• Introduction to Semiconductors and Semiconductor Diodes

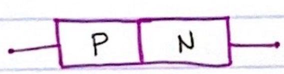
⇒ Electronics Devices

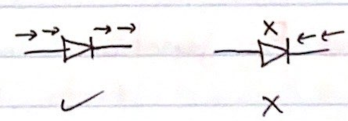
1. Diodes (Two Terminals)
   - a) Rectifier diode (AC → DC)
   - b) Zener diode (Voltage regulation)
   - c) Light Emitting Diode (LED)

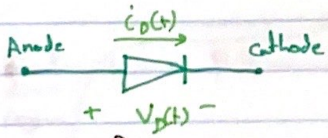
   } 5-6 Lectures
2. Transistors (3 Terminals)
   - a) Bipolar Junction Transistor (BJT) → 6-7 lectures
   - b) Field Effect Transistor (FET) → 4-5 lectures
3. Integrated Circuits (IC)

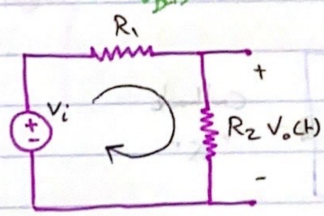
⇒ Diode

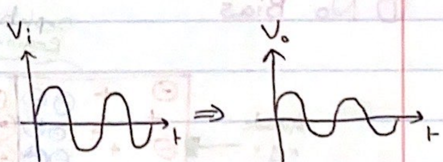
يمرر التيار باتجاه واحد ⇐

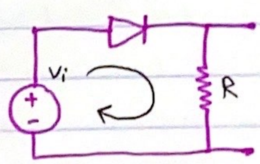


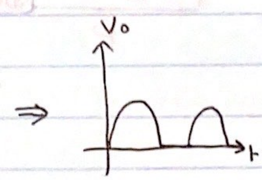












* $R_{conductor} < R_{semiconductor} < R_{Insulator}$

⇒ Semiconductors: Materials whose resistance lies between low resistance of conductor and the high resistance of insulator

⇒ Doping

Manufacture process that adds free charge carriers (free electron or hole)

① n-type (بكون فيه الكترون طاير مثلاً)

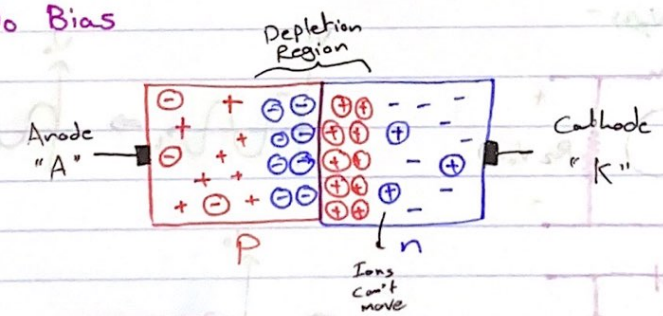
- Majority carriers are **electrons**, minority carriers are holes
- Donor atom ⇒ **phosphorus**

② P-type

- Trivalent impurity atoms are added (with 3 Valence electrons) such as **Boron (B)** or **Gallium (Ga)**
- Majority carriers are **holes**, Electrons are minority carriers

⇒ Pn junction

① No Bias



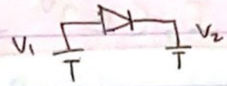
Reverse & Forward Bias

⇒ بالجسم بجدية دراسة
الكعز حاليا ٢٠٢٤م

⇒ Barrier Potential

at 25 deg C:

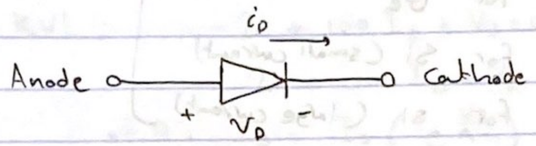
- for Silicon = 0.7
- for Germanium = 0.3

