EE100Su08 Lecture #15 (July 30th 2008)

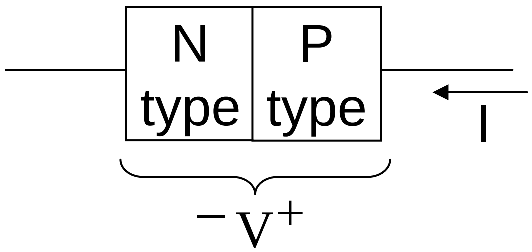
- Outline
  - MultiSim:
    - Step 1: Download program from (257.5 MB):

      http://ftp.ni.com/support/softlib/Circuit_Design_Suite/10.0/10.0.1/NI_CDS_10_0_1_Stu.exe
    - Step 2: Use license key given out in class
  - Project labs START NEXT WEEK (see updated schedule online tonight). For this week, make sure you finish Strain Gauge.
  - QUESTIONS?
  - Diodes: Wrap up
- Reading
  - Chapter 2 from your reader (Diode Circuits)

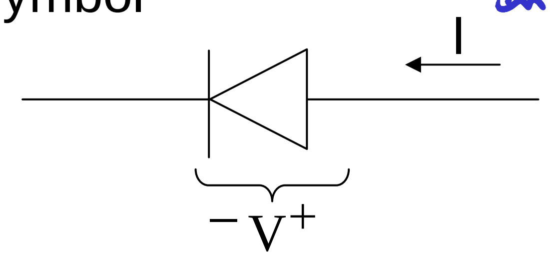
Diode Physical Behavior and Equation

Ref: Howe & Sodini, Microelectronics: An Integrated Approach.

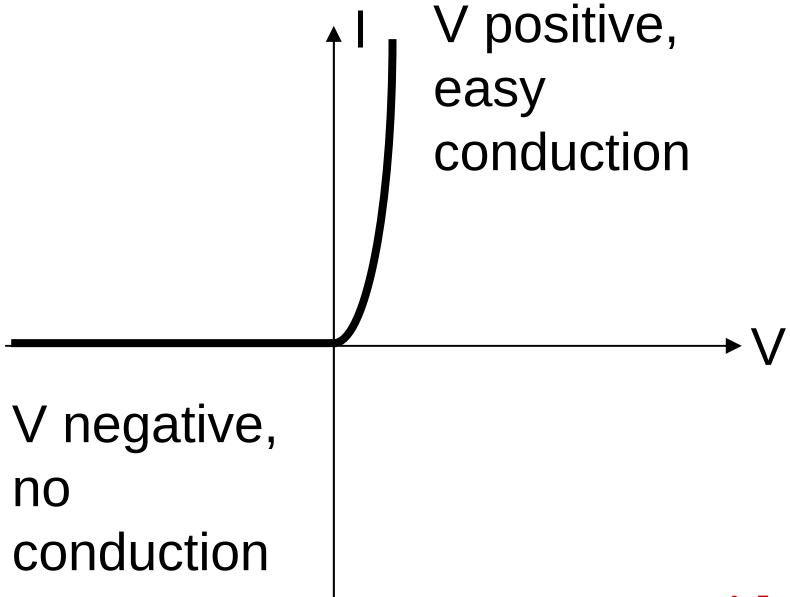
Schematic Device



Symbol



Qualitative I-V characteristics:



Quantitative I-V characteristics:

$$I = I_0(e^{qV/kT} - 1)$$

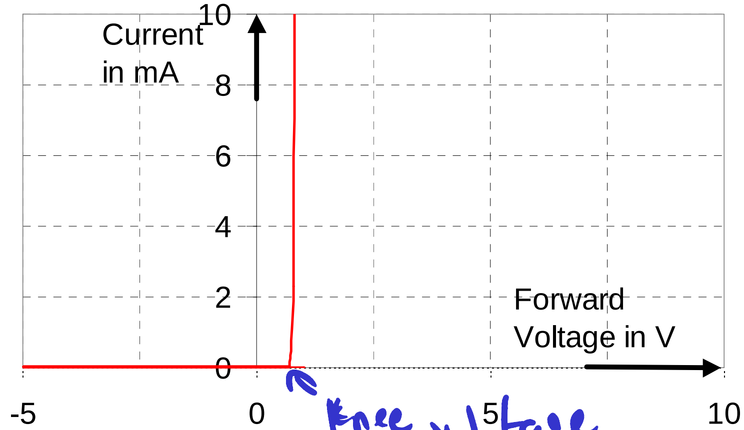
In which kT/q is 0.026V and I_O is a constant depending on diode area. Typical values: 10^{-12} to 10^{-16} A. Interestingly, the graph of this equation looks just like the figure to the left.

