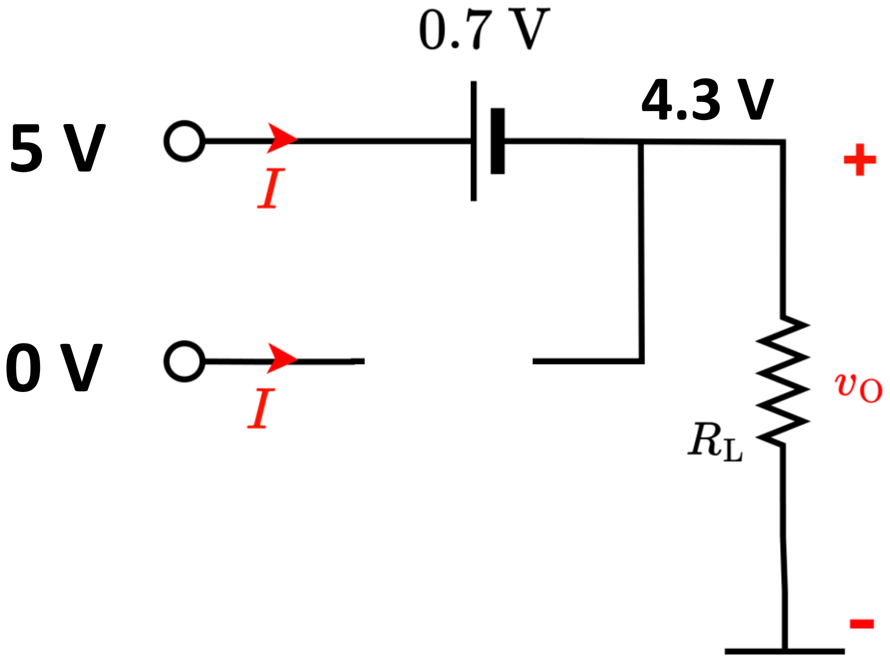


Z = 5 V

Logical Operations with Diode (OR)

CVD diode



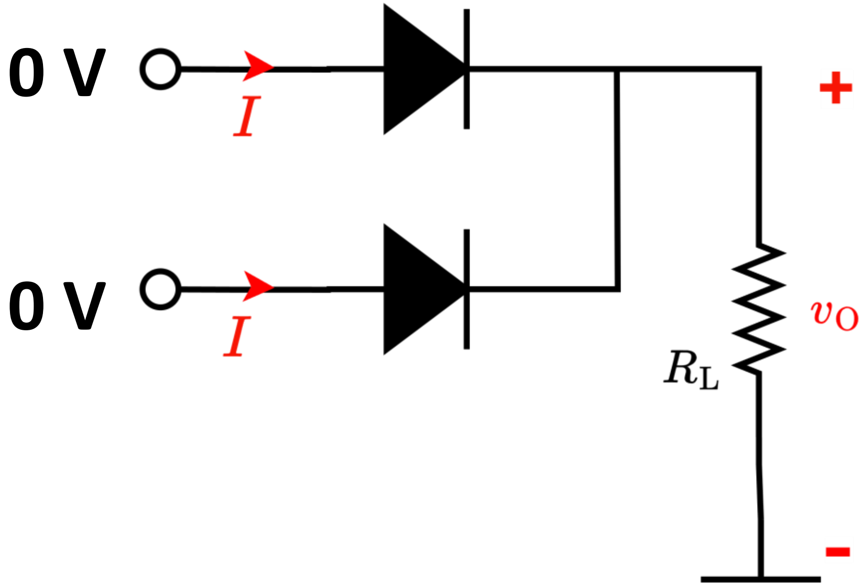


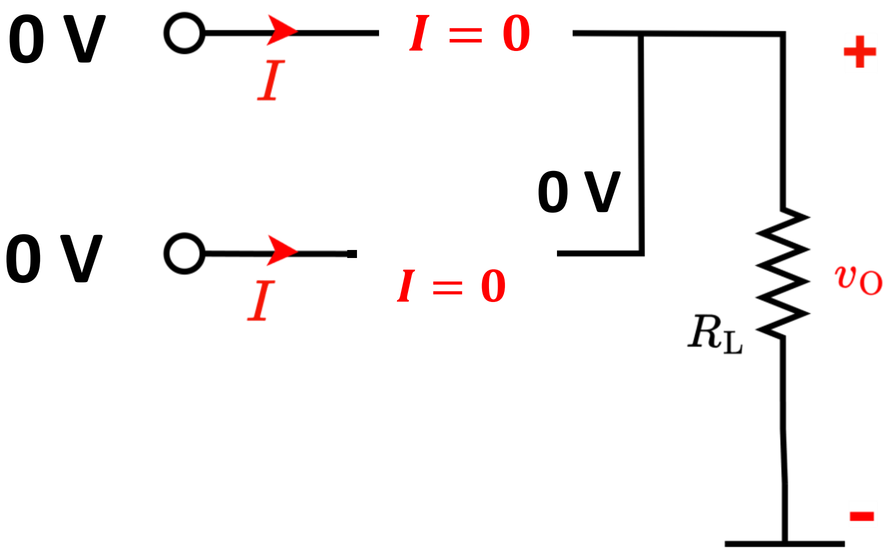
Z = 4.3 V

Degraded 5 V

Logical Operations with Diode (OR)

Ideal diode

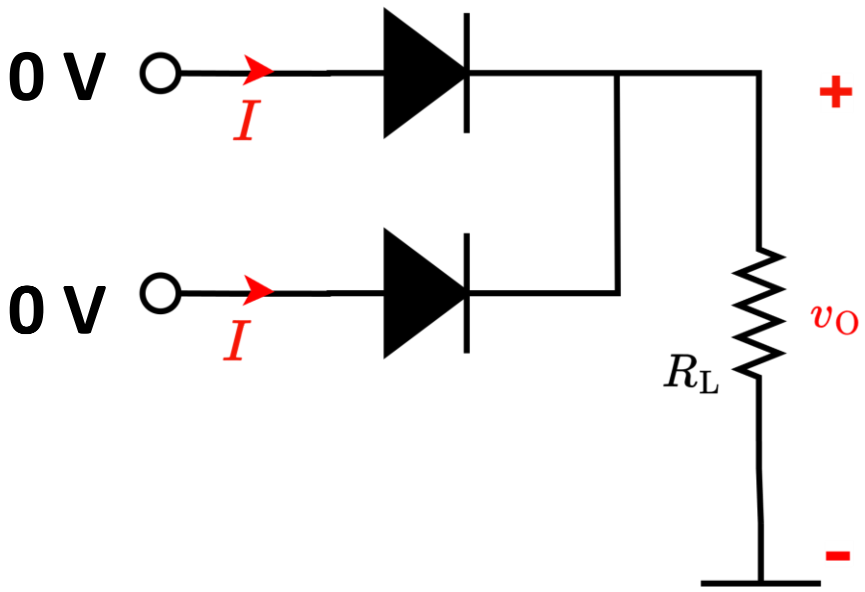


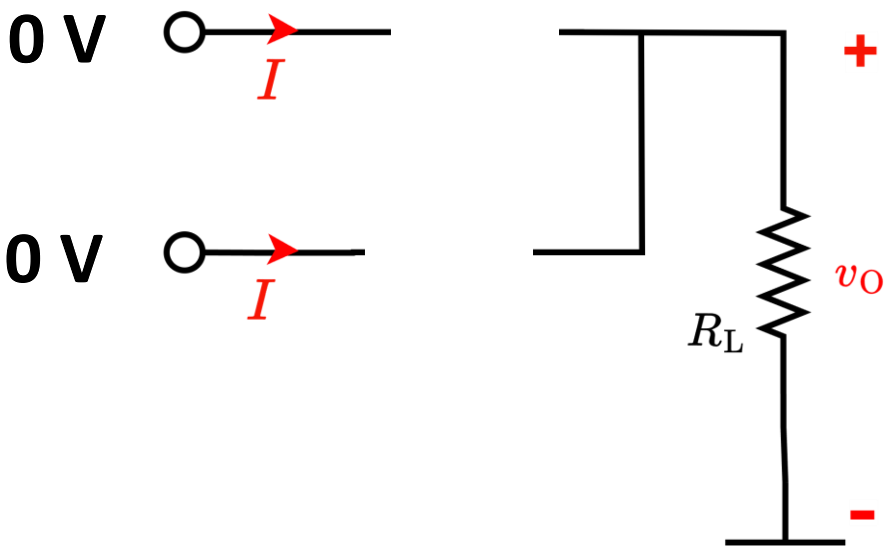


Z = 0 V

Logical Operations with Diode (OR)

CVD diode

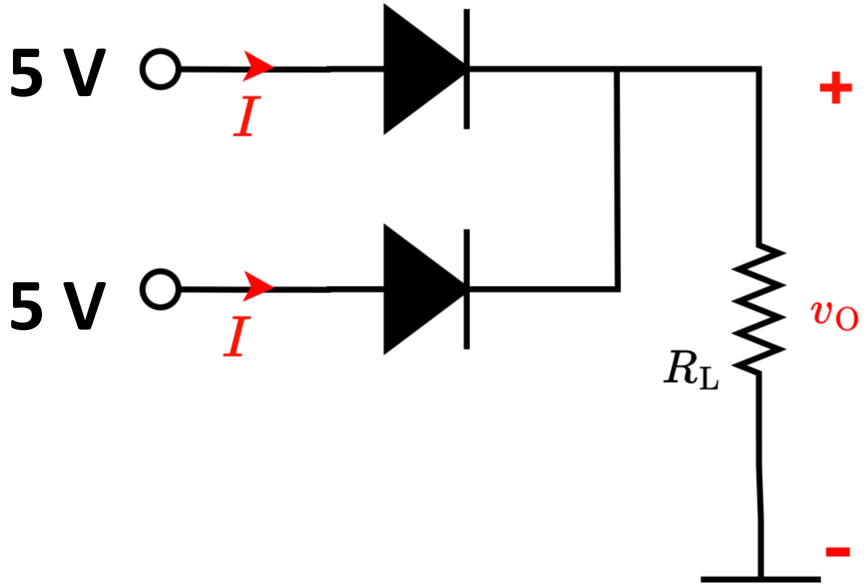


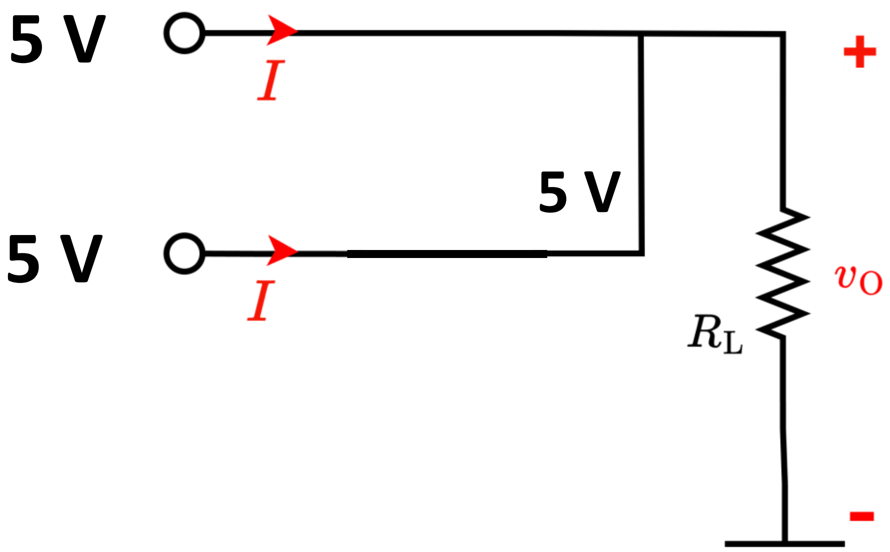


Z = 0 V

Logical Operations with Diode (OR)