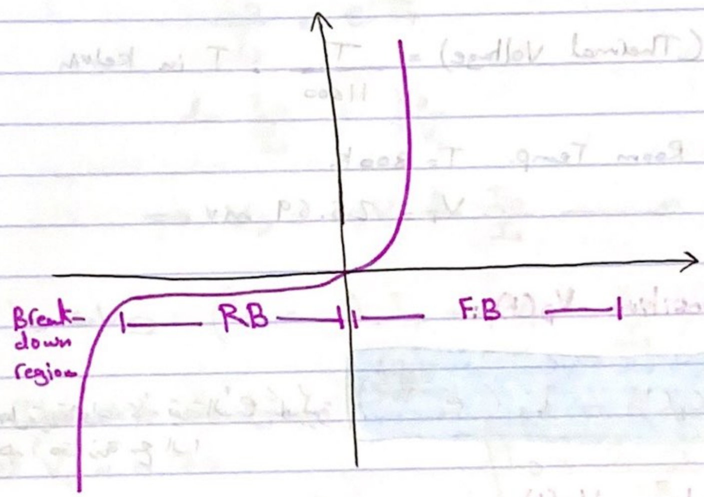


$V_1 > V_2$

0.7 بحدود

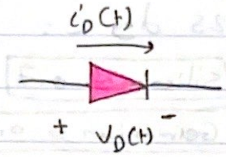
⇒ Semiconductor Diode I-V curve





• Semiconductor Diodes and their Models

$$i_D(t) = I_s\left(e^{\frac{V_D(t)}{\eta V_T}} - 1\right)$$



I_s: Reverse saturation current
I_s: $10^{-12}, 10^{-14}$ A

$$\eta\,(\text{eta}) = \begin{cases} 1 & \text{for Ge} \\ 2 & \text{for Si (small current)} \\ 1 & \text{for Si (large current)} \end{cases}$$

V_T (Thermal Voltage) $= \dfrac{T}{11600}$; T in kelvin

• at Room Temp. T = 300 K

$\therefore V_T = 25.69$ mV

* For positive $V_D(t)$:

$$i_D(t) = I_s\left(e^{\frac{V_D(t)}{\eta V_T}}\right)$$

⇐ بنهمل قيمة الواحد لأنه قيمة الـ e^x بتكون كبيرة جداً مقارنة مع الـ 1

* For negative $V_D(t)$

$$i_D(t) = -I_s$$

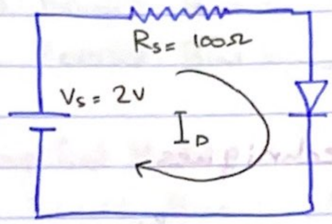
⇐ قيمة الـ e^x بتكون صغيرة جداً منهملها مقارنة مع الـ 1

⇒ Approches to Diode Circuit Analysis

There are essentially three basic approaches to the solution of such problem:

① The use of non-linear mathematics (لازم يكون معنا المعادلة والبارميترز)
② The use of Graphical Technique (تبكون معنا الرسمة وبنستنتج الحل منها)
③ The use of equivelant circuit (Models)

① Non-linear Mathematic (مش مطلوبة معنا، مثال للتوضيح)



$\eta = 1.1$

$I_s = 10^{-14} A$

$\Rightarrow$ KVL : $-2 + 100 I_D + V_D = 0$

$$2 = 100 I_D + V_D \quad \text{——①}$$

*F.B : $I_D = I_s \left(e^{\frac{V_D}{\eta V_T}} \right)$

$$\frac{I_D}{I_s} = e^{\frac{V_D}{\eta V_T}}$$

$$\ln \frac{I_D}{I_s} = \frac{V_D}{\eta V_T}$$

$$\Rightarrow V_D = \eta V_T \ln \frac{I_D}{I_s} \quad \text{——②}$$

by solving : $\left(V_s = R_s I_D + \eta V_T \ln \frac{I_D}{I_s} \right)$

· Iternative Analysis:

$I_D = \frac{2 - V_D}{100}$
$V_D = \eta V_T \ln \frac{I_D}{I_s}$

1) let $V_D = 0.7V$

$I_D = \frac{2-0.7}{100} = 13 \text{ mA}$

$\Rightarrow V_D = 0.7882392 V$ (The error is large)

2) let $V_D = 0.7882392 V$

$I_D = 12.117608 \text{ mA}$

$\Rightarrow V_D = 0.7862529 V$ (The error is small)

3) let $V_D = 0.7862529$

$I_D = 12.137471 \text{ mA}$

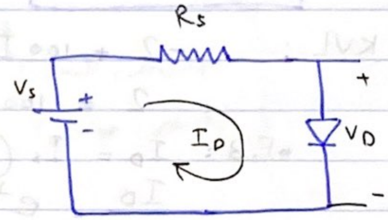
$V_D = 0.7862991 V$ (The error are getting smaller)

4) let $V_D = 0.7862991\,V$

$$I_D = 12.137009\ mA$$
$$V_D = 0.786298066\,V$$ ✓

② The use of Graphical Techniques

$$V_s = R_s I_D + V_D$$

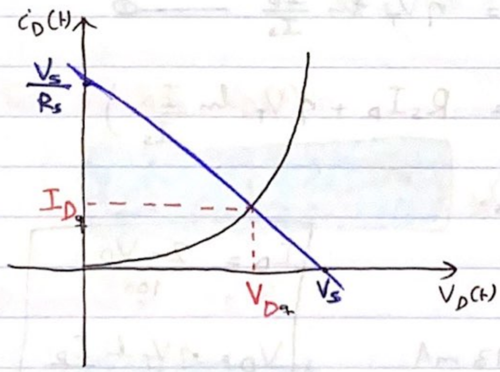


$$I_D = \frac{V_s}{R_s} - \frac{1}{R_s} V_D$$

$$I_D = \frac{-1}{R_s} V_D + \frac{V_s}{R_s}$$

$$= mx + b$$

⇐ بنرسم المعادلة الي طلعت معنا على ال Graph ، نقطة التقاطع هي الحل



dc ≡ operating point ≡ Q-point = (V_{DQ}, I_{DQ})

③ Diode (Models)

- → Ideal Model
- → Simplified / piecewise / Knee / partial model
- → Complete diode model

I) Ideal Model

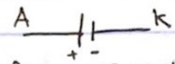
a) Forward Bias : 

(short circuit) ⇒ $V_{AK} = 0$

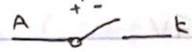
b) Reversed Bias : 

(open circuit) ⇒ $I_{AK} = 0$

II) Simplified Model

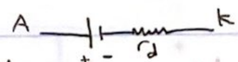
a) Forward Bias : 

$V_{AK} = 0.7V$

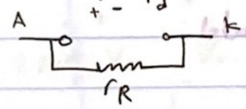
b) Reversed Bias : 

(open circuit) → $I_{AK} = 0$

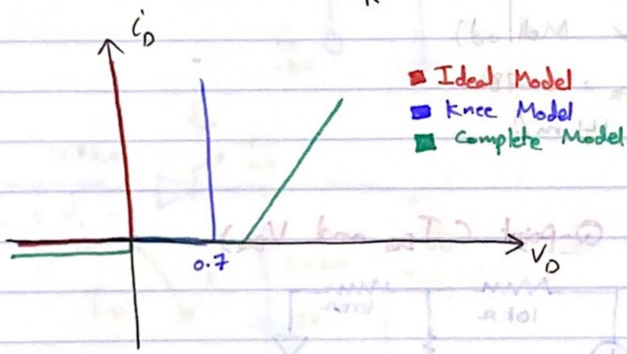
III) Complete Model

a) Forward Bias : 

