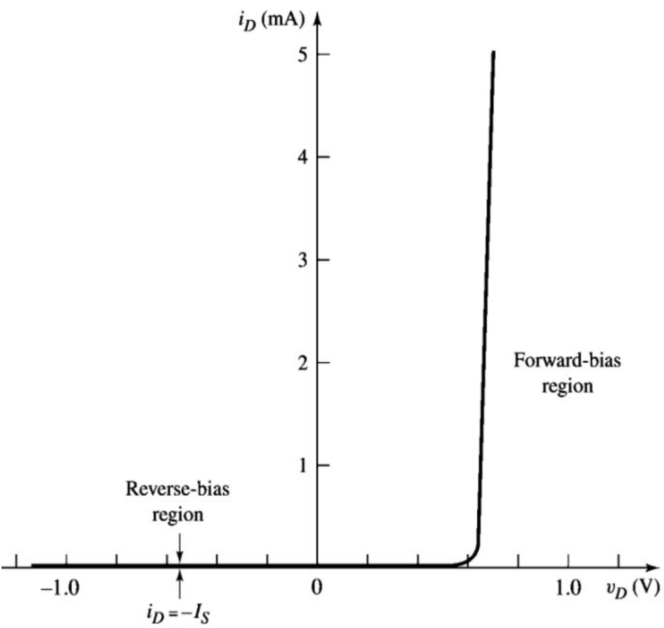
Diode: Method of Assumed States

Lecture 8

Course No: CSE 251

Course Title: Electronic Devices and Circuits

Real diode



I-V characteristics of a real diode

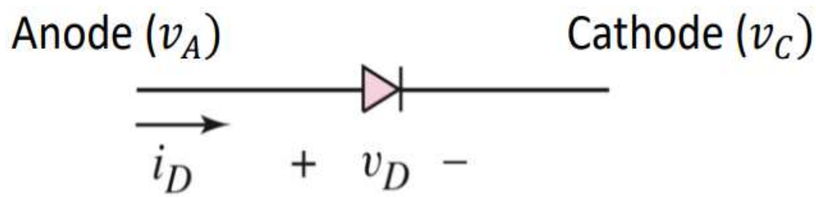
Relation between diode current and diode voltage:

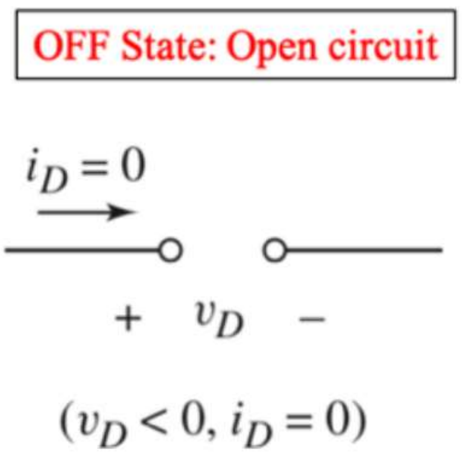
$$i_D = I_S\left(e^{\frac{v_D}{\eta V_T}} - 1\right)$$

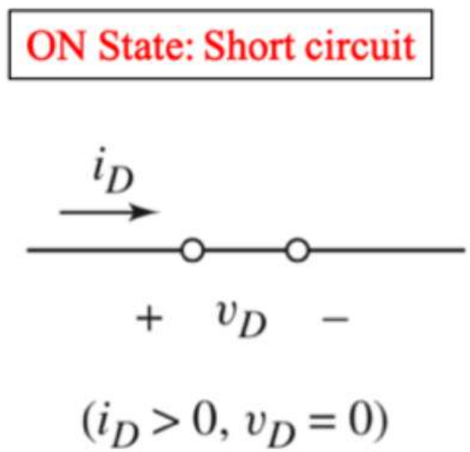
where $v_D\ (= v_A - v_C)$ is the voltage across the diode, i_D is the current through the diode (from anode to cathode) and V_T, called the thermal voltage, is a temperature dependent constant. For temperature $T = 300K$, $V_T = 25\ mV$.