A non-ideality factor n times kT/q is often included.

Diode Ideal (Perfect Rectifier) Model

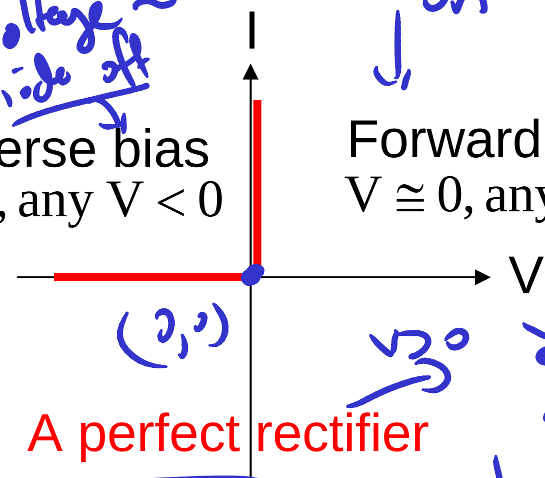
The equation $I = I_0 \exp(qV/kT - 1)$

is graphed below for $I_0 = 10^{-15}$ A



Simple "Perfect Rectifier" Model

If we can ignore the small forward-bias voltage drop of a diode, a simple effective model is the "perfect rectifier," whose I-V characteristic is given below:

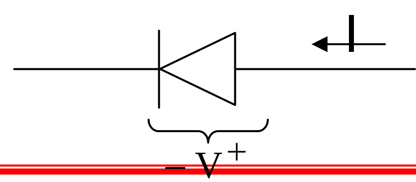


Reverse bias
$I \cong 0$, any $V < 0$

Forward bias
$V \cong 0$, any $I > 0$

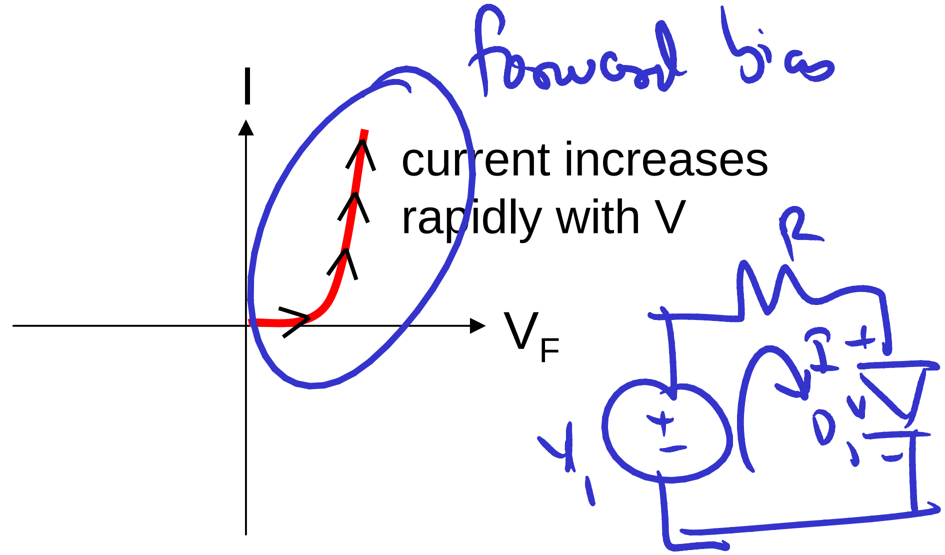
A perfect rectifier

The characteristic is described as a "rectifier" – that is, a device that permits current to pass in only one direction. (The hydraulic analog is a "check value".) Hence the symbol:

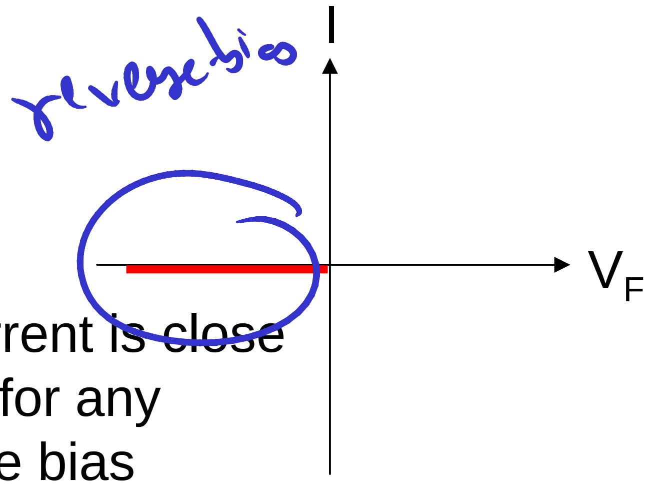


I-V Characteristics

In forward bias (+ on p-side) we have almost unlimited flow (very low resistance). Qualitatively, the I-V characteristics must look like:



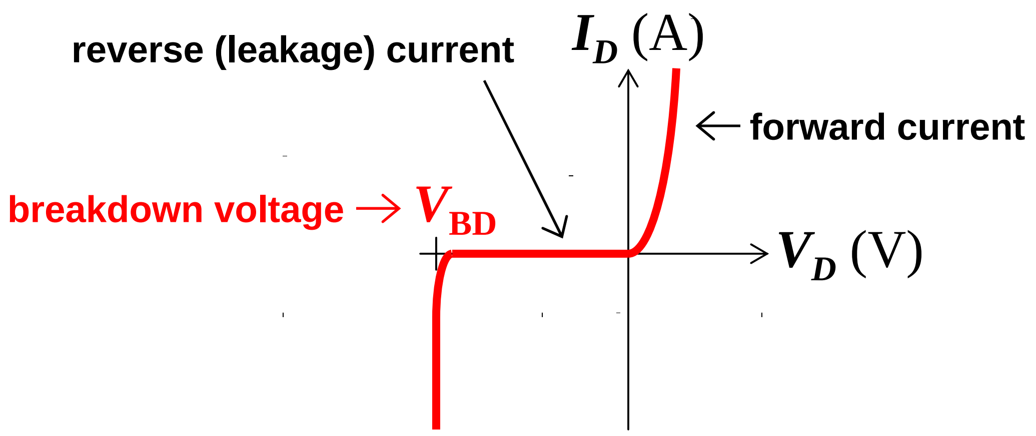
In reverse bias (+ on n-side) almost no current can flow. Qualitatively, the I-V characteristics must look like:



The current is close to zero for any negative bias

pn-Junction Reverse Breakdown

- As the reverse bias voltage increases, the peak electric field in the depletion region increases. When the electric field exceeds a critical value ($E_{crit} \cong 2\text{x}10^5$ V/cm), the reverse current shows a dramatic increase:



The pn Junction I vs. V Equation

I-V characteristic of PN junctions

In EECS 105, 130, and other courses you will learn why the I vs. V relationship for PN junctions is of the form

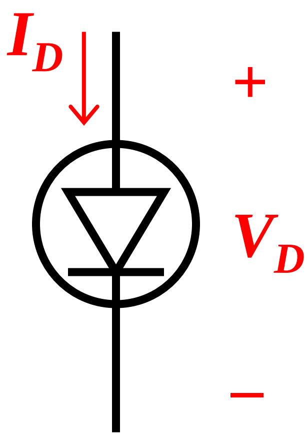
$$I = I_0(e^{qV/kT} - 1)$$

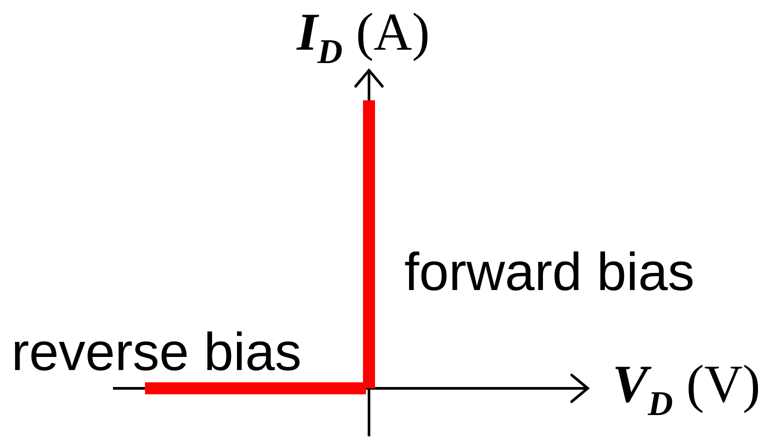
where I_0 is a constant proportional to junction area and depending on doping in P and N regions, $q = \text{electronic charge} = 1.6 \times 10^{-19}$, k is Boltzman constant, and T is absolute temperature.
$KT/q = 0.026V \text{ at} 300°K$, a typical value for I_0 is $10^{-12} - 10^{-15} A$

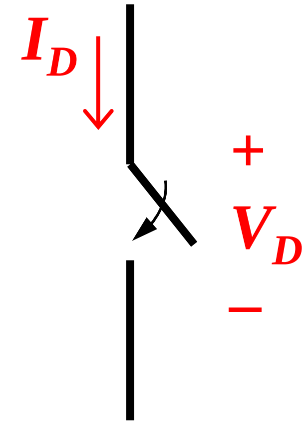
We note that in forward bias, I increases **exponentially** and is in the μA-mA range for voltages typically in the range of 0.6-0.8V.
In reverse bias, the current is essentially zero.