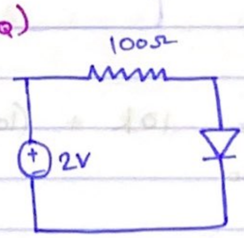
$V_{AK} = 0.7 + I_D r_d$, $r_d = \frac{V_T}{I_{DQ}}$

b) Reversed Bias : 

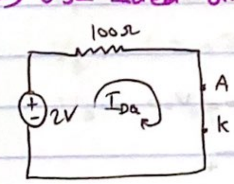
r_R is high (MΩ's)



ex Find the Q-point (I_{DQ} and V_{DQ})



a) Use Ideal diode Model

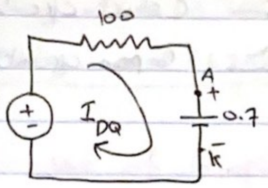


$V_{AK} = V_{DQ} = 0$ (short circuit)

$-2 + 100 I_{DQ} = 0$

$I_{DQ} = \frac{2}{100} = 0.02 A = 20mA$

b) Use practical diode Model



$V_{AK} = V_{DQ} = 0.7V$

$-2 + 100\, I_{DQ} + 0.7 = 0$

$I_{DQ} = \frac{1.3}{100} = 13\,mA$

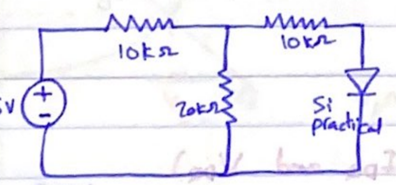
c) Use exact model

(Non-linear Method)

$V_{DQ} = V_{AK} = 0.786V$

$I_{DQ} = 12.14\,mA$

ex Find the Q-point (I_{DQ} and V_{DQ})

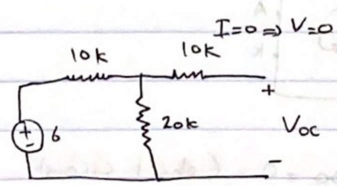


$R_{th}\big|_{6V=0} = 10k + (10k \,//\, 20k) = 16.667\ k\Omega$

$V_{th} = V_{oc} = V_{20k}$

$= \frac{20k}{20k + 10k} \cdot 6$

$= 4V$



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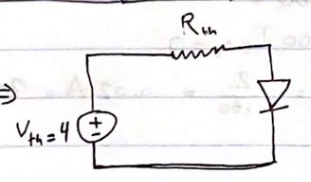
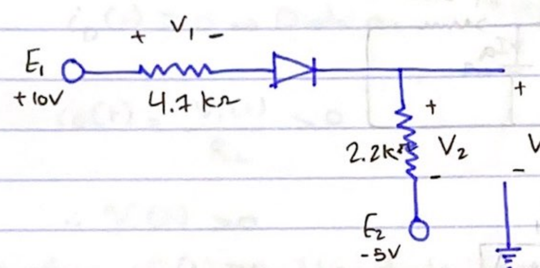


$$V_{AK} = \boxed{V_{DQ} = 0.7V}$$

$$4 = 16.67k\,I + 0.7$$

$$I = \frac{4-0.7}{16.67k} = \boxed{0.198\,mA = I_{DQ}}$$

ex Find I, V_1, V_2 and V_o (simplified method)



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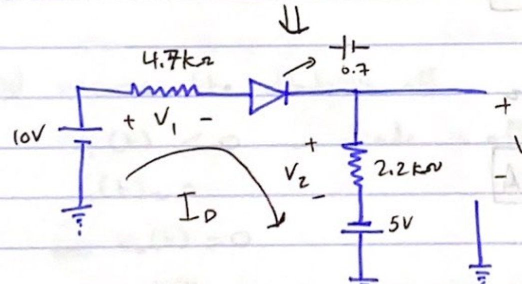