Ideal diode

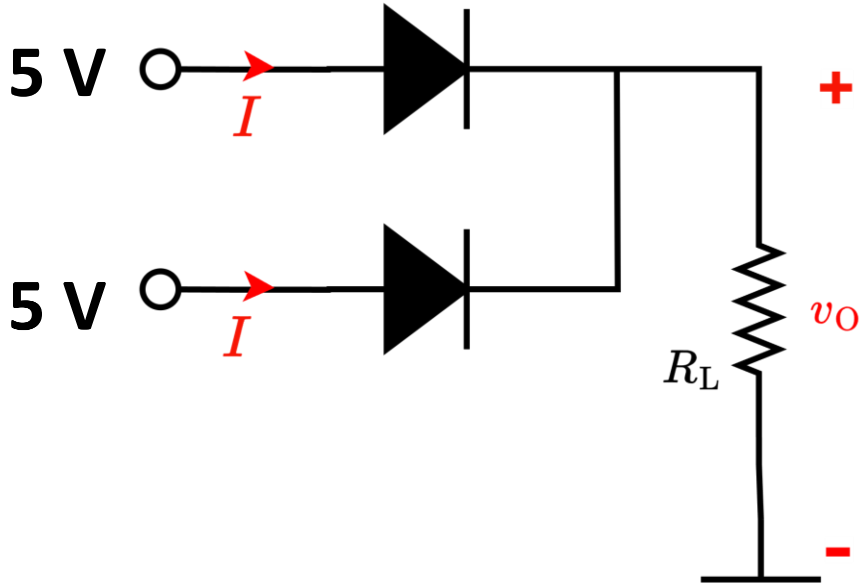


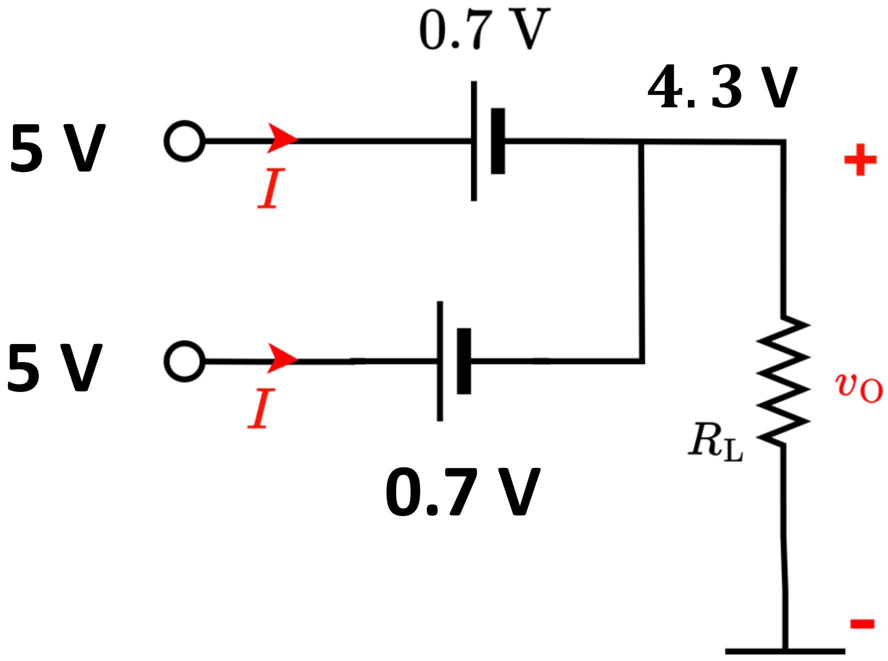


Z = 5 V

Logical Operations with Diode (OR)

CVD diode





Z = 4.3 V

Degraded 5 V

Both diodes have same V_{DO}

Logical Operations with Diode (OR)

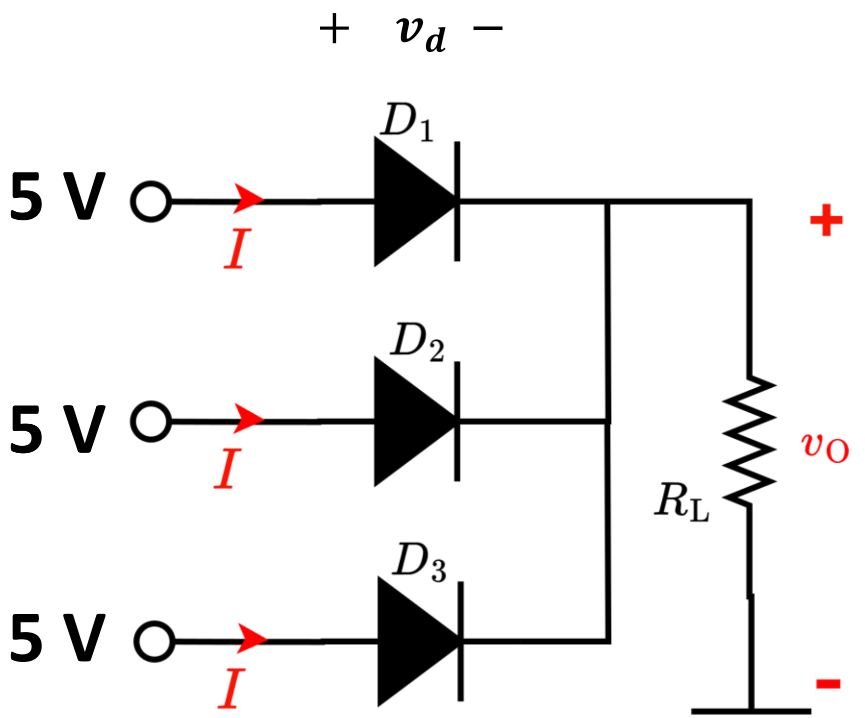
CVD diode

What if the diodes have different V_{DO}?

$$V_{D1} = 1\text{ V}$$

$$V_{D2} = 0.7\text{ V}$$

$$V_{D3} = 0.5\text{ V}$$



Logical Operations with Diode (OR)

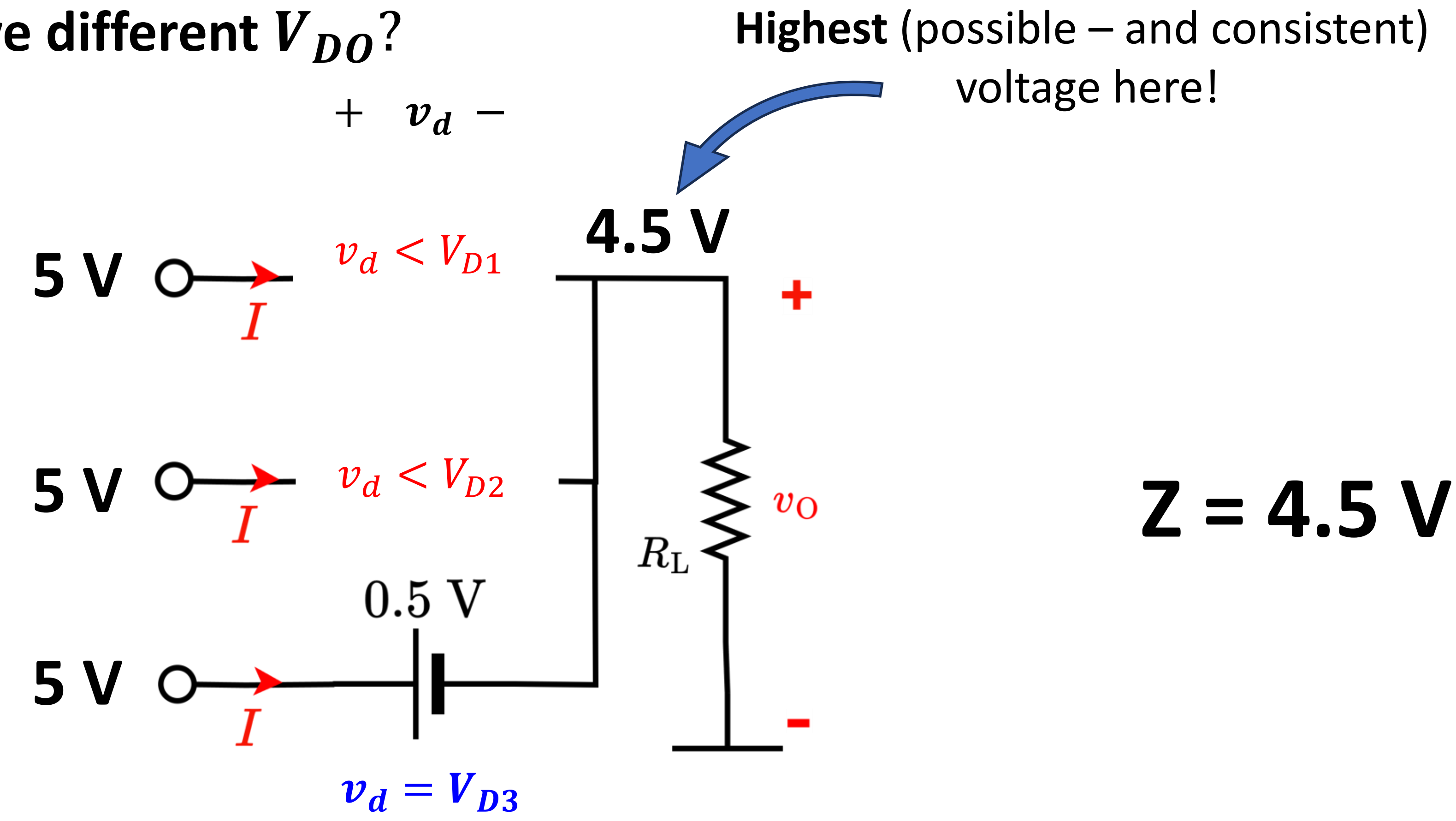
CVD diode

What if two diodes have different V_{DO}?

$V_{D1} = 1\text{ V}$

$V_{D2} = 0.7\text{ V}$

$V_{D3} = 0.5\text{ V}$



Z = 4.5 V

Logical Operations with Diode (OR)

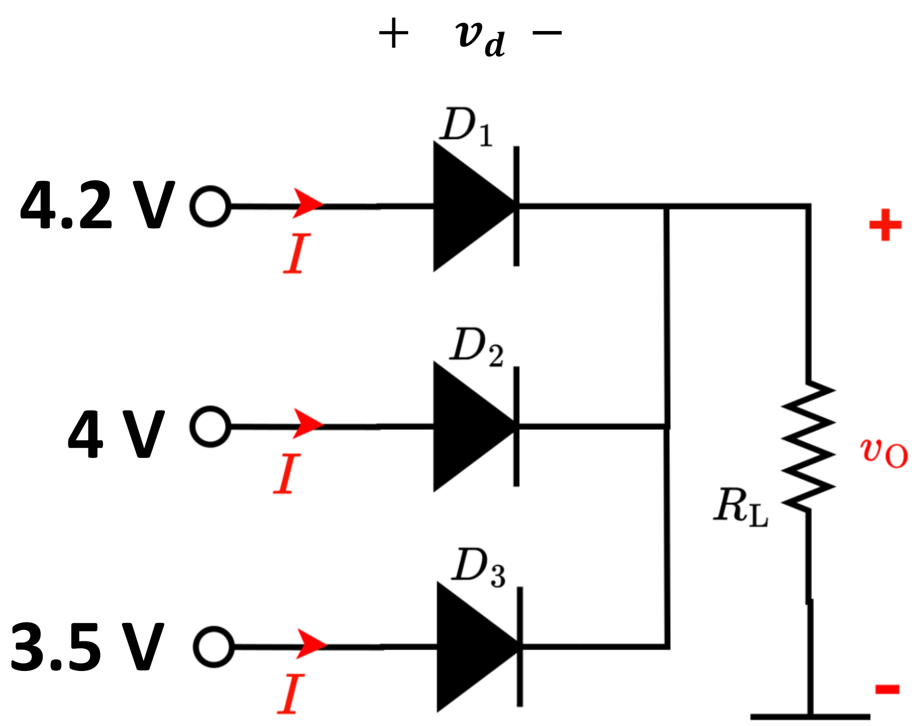
CVD diode

What if the input voltages are different?

$$V_{D1} = 1\text{ V}$$

$$V_{D2} = 0.7\text{ V}$$

$$V_{D3} = 0.5\text{ V}$$



Logical Operations with Diode (OR)

CVD diode

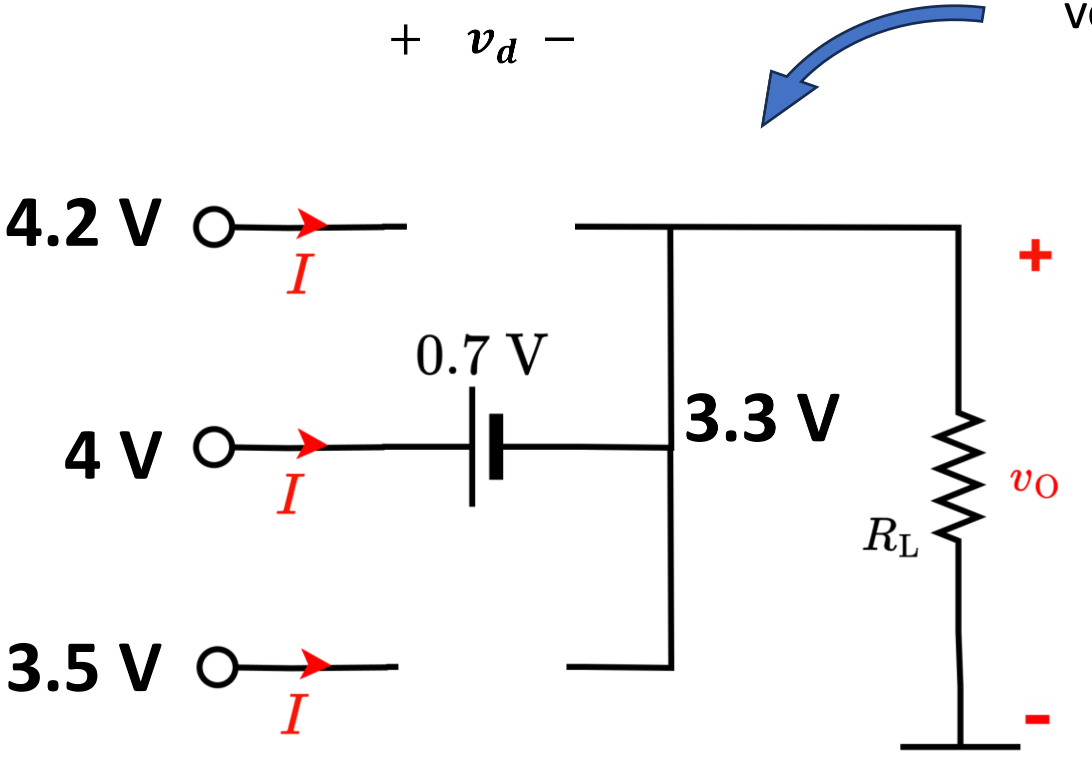
What if the input voltages are different?