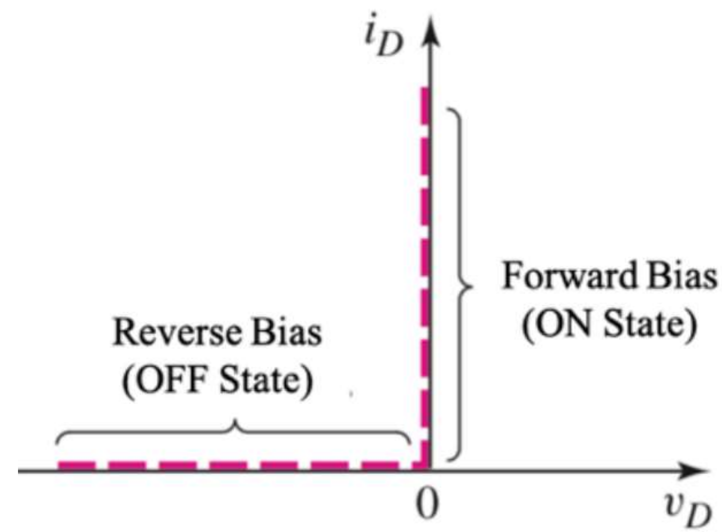
η is called the ideality factor (try to recall, you measured this in the lab!)

1. Ideal Diode Model





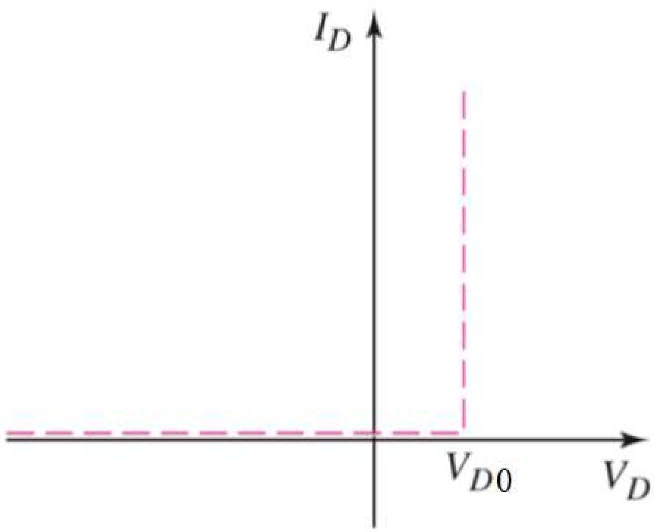




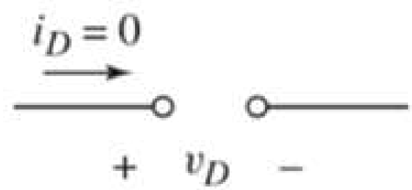
So, Power, $P = v_D . i_D = 0W$

Modeling the real diode

2. Constant voltage drop (CVD) model

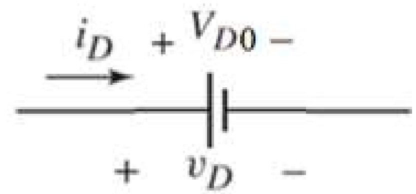


OFF State: Open circuit



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

ON State: Voltage source



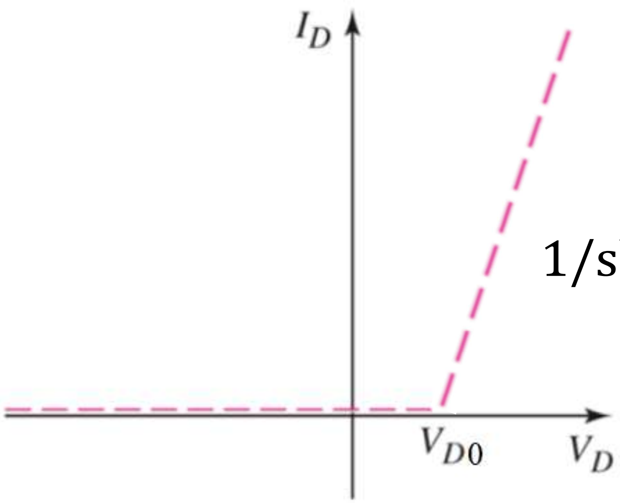
$(i_D > 0, v_D = V_{D0})$

Usually, $v_{D0} = 0.7V$ (Si)
$v_{D0} = 0.3V$ (Ge)