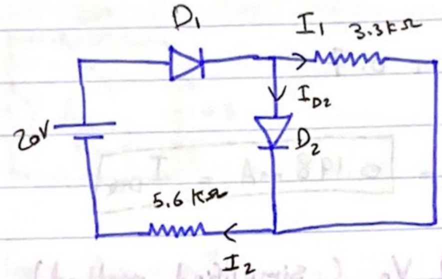
$$I_D = \frac{10 - 0.7 + 5}{4.7k + 2.2k} = 2.07\,mA$$

$$V_1 = (2.07m)(4.7k) = 9.74V$$

$$V_2 = (2.07m)(2.2k) = 4.56V$$

$$V_o = V_2 - 5 = -0.45V$$

ex Find I_1, I_2, I_{D2} (practical model)



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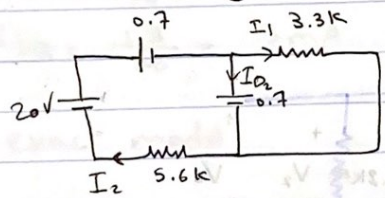


* $V_1 = 0.7 = 3.3k I_1$

$\Rightarrow \boxed{I_1 = 0.212\,mA}$

* $\frac{20 - 0.7 - 0.7}{5.6k} = I_2$

$\Rightarrow \boxed{I_2 = 3.32\,mA}$

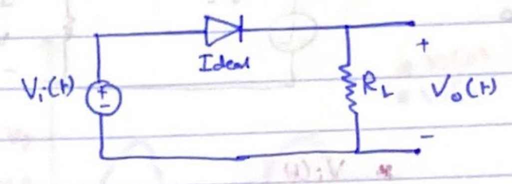
* $I_2 = I_1 + I_{D2}$

$3.32m = 0.212m + I_{D2}$

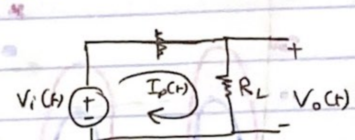
$\Rightarrow \boxed{I_{D2} = 3.108\,mA}$

· Diode Applications

⇒ Clipper circuits



a) assume the diode is on :



$i_D(t) > 0 \Rightarrow$ Diode On

$$i_D(t) = \frac{V_i(t)}{R_L} > 0$$

$\therefore V_i(t) > 0$

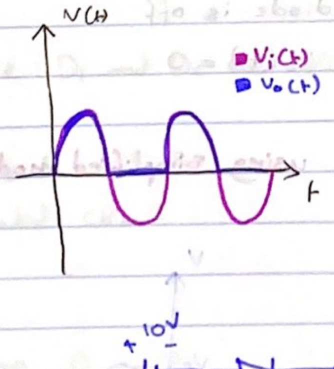
⇒ when $V_i(t) > 0$, the diode is on , $V_o(t) = V_i(t)$

b) assume the diode is off

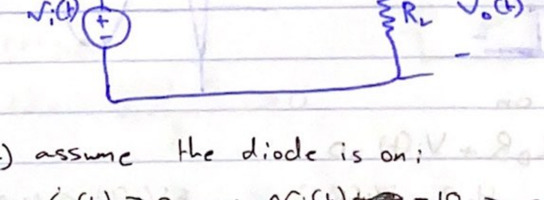
$V_i(t) < 0 \Rightarrow$ diode is off

$i(t) = 0$

$\Rightarrow V_o(t) = 0$



ex



a) assume the diode is on ;

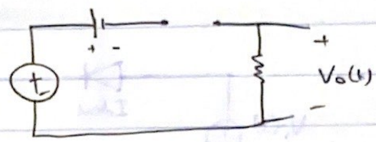
$$i_D(t) > 0 \Rightarrow \frac{V_i(t) - 10}{R_L} > 0 \Rightarrow V_i(t) > 10$$