Highest (possible – and consistent) voltage here!

$$V_{D1} = 1\ \text{V}$$

$$V_{D2} = 0.7\ \text{V}$$

$$V_{D3} = 0.5\ \text{V}$$



Z = 4.5 V

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

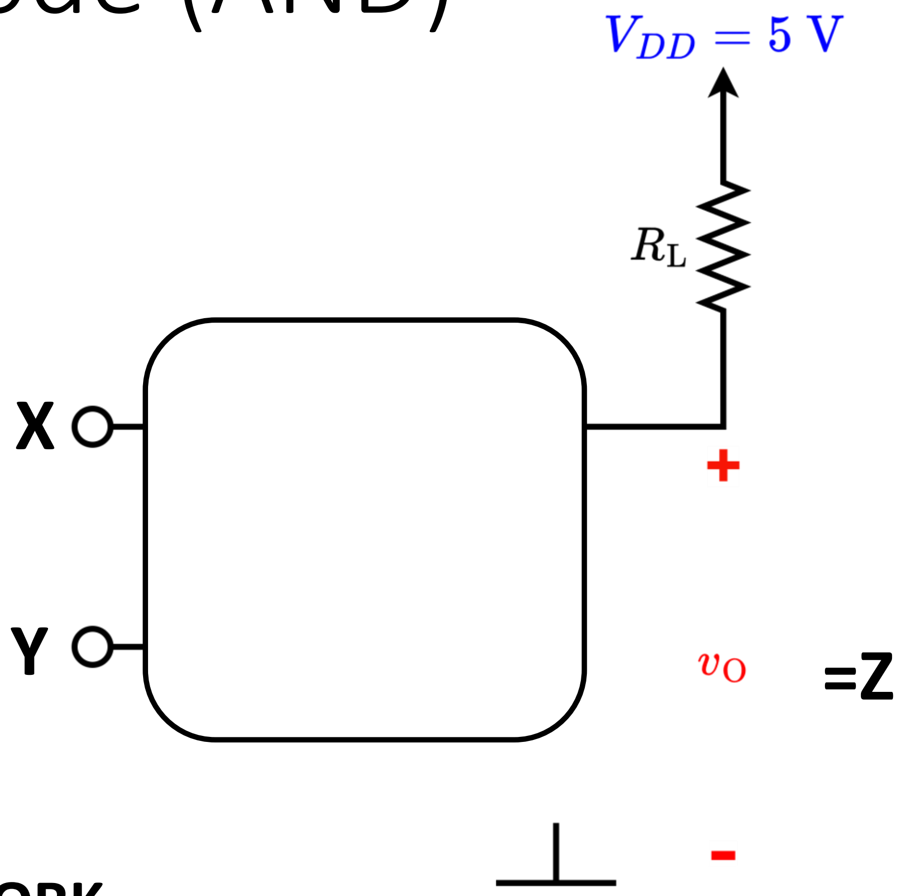
INPUTS		OUTPUT
X	Y	Z
0 V	0 V	0 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	5 V

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

Logical Operations with Diode (AND)

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



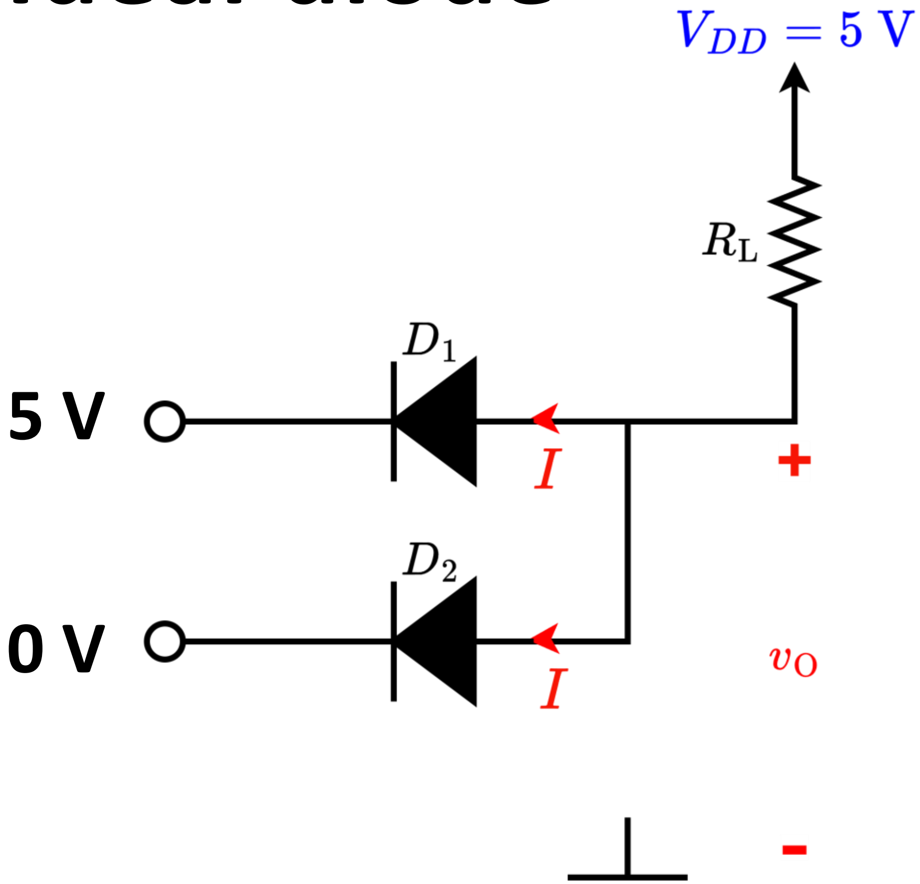
PULL UP NETWORK

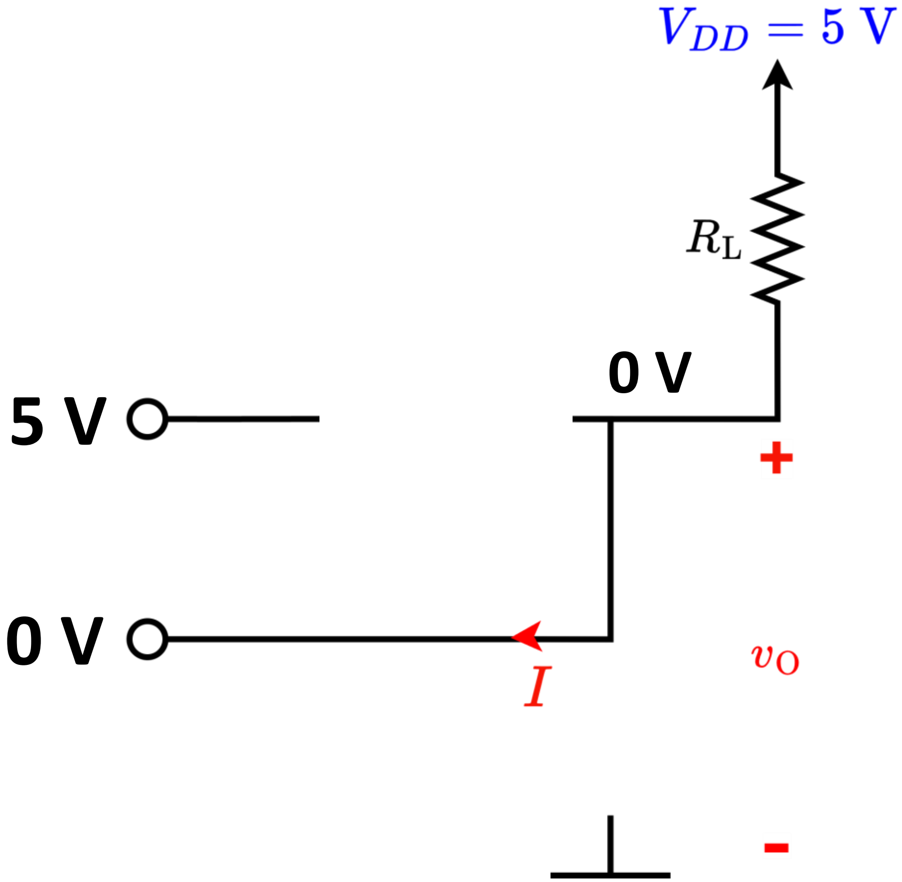
When all inputs are completely disconnected, $\boldsymbol{v_O}$ is <u>pulled up</u> to $\boldsymbol{V_{DD}}$

Degrades the <u>LOWEST</u> output voltage

Logical Operations with Diode (AND)

Ideal diode

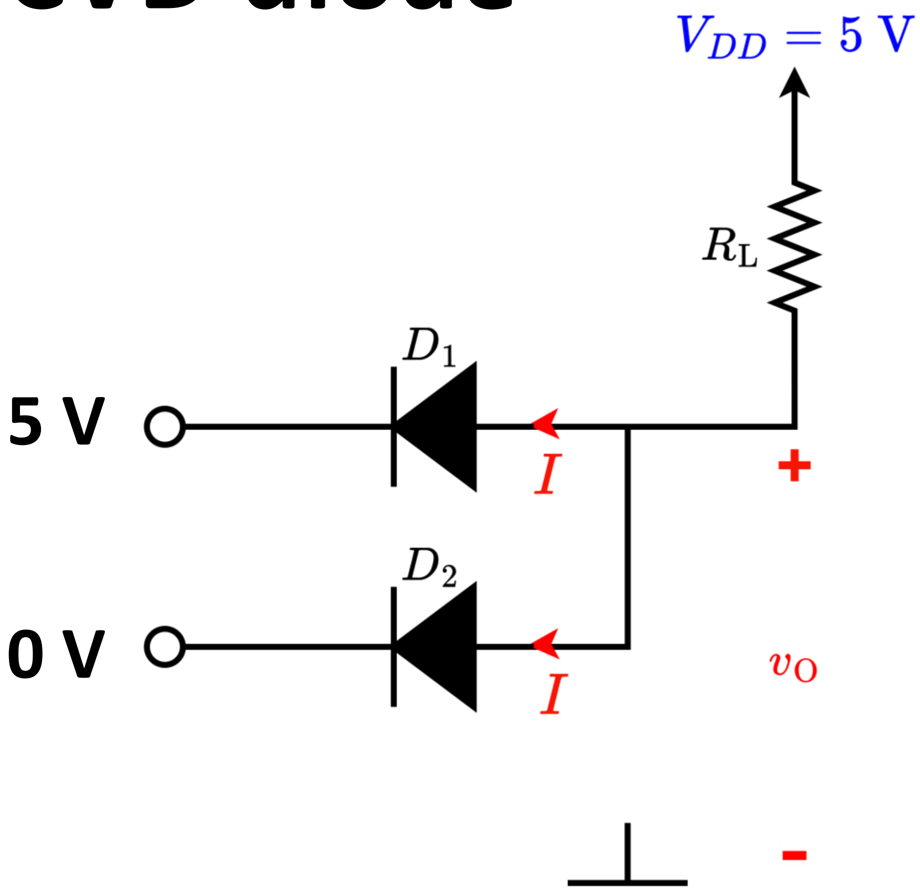




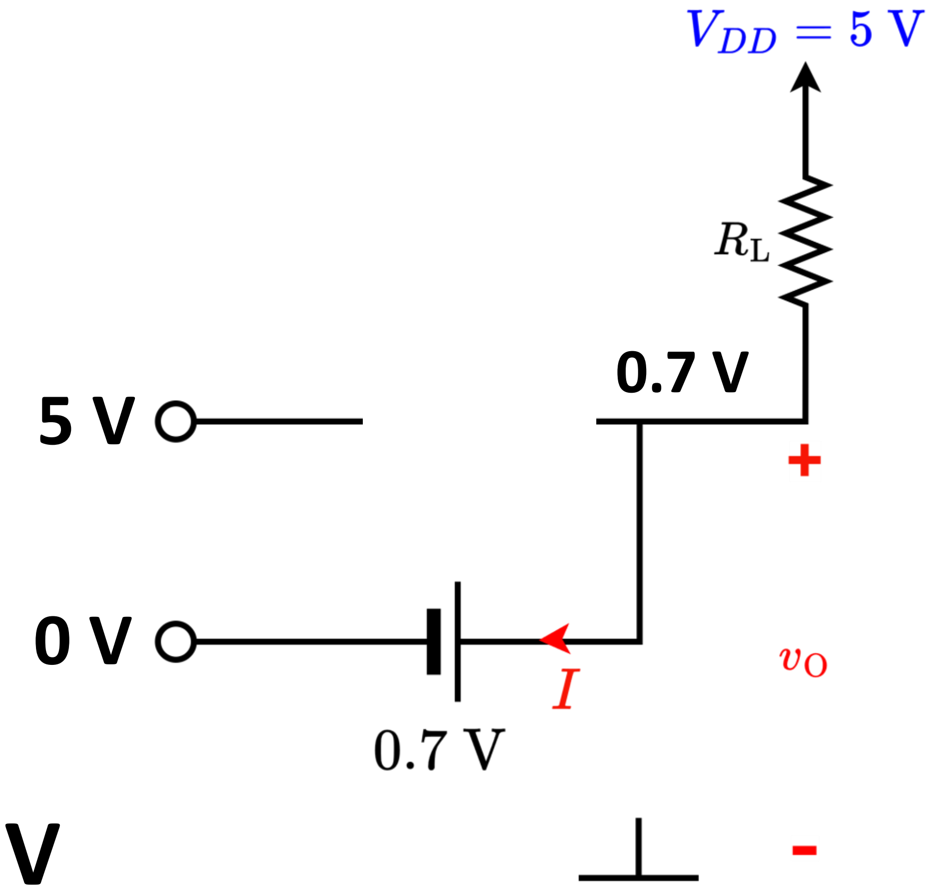
Z = 0 V

Logical Operations with Diode (AND)