So, Power, $P = v_{D0}.i_D > 0W$
$\therefore P \propto i_D$

Modeling the real diode

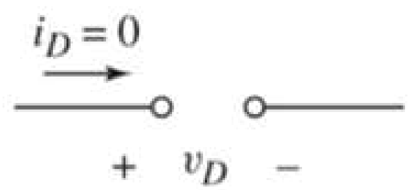
3. CVD+R model



$1/\text{slope} = r_D$

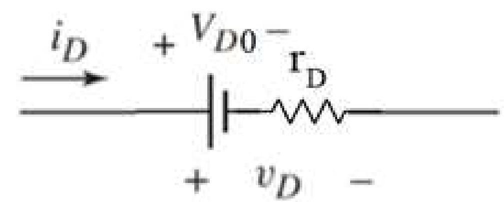
r_D~10-20Ω

OFF State: Open circuit



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

ON State: Voltage source



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

$$i_D = \frac{v_D}{r_D} - \frac{v_{Do}}{r_D}$$

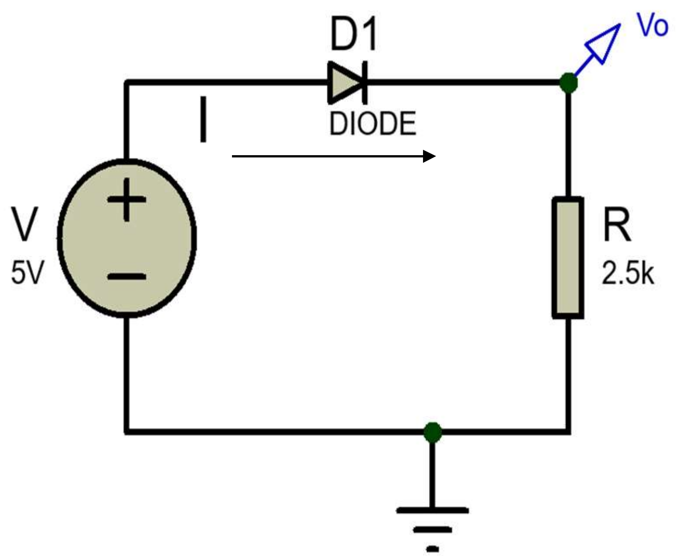
Comparison of Models

Ideal: Simple, Less Accuracy

CVD+R: Complex, Better Accuracy

Example

Find Vo, I using a) Ideal diode, b) CVD and c) CVD + r model (r= 10 Ω)



a) D1 ON→ Replace with short ckt

$Vo = 5V$

$I = 5V/2.5k\Omega = 2mA$

b) D1 ON→ Replace with constant voltage source of 0.7V

$Vo = 5-0.7 = 4.3V$

$I = 4.3V/2.5k\Omega =$ **1.72mA**

c) D1 ON→ Replace with constant voltage source of 0.7V & r= 10Ω

KVL: $5 = 0.7 + I(10+2500) \rightarrow \therefore$ **$I = 1.713$ mA**

$Vo = 2.5I = 4.283V$

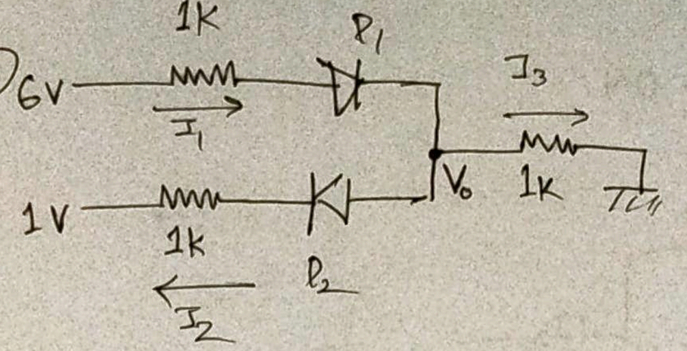
Steps for Method of Assumed States

Analyzing multi-diode circuits requires determining if the individual diodes are ON or OFF. In many cases, the choice is not obvious, so we must initially guess the state of each diode, then analyze the circuit to determine if we have a solution consistent with our initial assumption.