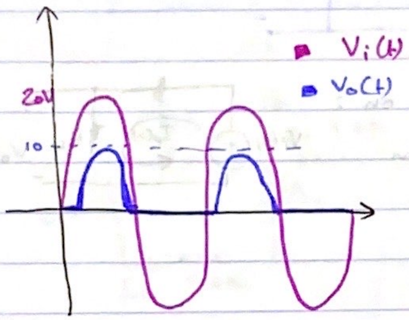
$V_o(t) = V_i(t) - 10$

when $V_i(t) < 10 \Rightarrow$ Diode is off

$\Rightarrow i_D(t) = 0$

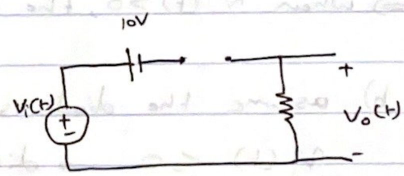
$\Rightarrow V_o(t) = 0$





* Second Method

- Assume the diode is off:



$V_D(t) < 0$

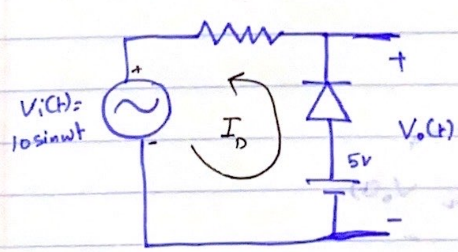
$V_D(t) = -10 + V_i(t)$

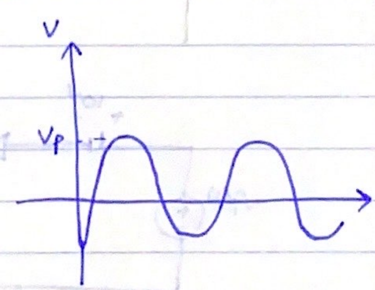
$V_i(t) < 10V$

When $V_i(t) < 10 \Rightarrow$ the diode is off

+ $V_o(t) = 0$

ex Calculate and sketch $V_o(t)$ using simplified model





a) Assume diode is on

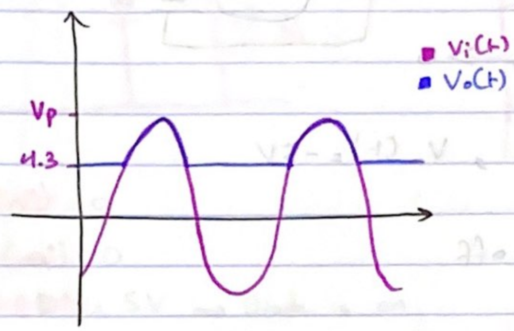
$-5 + 0.7 + I_D R + V_i(t) = 0$

$I_D(t) R = 4.3 - V_i(t) \Rightarrow \quad \& V_i(t) < 4.3V$

$\Rightarrow V_o(t) = 4.3V$

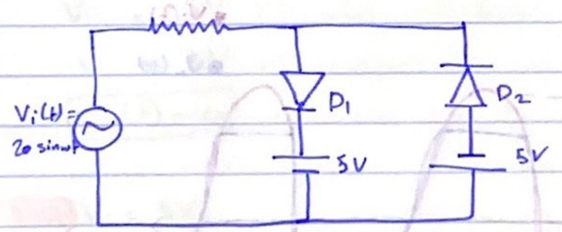
b) when $V_i(t) > 4.3V \Rightarrow$ The diode will be off

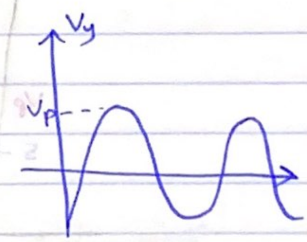
$V_o(t) = V_i(t)$



$\Rightarrow$ Circuit Containing Two Diodes

ex Calculate and sketch $V_o(t)$ using Ideal model

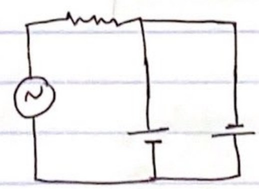




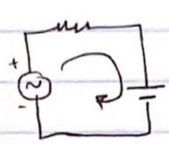
① Assume D_1 and D_2 are on

$V_o = 5 = -5$?