CVD diode



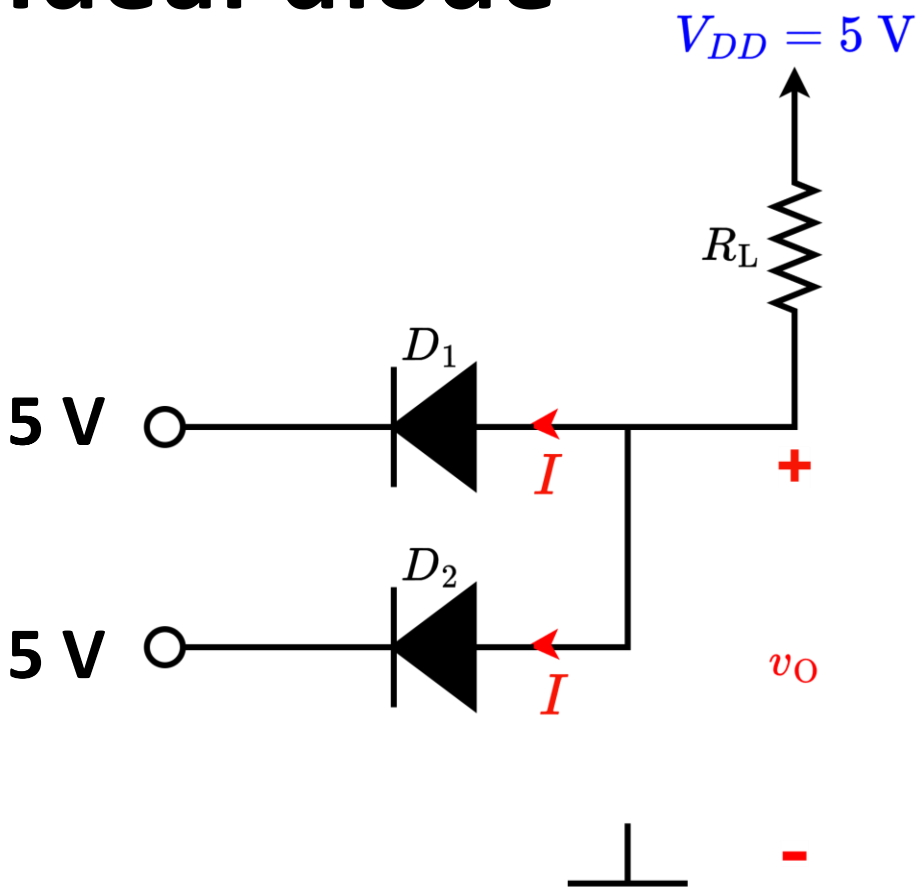
Z = 0.7 V

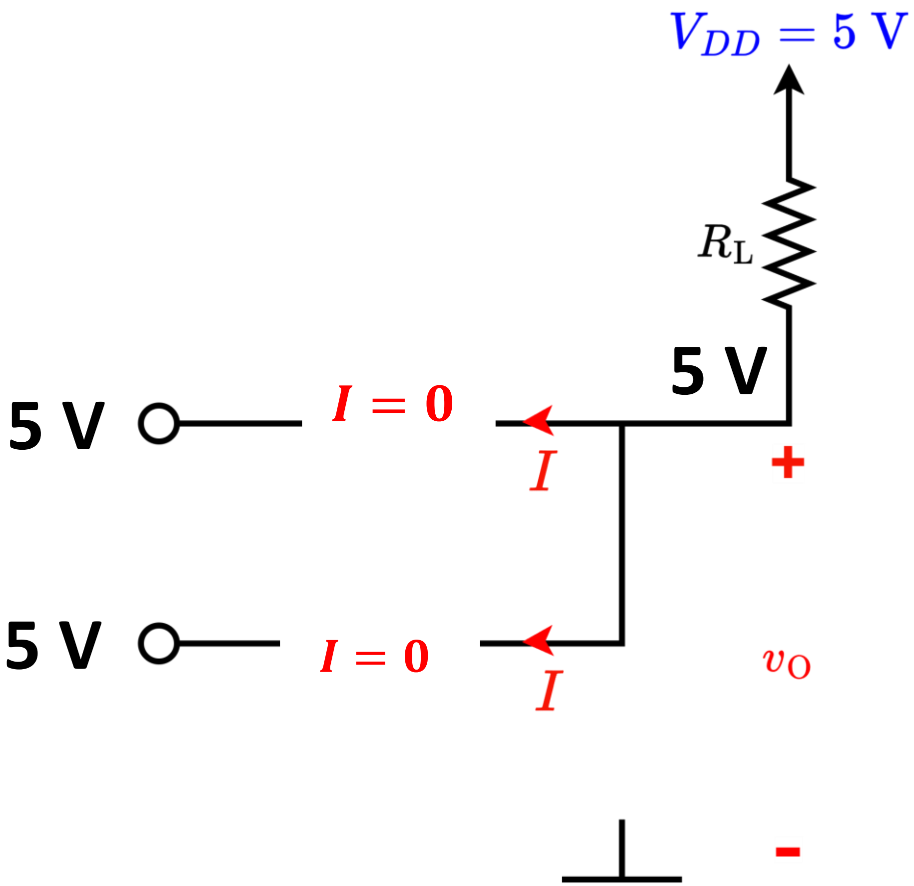


Degraded 0 V

Logical Operations with Diode (AND)

Ideal diode

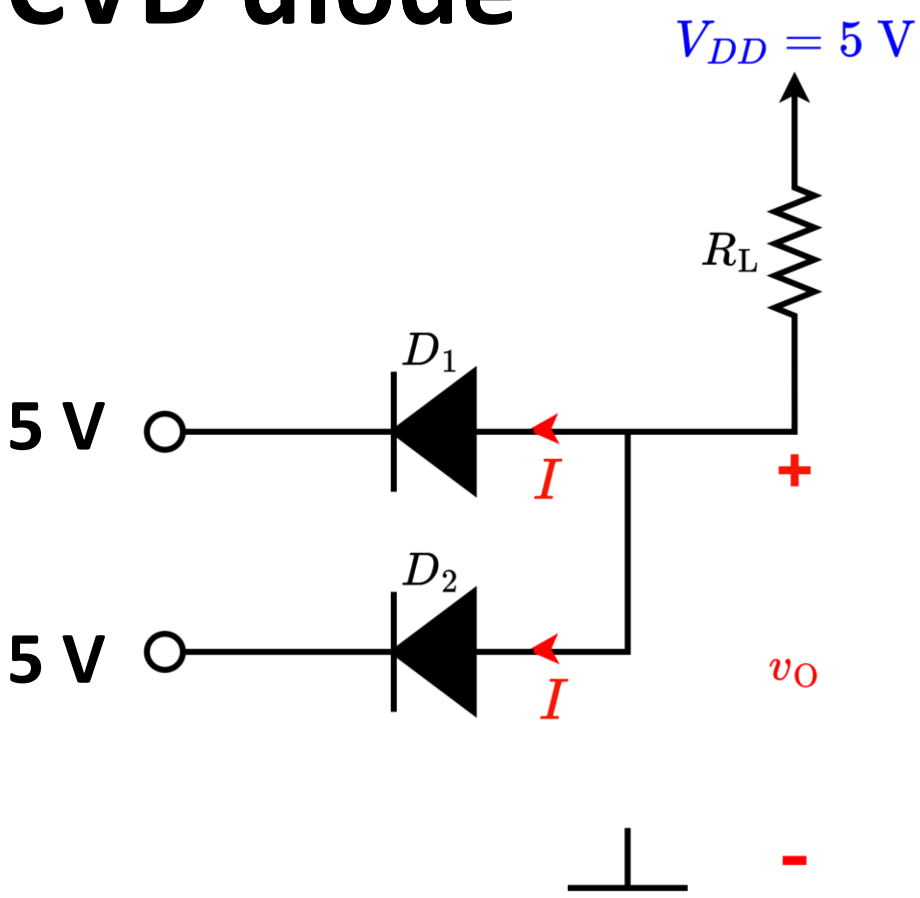




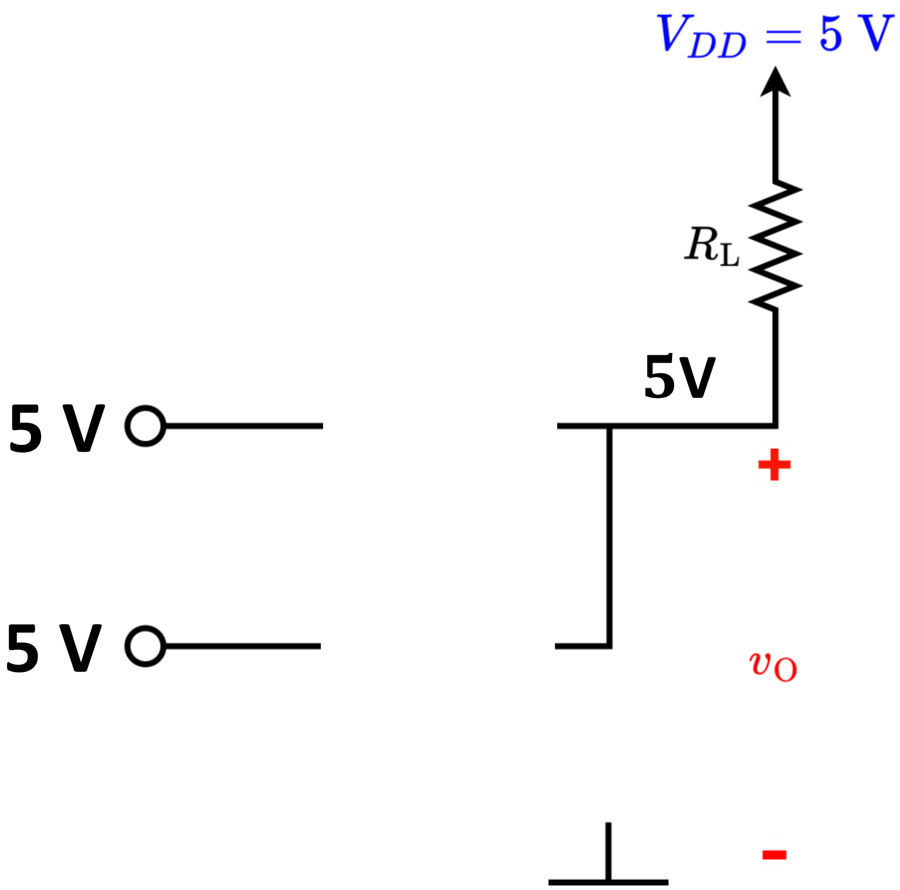
Z = 5 V

Logical Operations with Diode (AND)