1. Assume state for diode (on/off)
2. Solve circuit
3. Verify

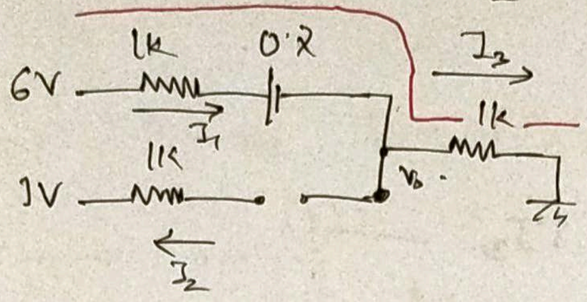
Ideal Model	**ON** $i_D>0$	**OFF** $v_D<0$
CVD Model	**ON** $i_D>0$	**OFF** $v_D \leq v_{D0}$

1



Find I_1, I_2, I_3, V_0. Use CVD model with $V_\gamma = 0.7V$

Sol^n: Assume $D_1 = ON$, $D_2 = OFF$



$I_2 = 0$. [OFF]

$I_1 = I_2 + I_3$ [KCL]

$\therefore I_1 = I_3$

Writing KVL along 6V to GND [Red line]

$$6 = 1I_1 + 0.7 + 1I_3 + 0$$

$$\Rightarrow 2I_1 = 6 - 0.7 \quad [\text{since } I_1 = I_3]$$

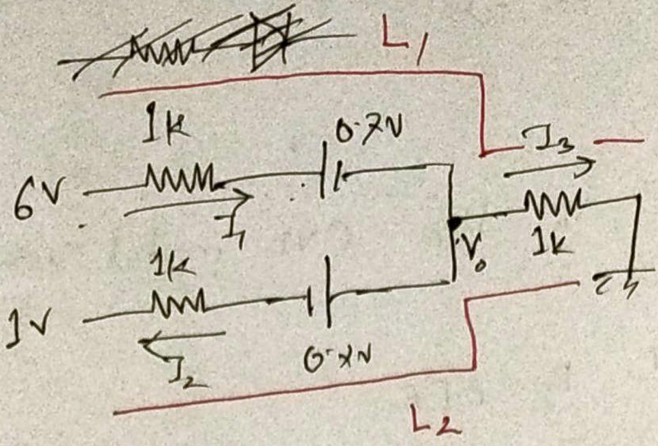
$$\Rightarrow I_1 = I_3 = 2.65 \text{ mA}$$

$$\therefore V_0 = 1I_3 = 2.65V$$

Now $I_1 = +ve$, so D_1 assumption correct

But for D_2,
$V_A = V_0 = 2.65V$
$V_C = 1V$
$\therefore V_D = 1.65V$
So assumption wrong

Assume $D_1 = ON$, $D_2 = ON$



KVL along L1

$$6 = 1I_1 + 0.7 + 1I_3 \quad \text{---} (I)$$

KVL along L2

$$1 = -1I_2 - 0.7 + 1I_3 \quad \text{---} (II)$$

KCL $\Rightarrow$

$$I_1 = I_2 + I_3 \quad \text{---} (III)$$

solving (I), (II) and (III)