Invalid circuit



② D_1 on , D_2 off

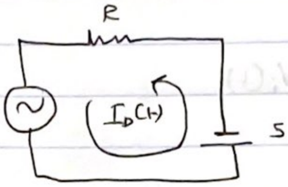


$i_D(t) > 0$

$$i_D(t) = \frac{V_i(t) - 5}{R} > 0$$

$\Rightarrow V_i(t) > 5$, $V_o(t) = 5$

② D_1 off , D_2 ON



$I_D(t) > 0$

$$I_D(t) = \frac{-V_i(t) - 5}{R} > 0$$

$\Rightarrow$ $V_i(t) < -5$, $V_o(t) = -5V$

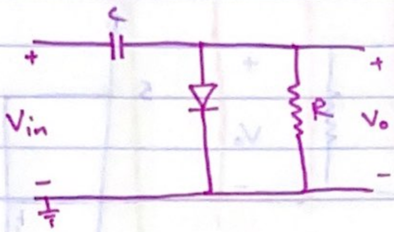
③ D_1 off , D_2 off

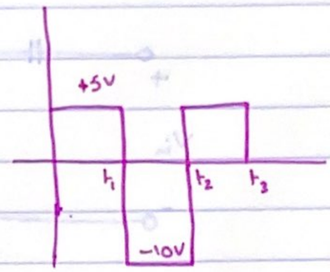
$V_o(t) = V_i(t)$

$-5 < V_i(t) < 5$

⟹ Clamper circuits

ex



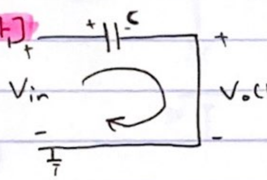


① $V_c(0^-) = 0$

② $V_c(0^+) = 0$

$V_i(0^+) = 5V$ ⟹ Diode is on

③ $[0^+, t_1]$



$V_{in} = 5V$

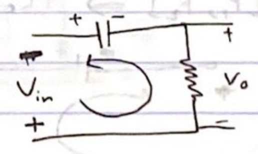
$V_c = 5V$

$\boxed{V_o(t) = 0}$

④ $[t_1, t_2]$ $V_c = 5V$

$V_{in} = -10V$ ⟹ Diode is off

$V_o(t) = -5 - 10 = -15V$

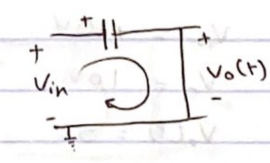


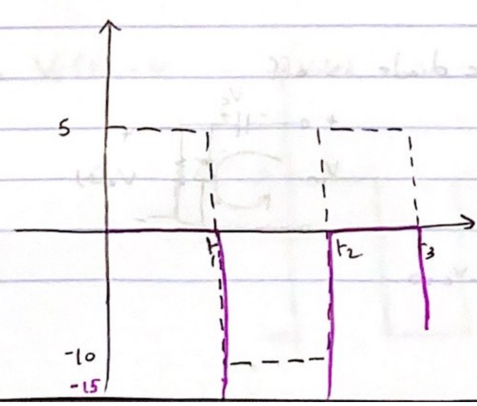
⑤ $[t_2, t_3]$

$V_c = 5V$

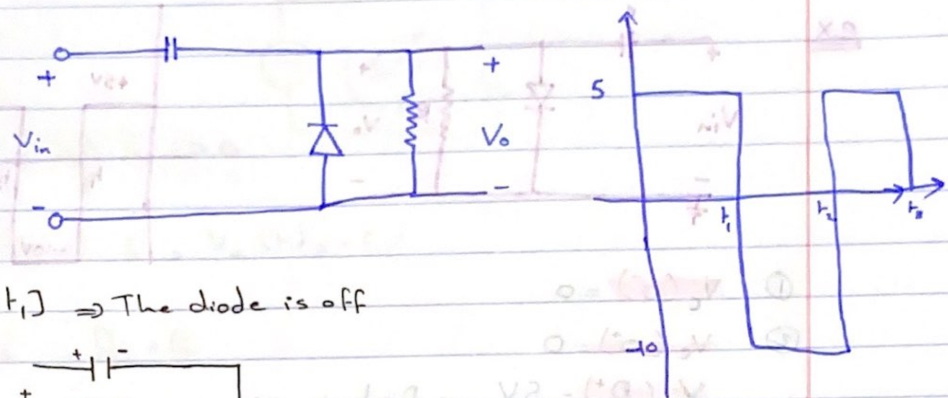
$V_{in} = 5V$

$V_o(t) = 0$

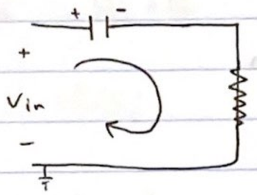