CVD diode

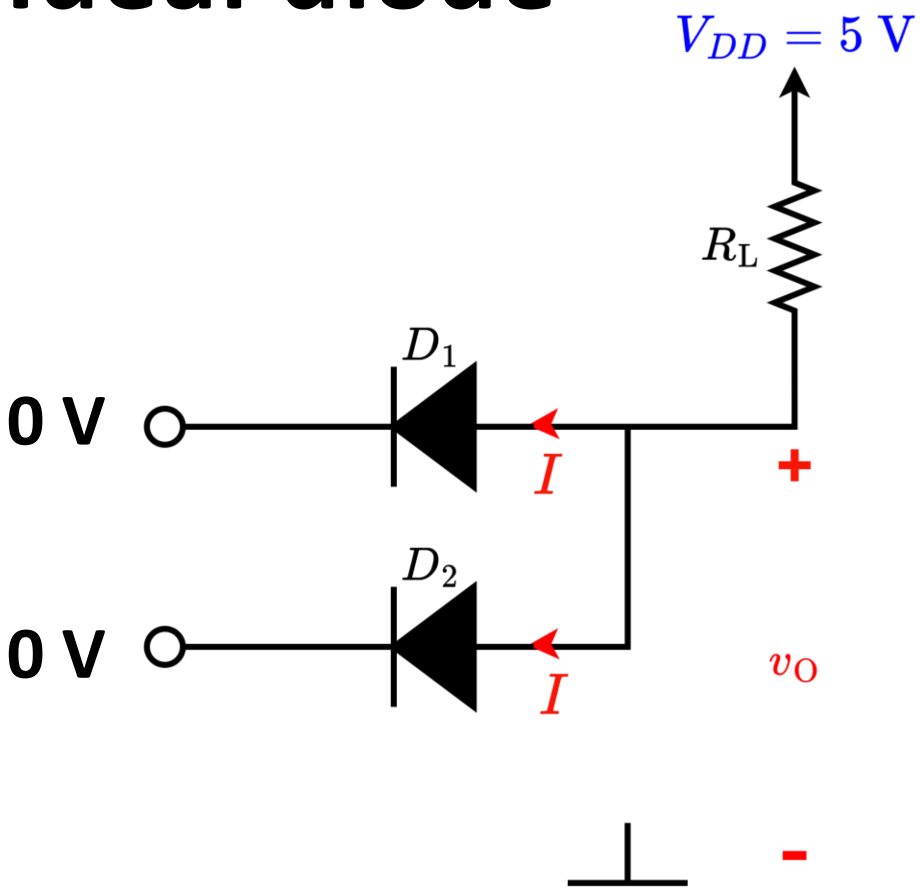


Z = 5 V

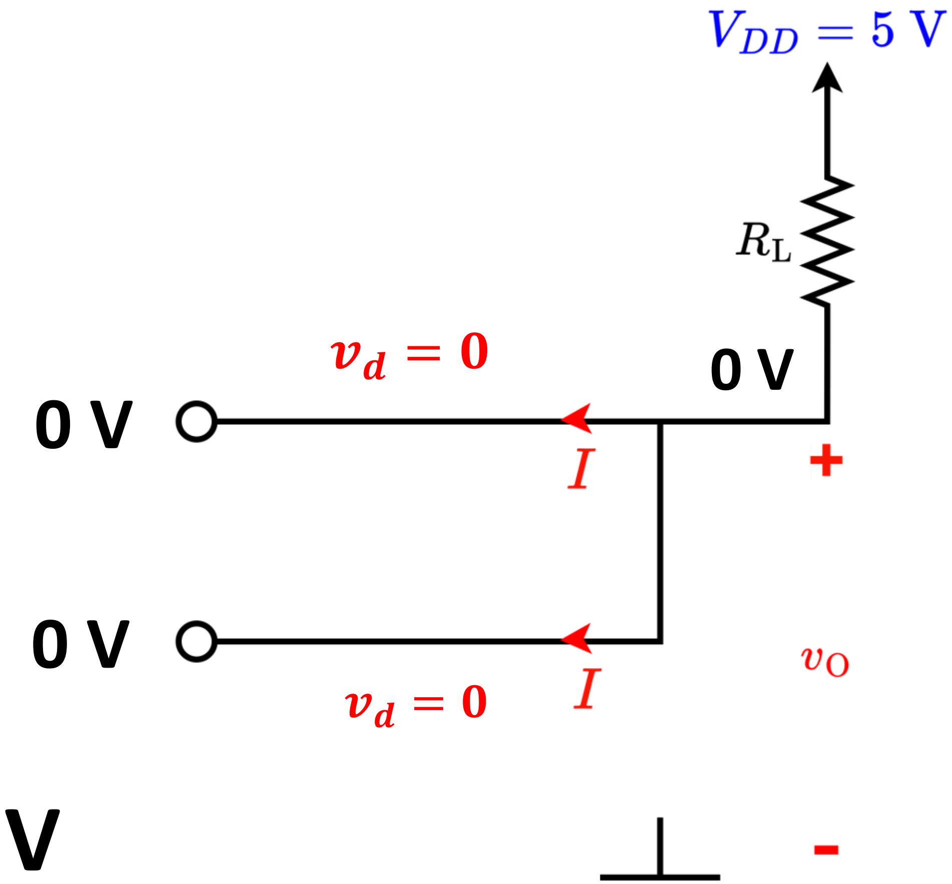


Logical Operations with Diode (AND)

Ideal diode

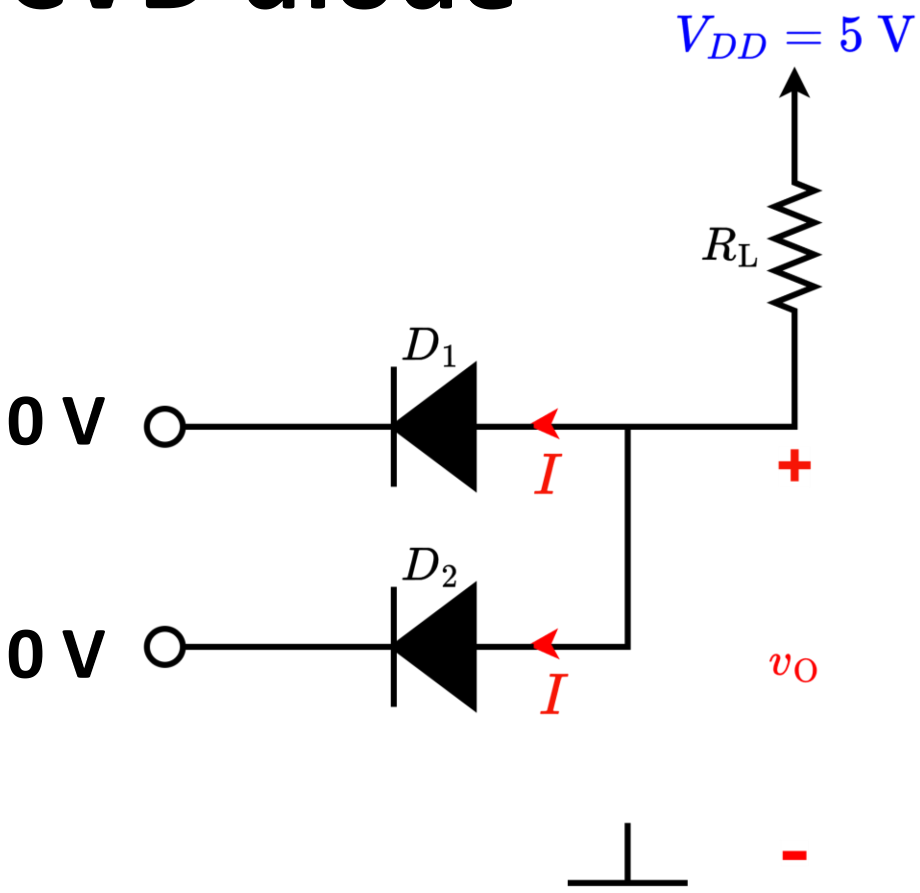


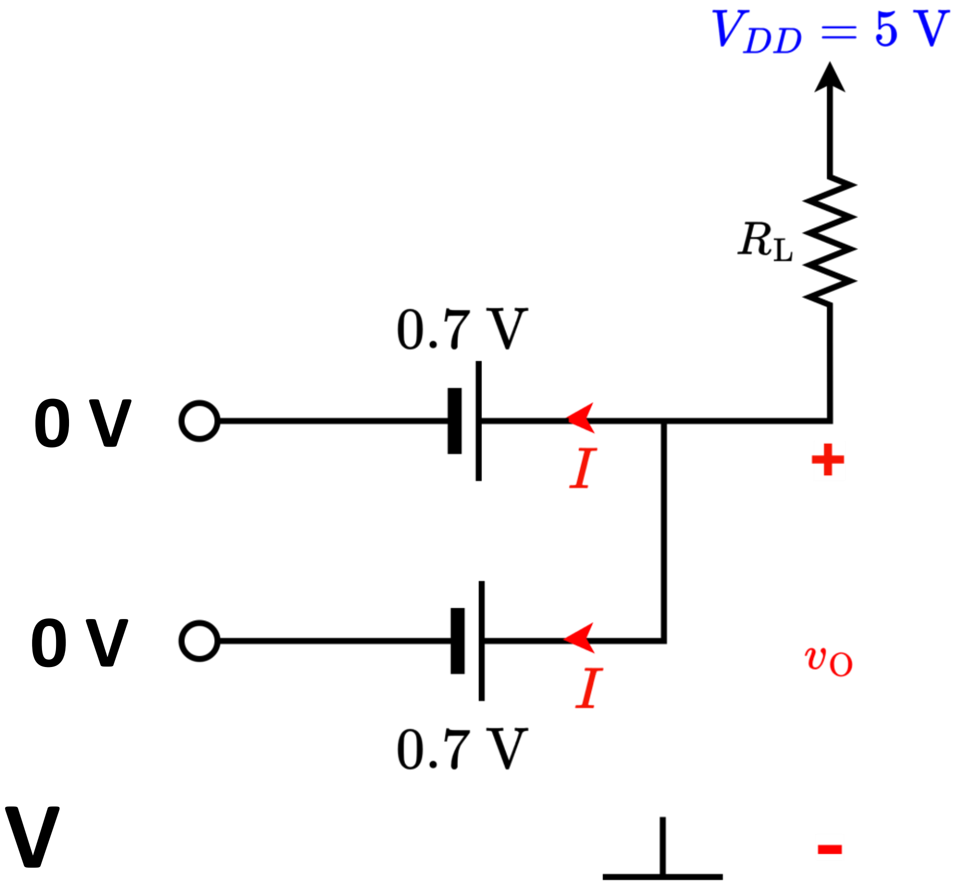
Z = 0 V



Logical Operations with Diode (AND)

CVD diode





Z = 0.7 V

Degraded 0 V

Both diodes have same V_{DO}

Logical Operations with Diode (AND)

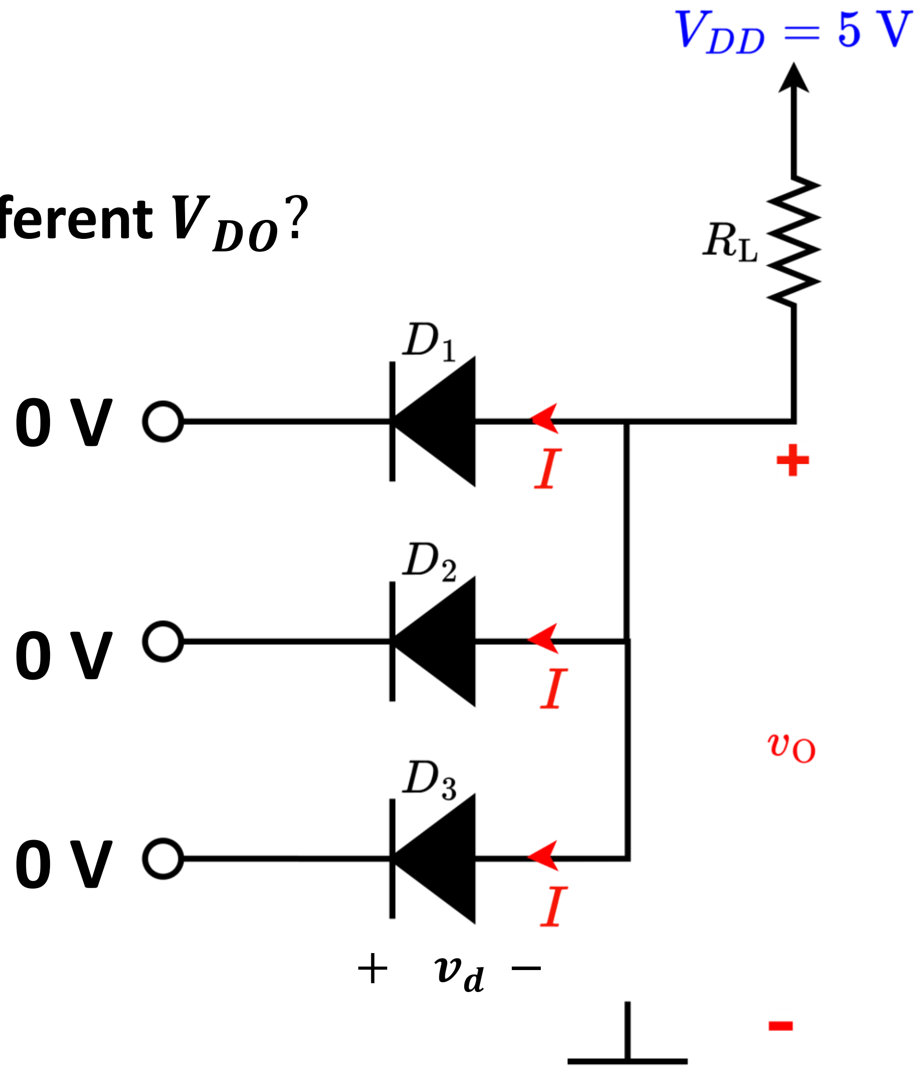
CVD diode

What if the diodes have different V_{DO}?

$$V_{D1} = 1\ \text{V}$$

$$V_{D2} = 0.7\ \text{V}$$

$$V_{D3} = 0.5\ \text{V}$$



Logical Operations with Diode (AND)