$I_1 = \cancel{1.3mA}$ 2.96 mA

$I_2 = 0.63mA$

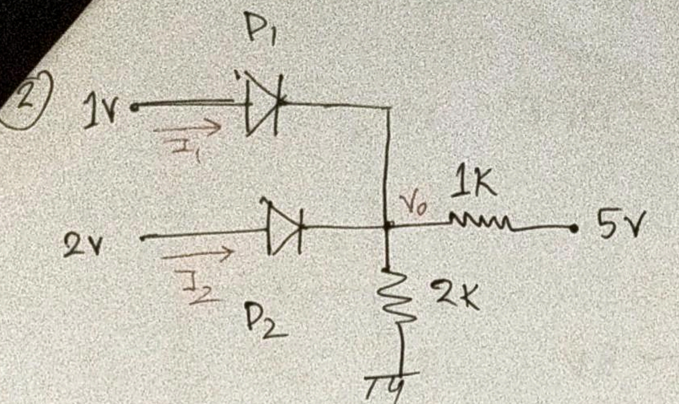
$I_3 = 2.33$ mA

$\therefore V_0 = 1I_3 = 2.33V$

$I_1 = +ve \Rightarrow D_1$ assumption correct ✓

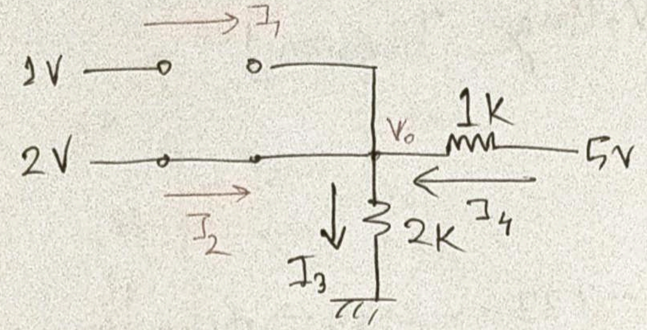
$I_2 = +ve \Rightarrow D_2$ " " ✓

(2)



Find I_1, I_2 and V_o. Assume the diodes are ideal.

Soln: Assume $D_1 = OFF$, $D_2 = ON$



$\therefore I_1 = 0$ (OFF)

$\therefore V_o = 2V$

$\therefore I_3 = \frac{V_o}{2} = 1mA$, $I_4 = \frac{5 - V_o}{1} = \frac{5-2}{1} = 3mA$

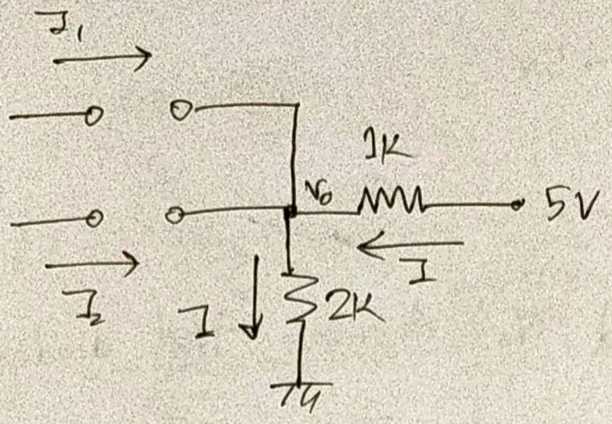
KCL $\Rightarrow I_2 + I_4 = I_3 \Rightarrow I_2 = I_3 - I_4$

$\therefore \boxed{I_2 = -2mA}$

$\therefore$ D_2 assumption wrong

For D_1: $V_D = V_A - V_C = 1 - 2 = -1 \Rightarrow$ Assumption correct

Assume $D_1 = OFF$, $D_2 = OFF$



$I_1 = 0$

$I_2 = 0$

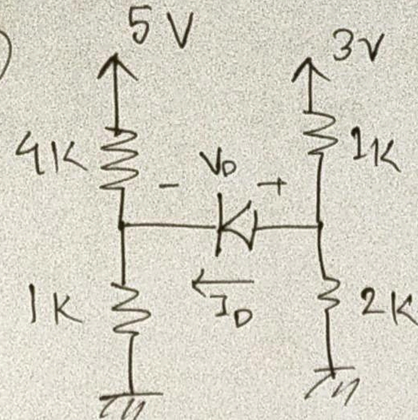
$V_0 = \frac{2}{2+1} \times 5$ [Voltage Division]