ex what happens if the diode was inversed



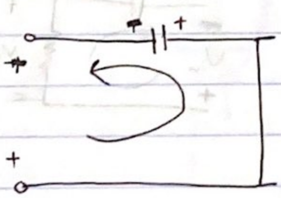
① $[0, t_1]$ ⇒ The diode is off



$V_{in} = 5$

$V_c = ?$ (we need the value for V_c to solve, so we will suppose that the diode is on, or go to the period the diode is on on it)

② $[t_1, t_2]$ ⇒ The diode is on



$V_{in} = +10V$

$V_c = 10V$

$V_o(t) = 0$

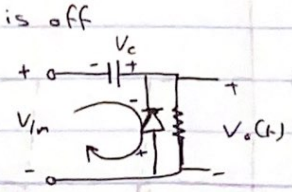
③ $[t_2, t_3]$ ⇒ The diode is off

$V_c = 10V$

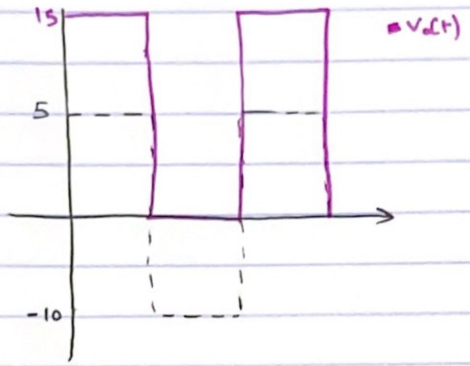
$V_{in} = 5$

$V_o(t) = +15V$

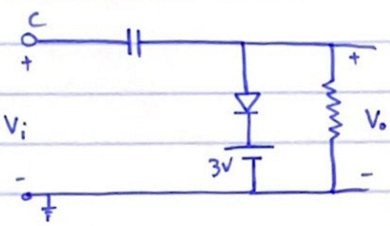
↳ $V_o(t) - V_{in} - V_c = 0$

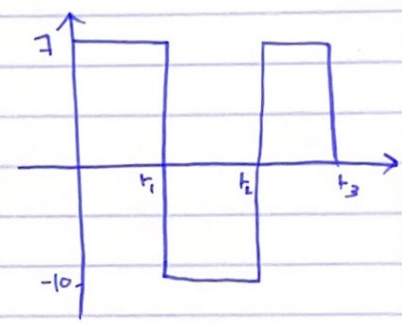


⇒ when the diode is off ⇒ $V_o(t) = V_i(t) + 10$



ex





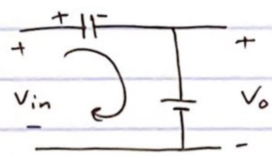
① $[0, t_1]$

$V_i(t) = 7$ ⇒ Diode is on

$V_c + 3 = V_{in}$

$\boxed{V_c = 4V}$

$\boxed{V_o = 3V}$

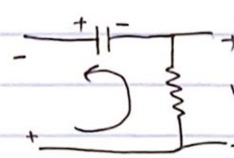


② $[t_1, t_2]$

$V_i(t) = -10$ ⇒ Diode is off

$V_C = 4V$

$V_o(t) = -4 - 10 = -14V$



⇒ $V_o(t) = V_i(t) - 4$