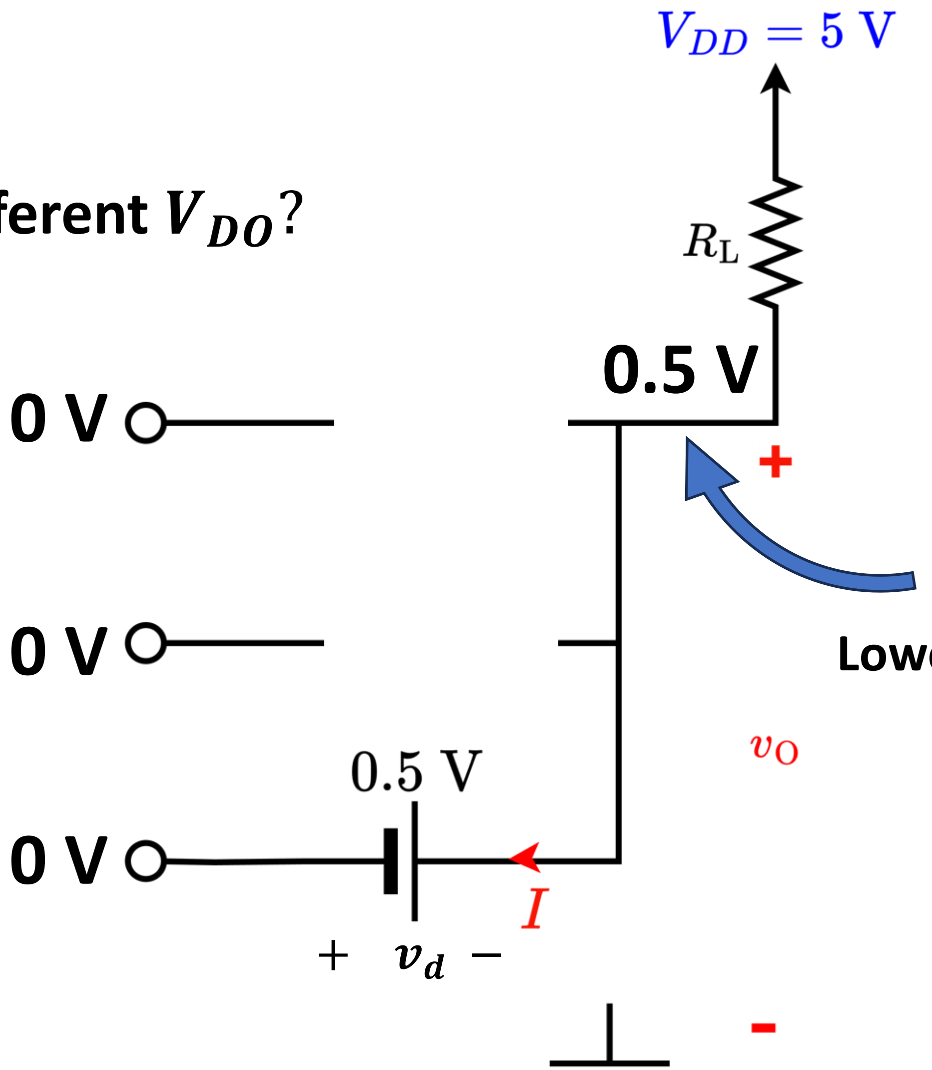
CVD diode

What if the diodes have different V_{DO}?

$V_{D1} = 1\text{ V}$

$V_{D2} = 0.7\text{ V}$

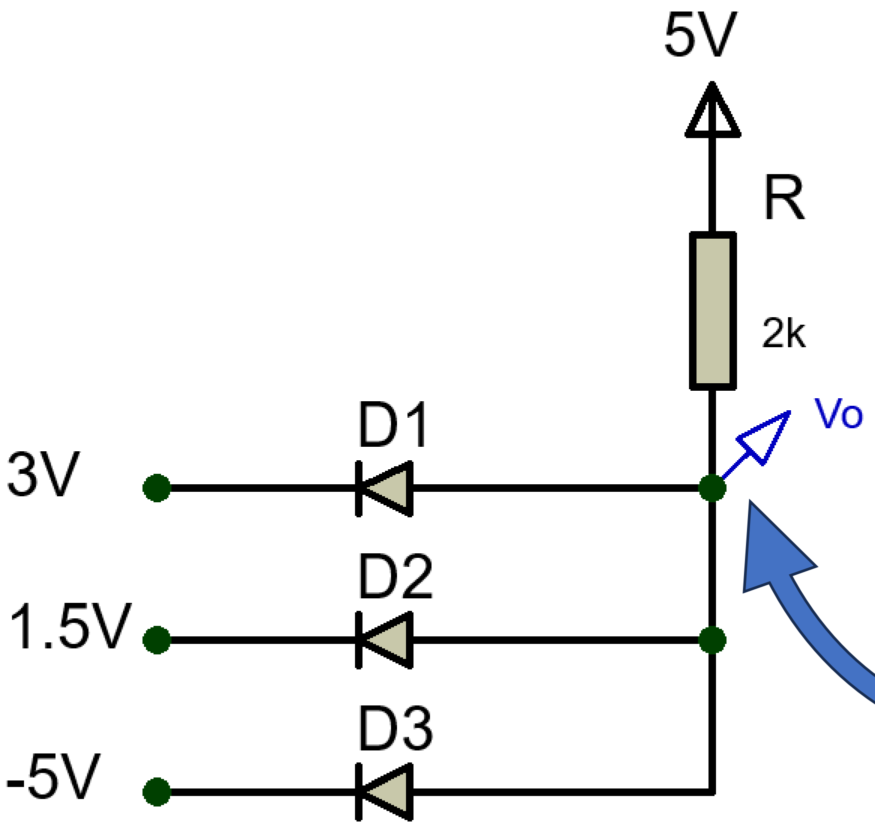
$V_{D3} = 0.5\text{ V}$



Lowest (possible – and consistent) voltage here!

Effect of input Voltage Variation in Logic Gates (AND)

Example 5: Find the value of Vo



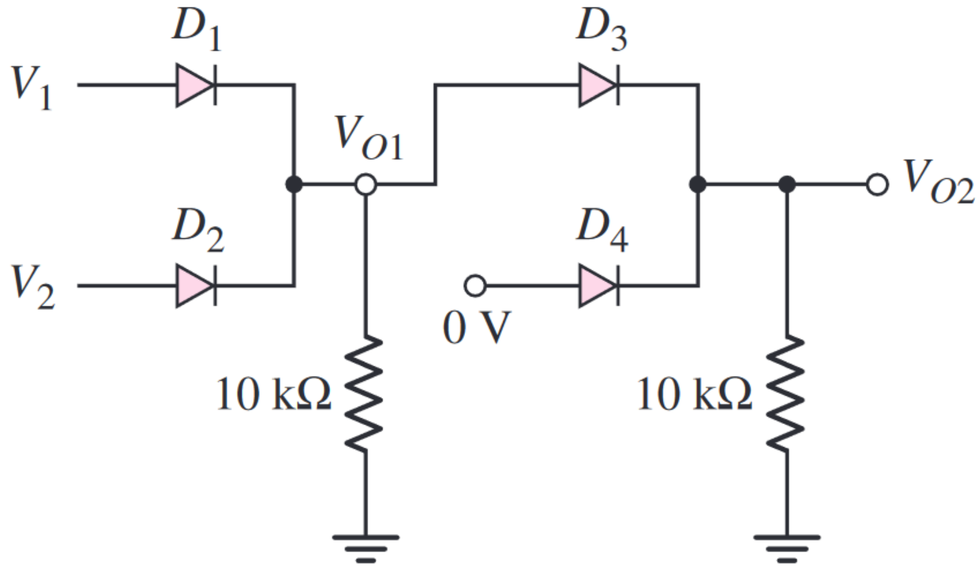
D1 and D2 are OFF → Open Circuit
Only D3 is ON → Short Circuit

$$V_O = -5\ \mathrm{V}$$

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

Lowest (possible – and consistent) voltage here!

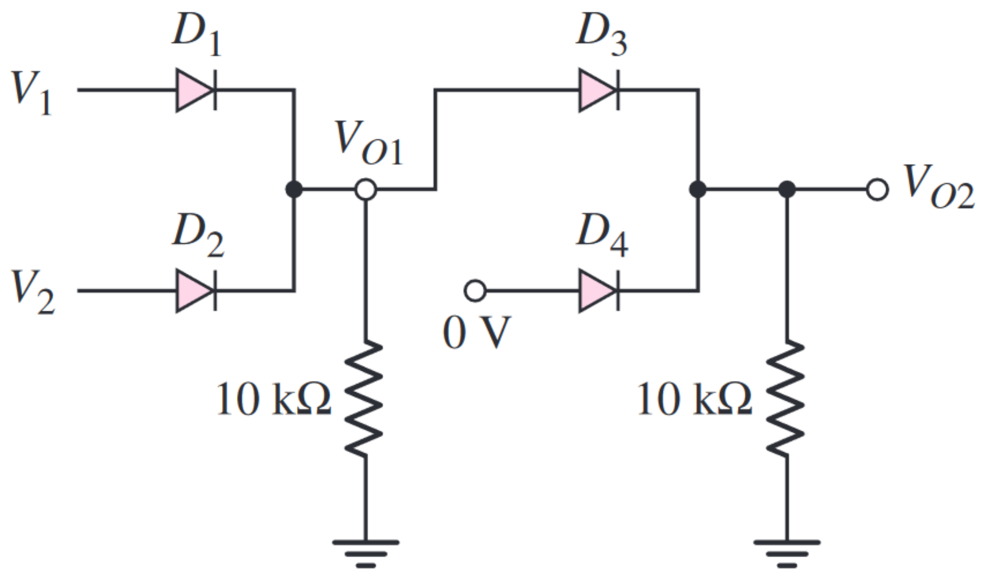
Combined Logic Circuits



$$\boldsymbol{V_{O1} = V_1} \text{ OR } \boldsymbol{V_2 = V_1 | V_2}$$

$$\boldsymbol{V_{O2}} = (\boldsymbol{V_{O1}} \text{ OR } \mathbf{0}) = \boldsymbol{V_{O1} = V_1 \mid V_2}$$

Combined Logic Circuits



** In CVD diode models, we are assuming that all diodes have equal drop.

Suppose: $\boldsymbol{V_1 = 3\ \mathrm{V}, V_2 = 2\ \mathrm{V}.}$

For Ideal diodes assumption:

$V_{O1} = V_1\ \mathrm{OR}\ V_2\ \rightarrow$ *Largest Value of the inputs*

$$\therefore\ V_{O1} = 3\ \mathrm{V}$$

$$\boldsymbol{V_{O2}} = (V_{O1}\ \mathrm{OR}\ 0) = V_{O1} = \mathbf{3\ V}$$

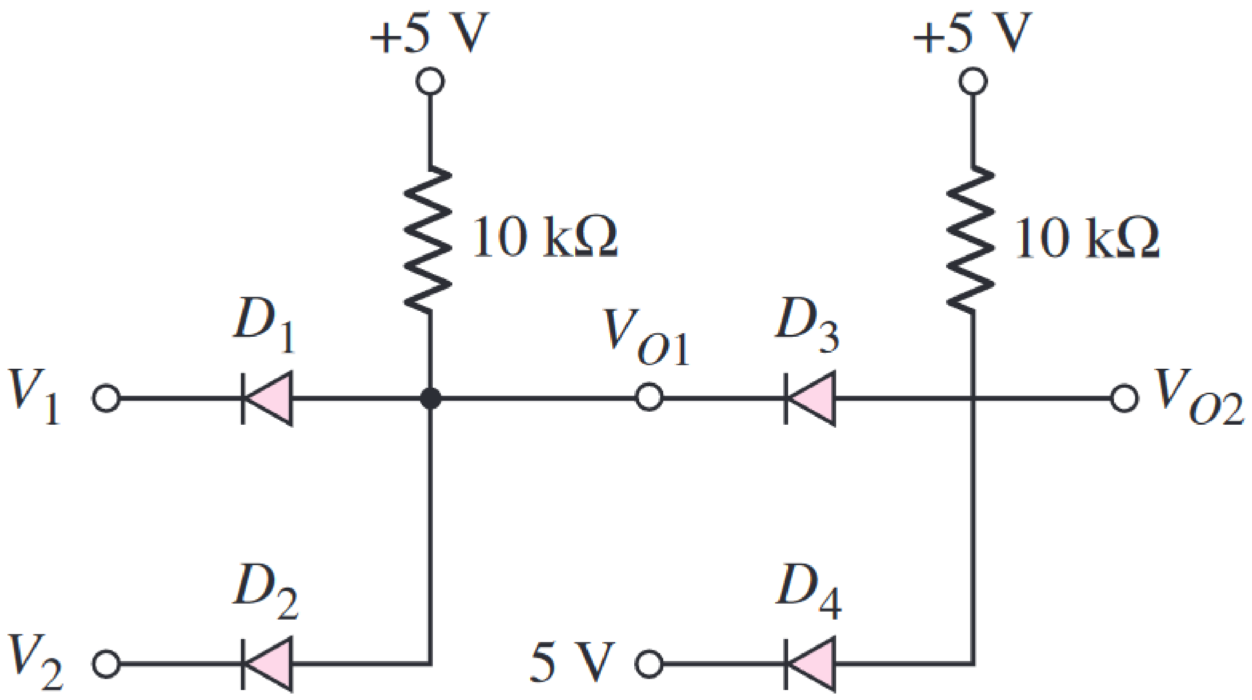
For CVD diodes assumption:

$V_{O1} = V_1\ \mathrm{OR}\ V_2\ \rightarrow$ *Largest Value of the inputs -* $\boldsymbol{V_{DO}}$

$$\therefore\ V_{O1} = (3\ - V_{DO})\ \mathrm{V}$$

$$\boldsymbol{V_{O2}} = (V_{O1}\ \mathrm{OR}\ 0) = V_{O1} - V_{DO} = (\mathbf{3 - 2}\ \boldsymbol{V_{DO}})\ \mathbf{V}$$