$\Rightarrow V_0 = 3.33V$

for $D_1 \Rightarrow V_D = V_A - V_C = 1 - 3.33 = -2.33 \Rightarrow$ Assumption correct

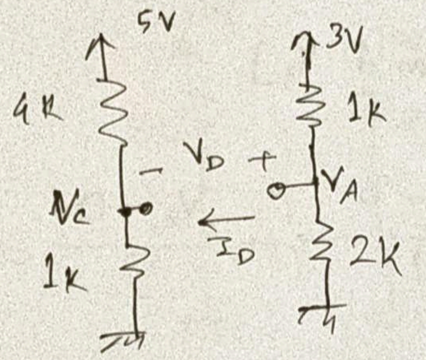
for $D_2 \Rightarrow V_D = V_A - V_C = 2 - 3.33 = -1.33 \Rightarrow$ " "

③



Find V_D and I_D. Use CVD with $V_\gamma = 0.7V$.

Solⁿ: Assume diode OFF



$\therefore I_D = 0$

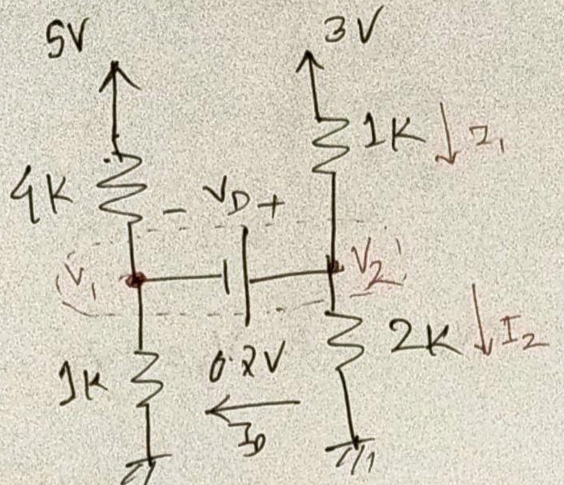
$$V_A = \frac{2}{2+1} \times 3 = 2V$$ [voltage division]

$$V_C = \frac{1}{4+1} \times 5 = 1V$$ [" "]

$$\therefore V_D = V_A - V_C = 2 - 1 = 1V$$

$\therefore$ Assumption wrong!

So, the diode would be on!



$\therefore V_D = 0.2V$

Super node equation (V_1 and V_2)

$$\frac{V_1 - 5}{4} + \frac{V_1 - 0}{1} + \frac{V_2 - 3}{1} + \frac{V_2 - 0}{2} = 0 \quad \text{—(i)}$$

$$V_2 - V_1 = 0.2 \quad \text{—(ii)}$$

solving (i) and (ii)

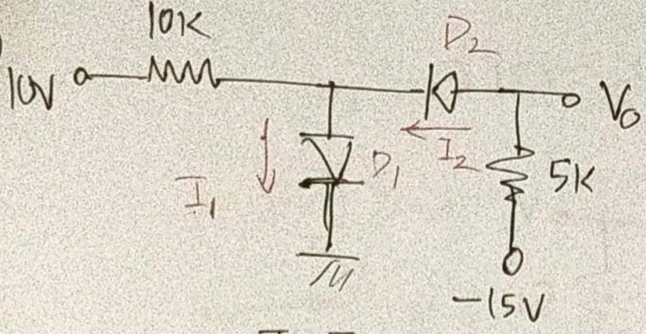
$V_1 = \cancel{1.636}\ 1.163\ V$

$V_2 = 1.863\ V$

$I_1 = \frac{3 - V_2}{1} = 1.137\ mA$, $I_2 = \frac{V_2 - 0}{2} = 0.932\ mA$

$\therefore I_D = I_1 - I_2$ [KCL] $= 0.205\ mA$ [correct assumption]