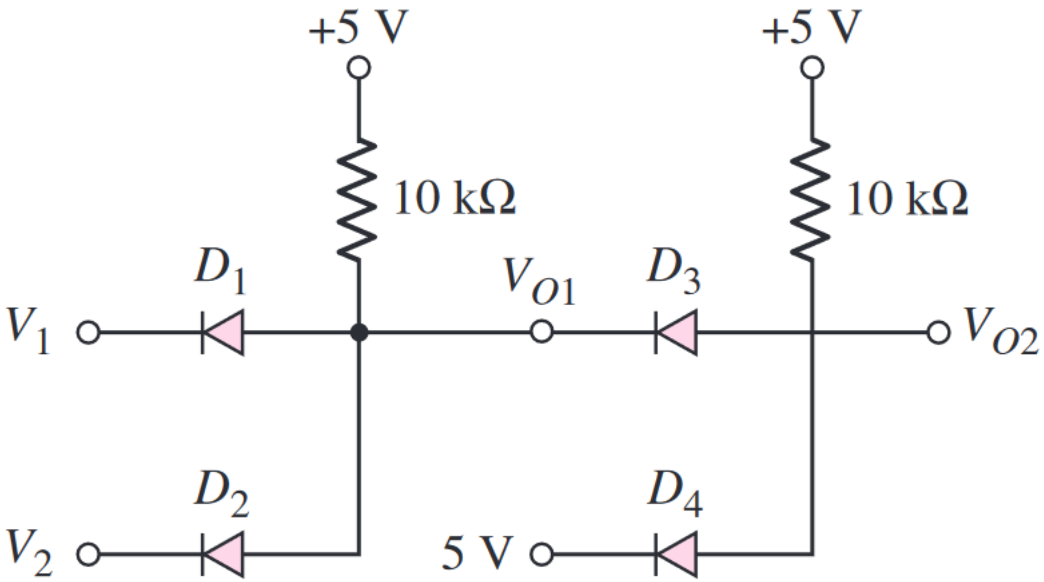
Combined Logic Circuits



$$\boldsymbol{V_{O1} = V_1 \text{ AND } V_2 = V_1 \cdot V_2}$$

$$\boldsymbol{V_{O2} = (V_{O1} \text{ AND } 5) = V_{O1} = V_1 \cdot V_2}$$

Combined Logic Circuits



Suppose: $\boldsymbol{V_1 = 3\ \mathrm{V}, V_2 = 1.5\ \mathrm{V}.}$

For Ideal diodes assumption:

$V_{O1} = V_1 \text{ AND } V_2$ → *Smallest Value of the inputs*

$$\therefore\ V_{O1} = 1.5\ \mathrm{V}$$

$\boldsymbol{V_{O2}} = (V_{O1} \text{ AND } 5) = V_{O1} = \mathbf{1.5\ V}$

For CVD diodes assumption:

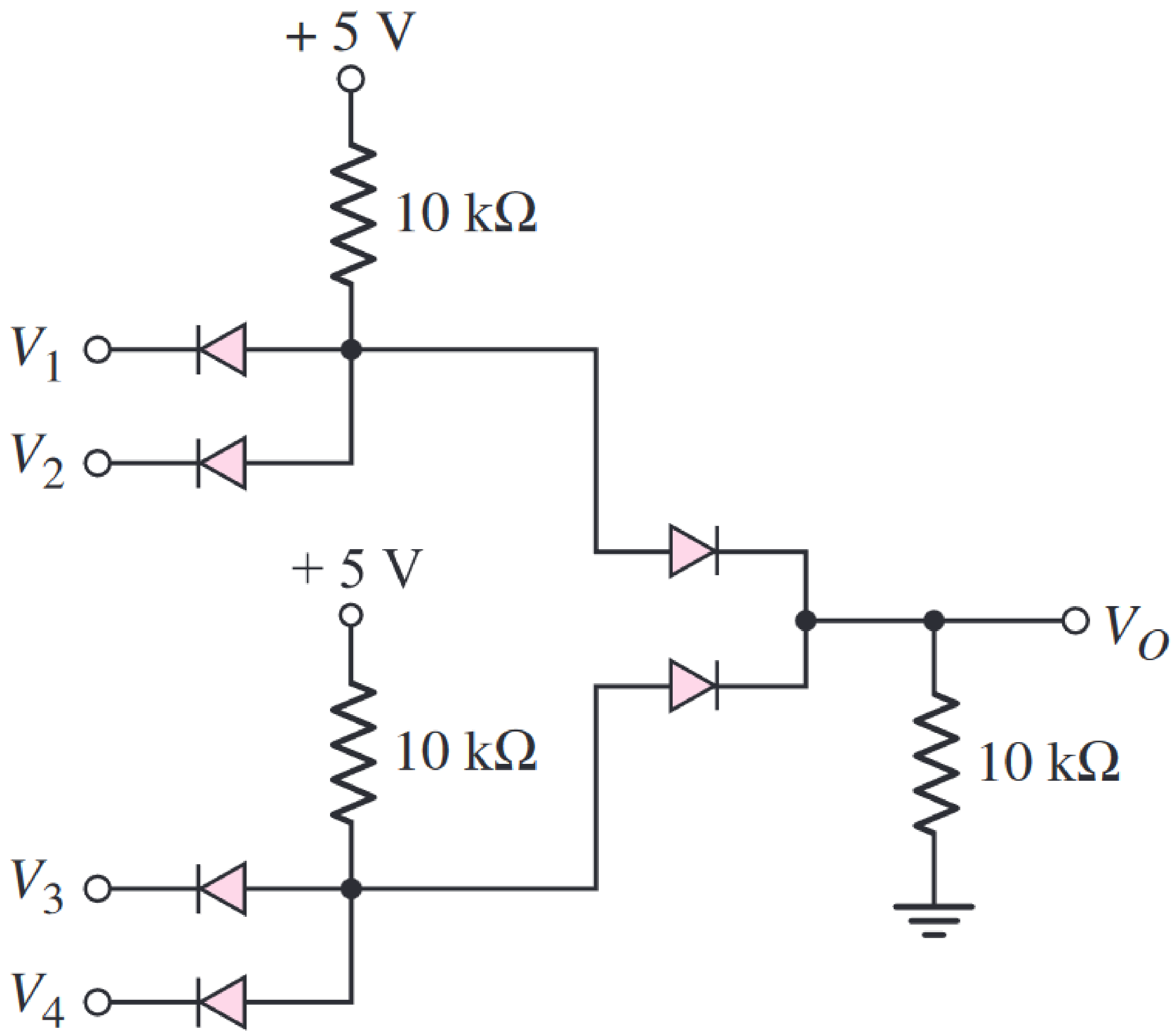
$V_{O1} = V_1 \text{ AND } V_2$ → *Smallest Value of the inputs* **+** $\boldsymbol{V_{DO}}$

$$\therefore\ V_{O1} = (1.5 + V_{DO})\ \mathrm{V}$$

$\boldsymbol{V_{O2}} = (V_{O1} \text{ AND } 5) = V_{O1} + V_{DO} = \mathbf{(1.5 + 2\ \boldsymbol{V_{DO}})\ V}$

** In CVD diode models, we are assuming that all diodes have equal drop.

Combined Logic Circuits

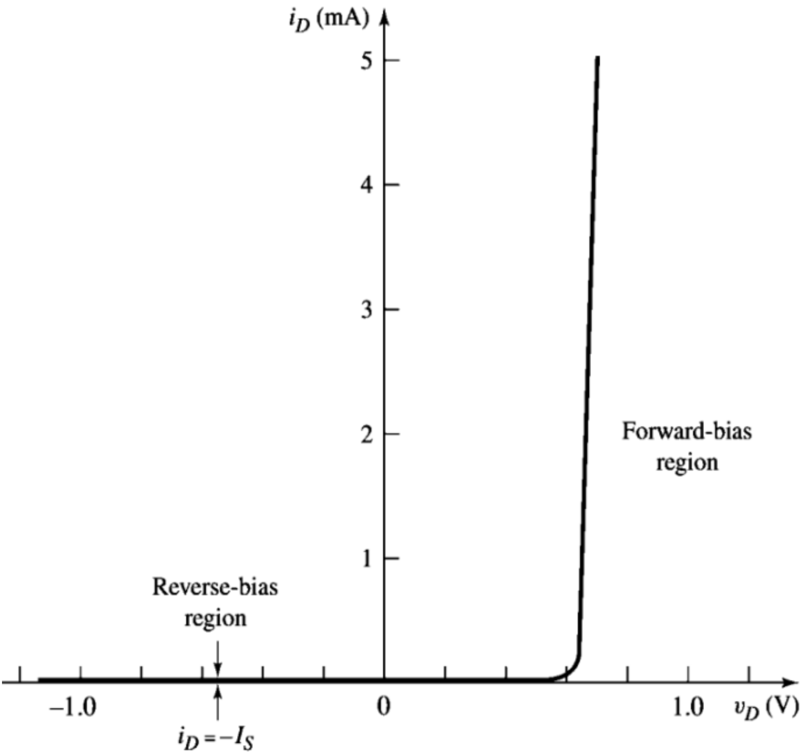


Express V_O as a Boolean expression of V_1, V_2, V_3 and V_4

$$V_O = (V_1 \cdot V_2)|(V_3 \cdot V_4)$$

$$V_O = (V_1 \,\textbf{AND}\, V_2)\ \textbf{OR}\ (V_3\ \textbf{AND}\ V_4)$$

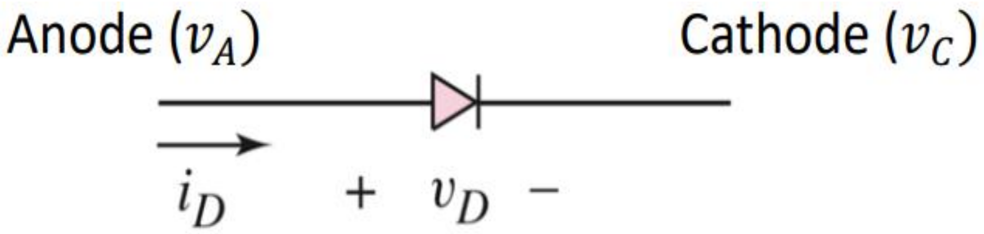
Real diode



I-V characteristics of a real diode

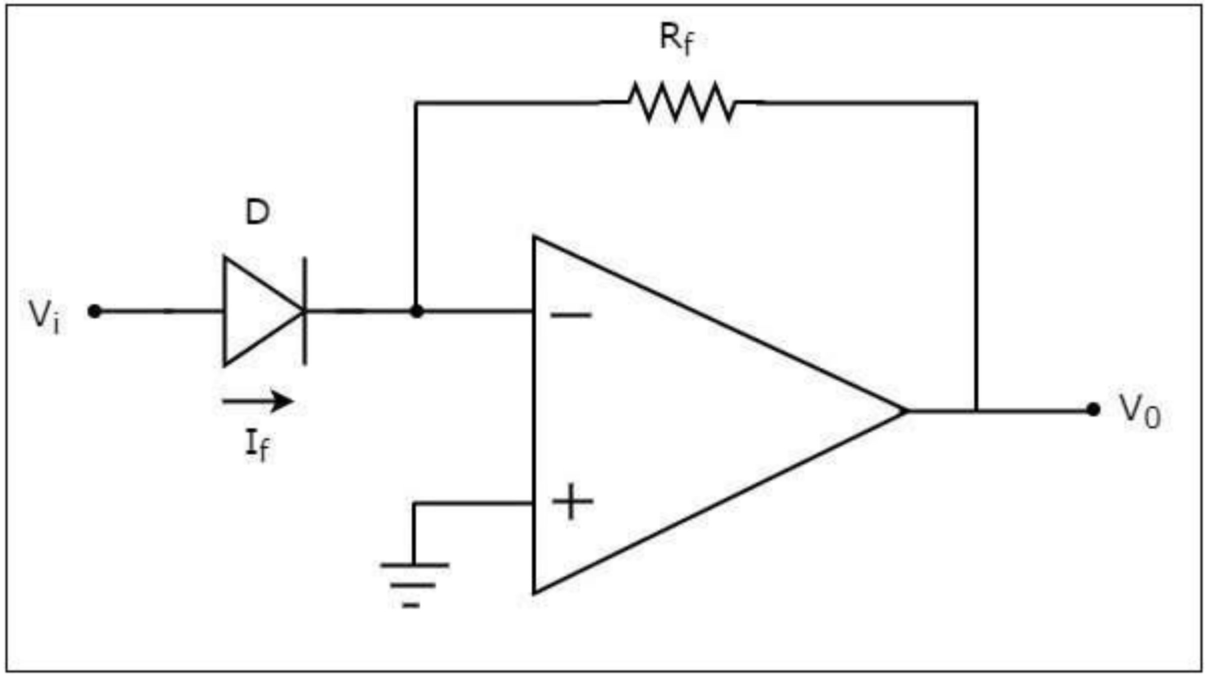
Relation between diode current and diode voltage:

$$i_D = I_S\left(e^{\frac{v_D}{\eta V_T}} - 1\right)$$



η is called the ideality factor (try to recall, you measured this in the lab!)

Exponential (Anti-log) Converter

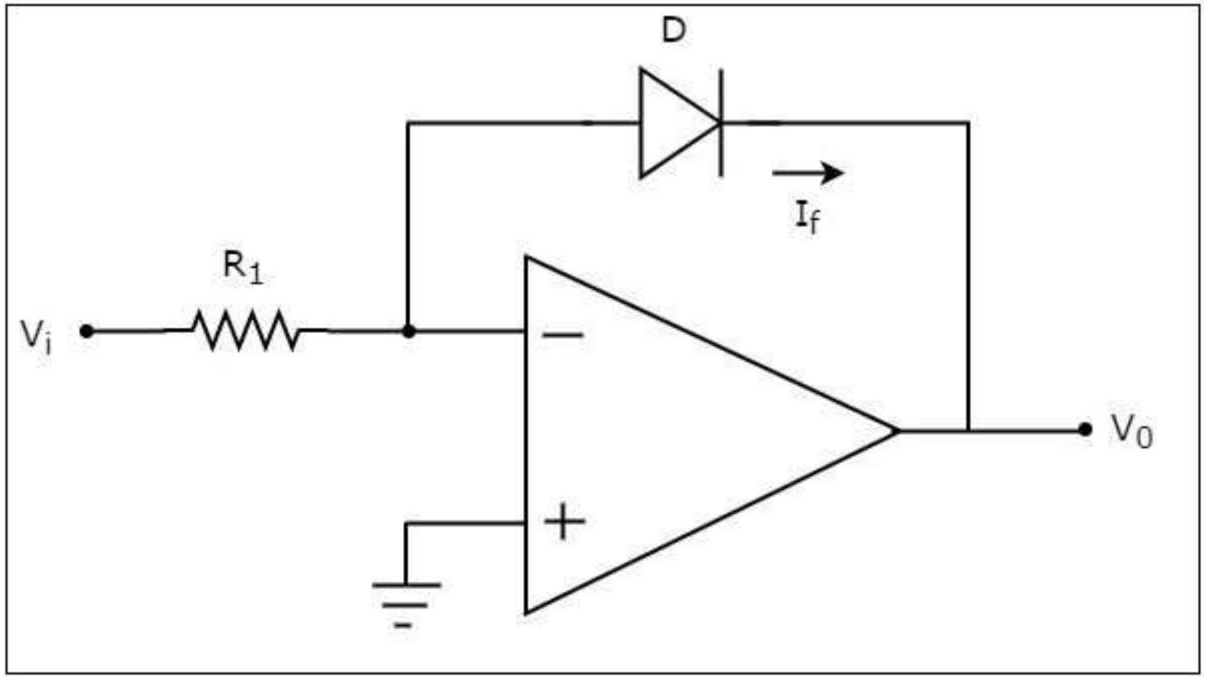


$$I_f = I_S \exp\left(\frac{V_i - 0}{V_T}\right)$$

$$\frac{0 - V_O}{R_f} = I_S \exp\left(\frac{V_i}{V_T}\right)$$

$$\boldsymbol{V_O = I_s R_f \cdot \exp\left(\frac{V_i}{V_T}\right)}$$

Logarithmic Amplifier



$$I_f = I_S \exp\left(-\frac{V_O}{V_T}\right)$$

$$\frac{V_i}{R_1} = I_S \exp(-\frac{V_O}{V_T})$$

$$\frac{V_i}{I_S R_1} = \exp(-\frac{V_O}{V_T})$$

$$\boldsymbol{V_O = -V_T \cdot \ln\left(\frac{V_i}{I_S R_1}\right)}$$

APPLICATIONS:

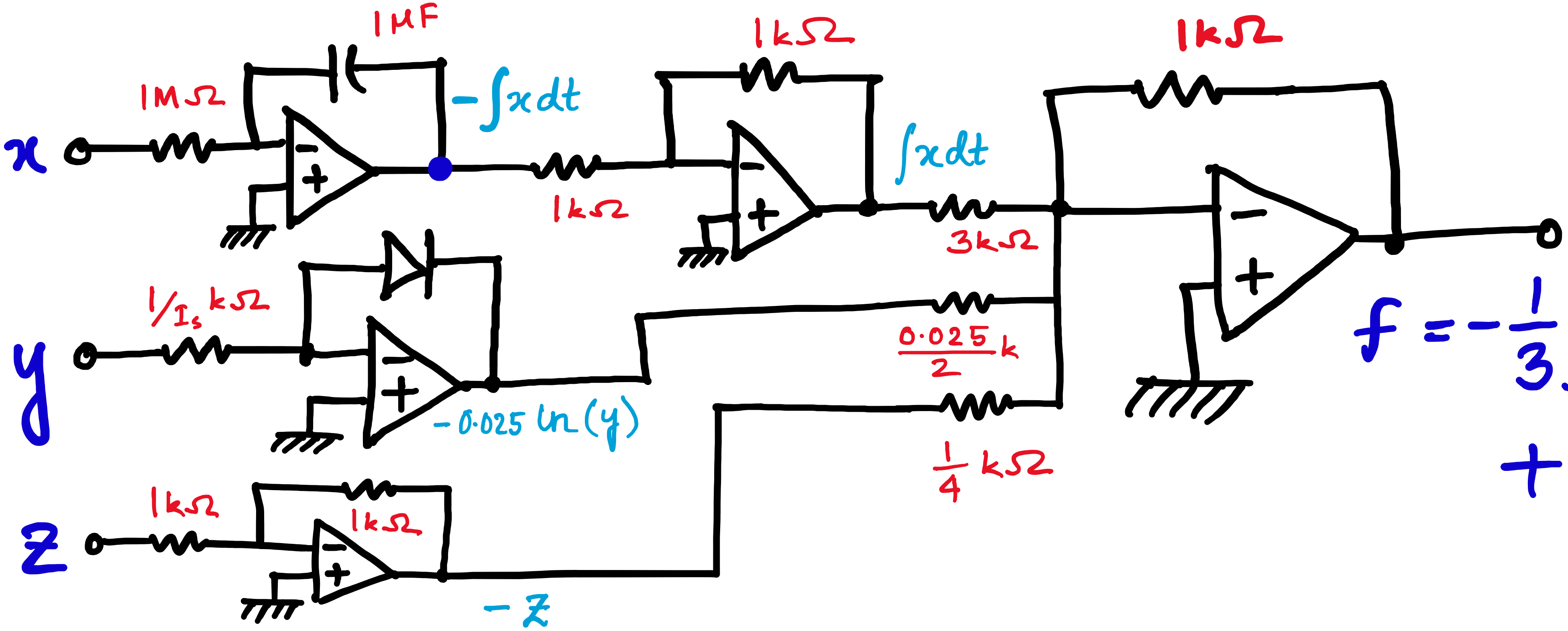
$V_T = 0.025\ V$

$I_s R_f = 1\ V$

$\therefore R_f = \frac{1}{I_s} k$

Implementing operational functions

- $f = -\frac{1}{3}\int x \cdot dt + 2\ln y + 4z = -\left(\frac{1}{3}\int x\,dt - 2\ln(y) - 4z\right)$



$f = -\frac{1}{3}\int x\,dt + 2\ln y + 4z$

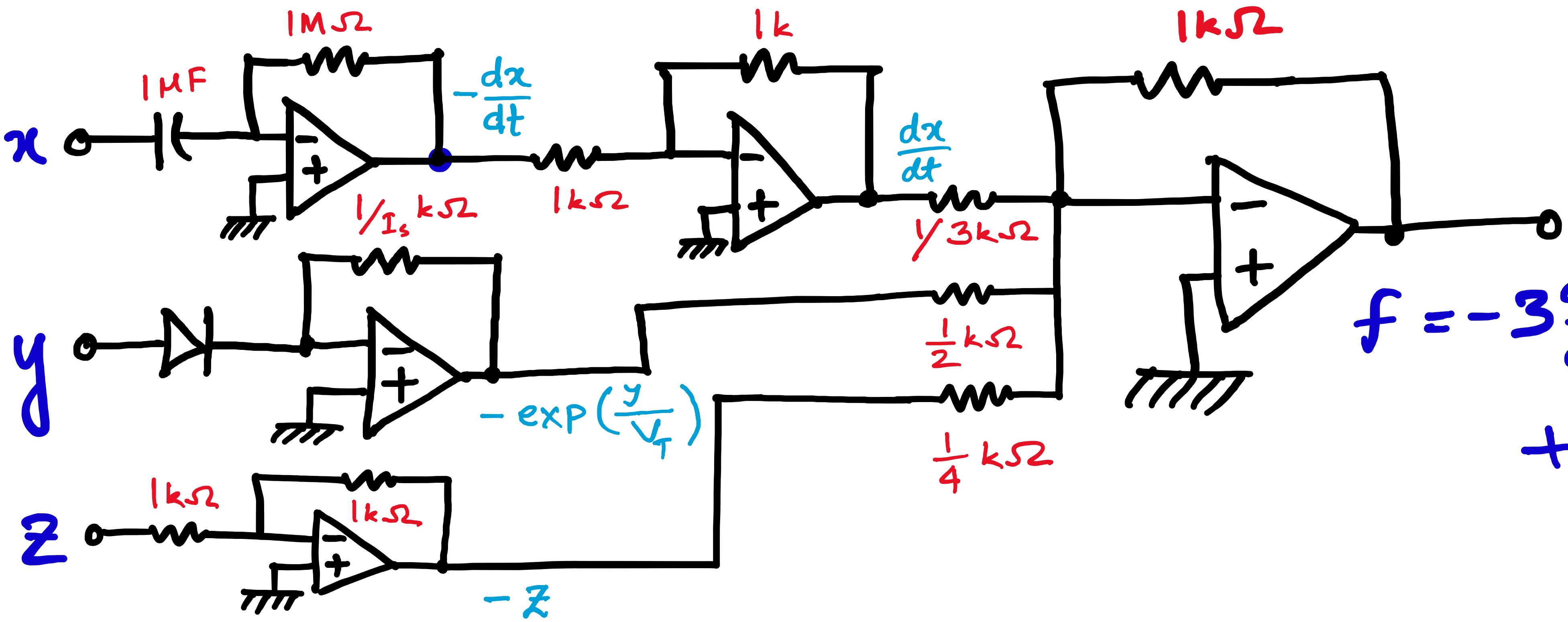
APPLICATIONS:

Implementing operational functions

- $f = -3\frac{dx}{dt} + 2\exp(y) + 4z$

$V_T = 1\ V$

$I_s R_f = 1\ V.$



$$f = -3\frac{dx}{dt} + 2\exp(y) + 4z.$$

Multiplier

$$f = xy$$

$$\ln(f) = \ln(xy) = \ln(x) + \ln(y)$$

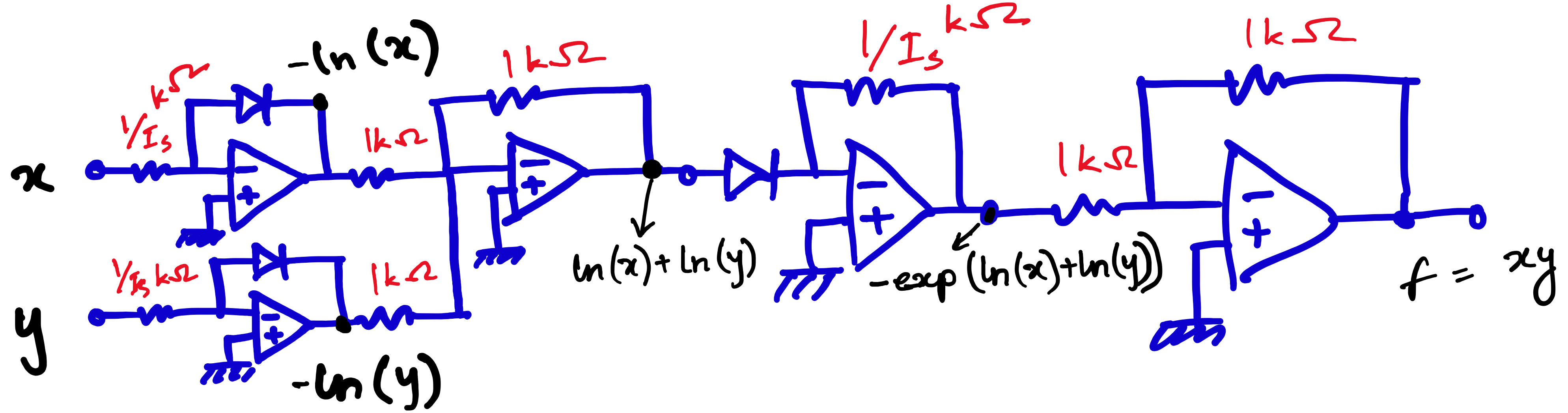
$$f = \exp(\ln(x) + \ln(y))$$

$V_T = 1\,V$

$I_s R_f = 1\,V$

So,

$f = \exp(z)$ where $z = \ln(x) + \ln(y)$



Divider

$$f = xy/z$$

$$\ln(f) = \ln(xy/z) = \ln(x) + \ln(y) - \ln(z)$$

$$f = \exp(\ln(x) + \ln(y) - \ln(z))$$

So,

$$f = \exp(z) \text{ where } z = \ln(x) + \ln(y) - \ln(z)$$

$V_T = 1\ V$

$I_s R_f = 1\ V.$