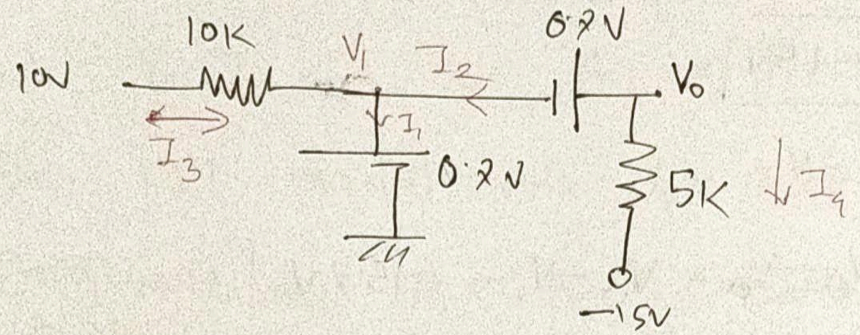
(5)



[Neaman: 2.55]

Find V_o, I_1, I_2. Use CVD model with $V_\gamma = 0.7V$.

Sol^n: Assume $D_1 = ON$, $D_2 = ON$.



$V_1 = 0.7V$

$V_o = V_1 + 0.7V = 1.4V$

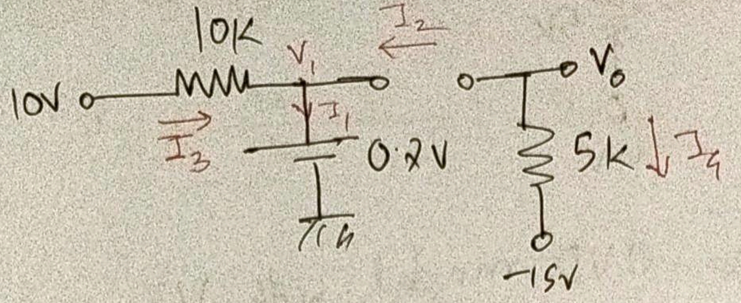
$I_3 = \frac{10 - 0.7}{10} = 0.93 mA$

$I_4 = \frac{1.4 - (-15)}{5} = 3.28 mA$

From KCL, $I_2 = -I_4 = -3.28 mA$ [Assumption wrong for D_2]

$I_1 = I_3 + I_2 = -2.35 mA$ [Assumption wrong for D_1]

Assume $D_1 = ON$, $D_2 = OFF$



Open CKT $\Rightarrow I_2 = 0$

$I_4 = 0$

$\therefore \boxed{V_o = -15V}$

$V_1 = 0.2V$

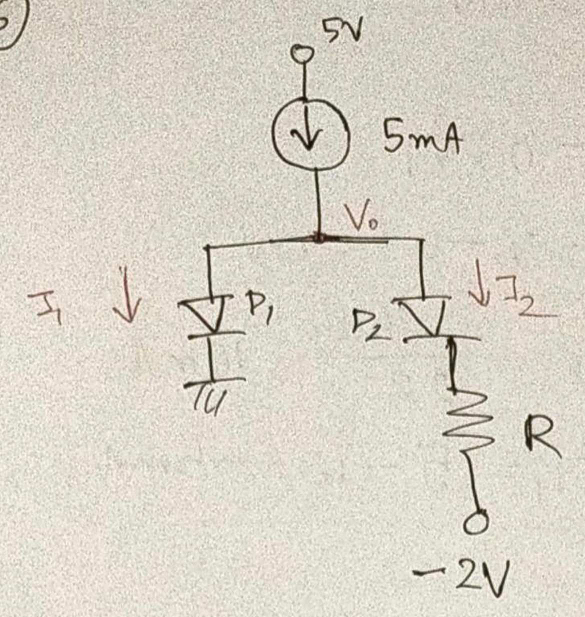
$\therefore V_{D2} = \cancel{V_o - V_p} = V_o - V_1 = -15.2V$ [Assumption correct for D_2]

$I_3 = \frac{10 - V_1}{10} = \frac{10 - 0.2}{10} = 0.93mA$

$I_1 = I_3 = 0.93 mA$ [KCL] [Assumption correct for D_1]

So, $\boxed{V_o = -15V}$ Ans

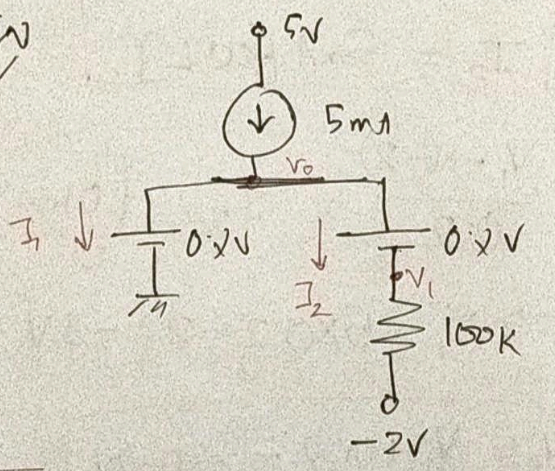
(6)



Find V_o, I_1 and I_2 for (a) $R = 100\,K$, (b) ~~R = 1k~~ $R = 0.2K$.

Use CVD model with $V_\gamma = 0.2V$.

Soln: (a) assume $D_1 = ON$, $D_2 = ON$



$\boxed{V_o = 0.2V}$

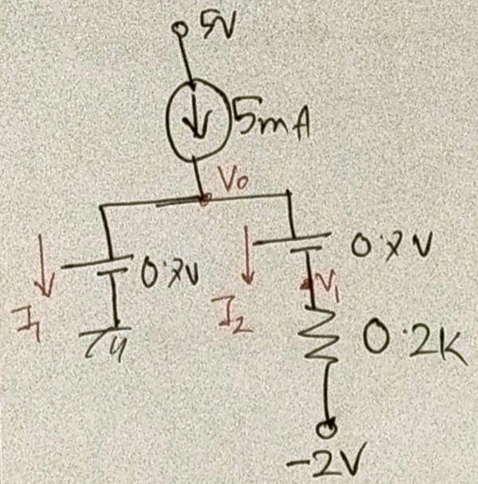
$V_1 = V_o - 0.2 = 0V$

$$\therefore \boxed{I_2 = \frac{0-(-2)}{100} = 0.02\,mA}$$

$$\boxed{I_1 = 5 - I_2 \; [KCL] = 4.98\,mA}$$

Since I_1 and I_2 both are positive, Assumption correct.

(b) Assume $D_1 = ON$, $D_2 = ON$



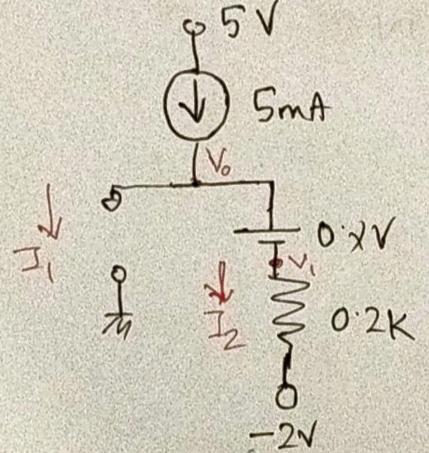
$$\boxed{V_o = 0.7V}$$

$$V_1 = V_o - 0.7 = 0V$$

$$\boxed{I_2 = \frac{0-(-2)}{0.2} = 10mA \qquad \therefore I_1 = 5 - I_2 = -5mA}$$

Since current through D_1 is negative, assumption wrong.

Assume $D_1 = OFF$, $D_2 = ON$



$$\boxed{I_1 = 0\,mA \qquad I_2 = 5mA\ [KCL]}$$

$$\frac{V_1 - (-2)}{0.2} = I_2 \quad [\text{Ohm's law}]$$

$$\Rightarrow V_1 = 5 \times 0.2 - 2 = -1V$$

$$\boxed{V_o = V_1 + 0.7 = -0.3V}$$

Since $V_D = -0.3V$ for D_1 and $V_D < 0.7V$,
assumption for D_1 correct.
$I_1 = +ve \Rightarrow$ Assumption for D_2 correct.