Ideal Diode Model of PN Diode

Circuit symbol	***I-V* characteristic**	**Switch model**



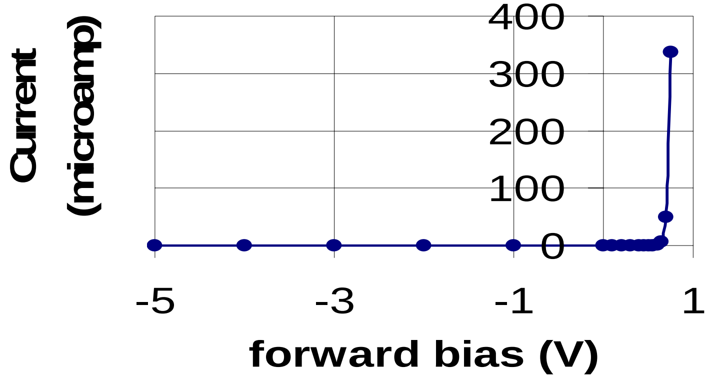


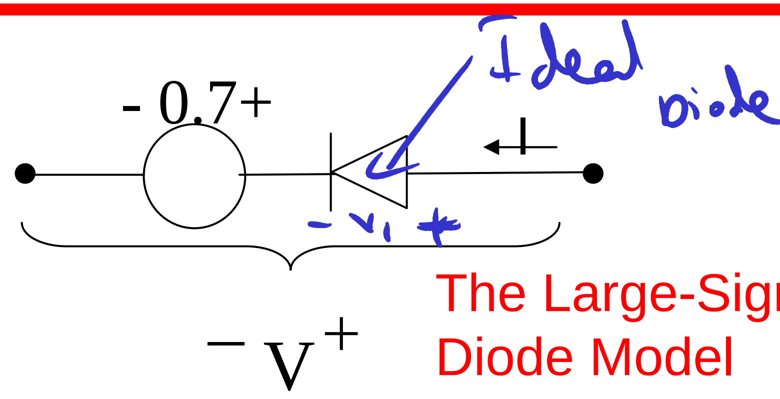


- An ideal diode passes current only in one direction.
- An ***ideal diode*** has the following properties:
  - when $I_D > 0$, $V_D = 0$
  - when $V_D < 0$, $I_D = 0$

Diode behaves like a switch:
- closed in forward bias mode
- open in reverse bias mode

Diode Large-Signal Model (0.7 V Drop)

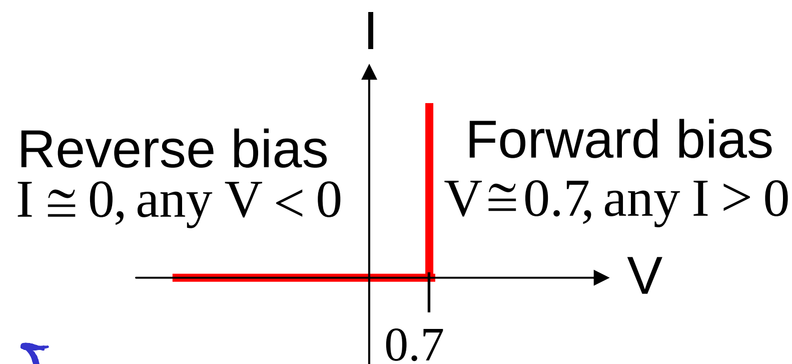


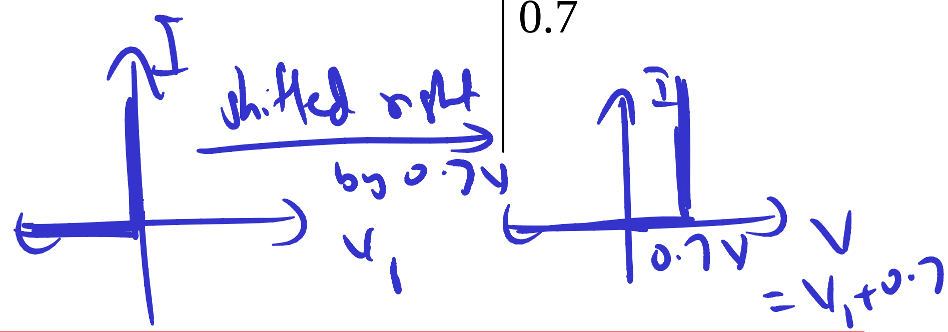


The Large-Signal Diode Model

Improved "Large-Signal Diode" Model:

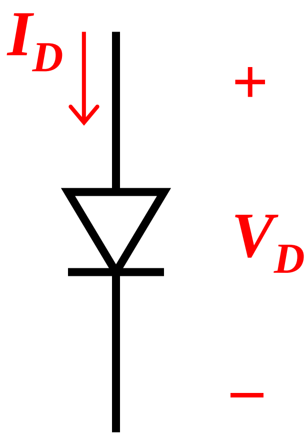
If we choose not to ignore the small forward-bias voltage drop of a diode, it is a very good approximation to regard the voltage drop in forward bias as a constant, about 0.7V. the "Large signal model" results.



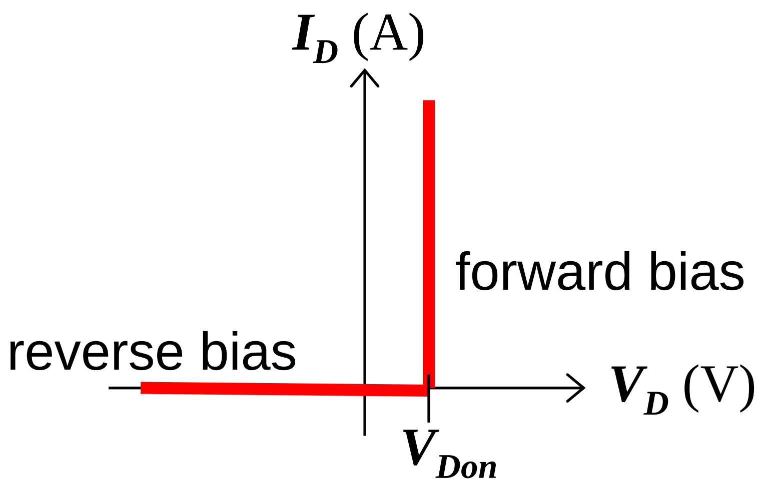


Large-Signal Diode Model

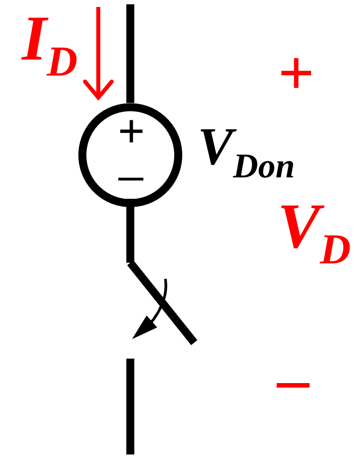
Circuit symbol



***I-V* characteristic**



Switch model



For a Si pn diode, $V_{Don} \cong 0.7$ V

RULE 1: When $I_D > 0$, $V_D = V_{Don}$

RULE 2: When $V_D < V_{Don}$, $I_D = 0$

Diode behaves like a voltage source in series with a switch:
- closed in forward bias mode
- open in reverse bias mode

How to Analyze Circuits with Diodes

A diode has only two states:

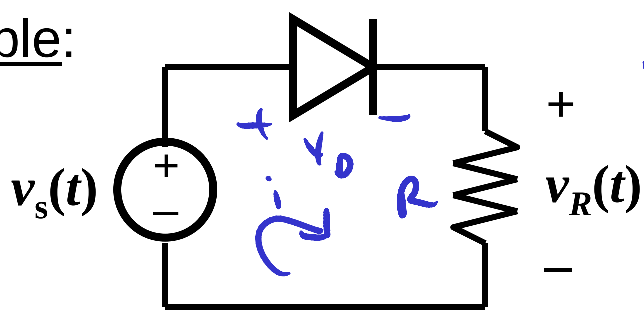
- **forward biased:** $I_D > 0$, $V_D = 0$ V
- **reverse biased:** $I_D = 0$, $V_D < 0$ V (or 0.7 V)

Procedure:

1. Guess the state(s) of the diode(s)
2. Check to see if KCL and KVL are obeyed.
3. If KCL and KVL are not obeyed, refine your guess
4. Repeat steps 1-3 until KCL and KVL are obeyed.

Note:
$V_S - V_D = V_R$
$\Rightarrow V_S - V_D = iR$ // ①
$f(V_D)$ ↓ Diode
Try solving ① in MATLAB

Example:



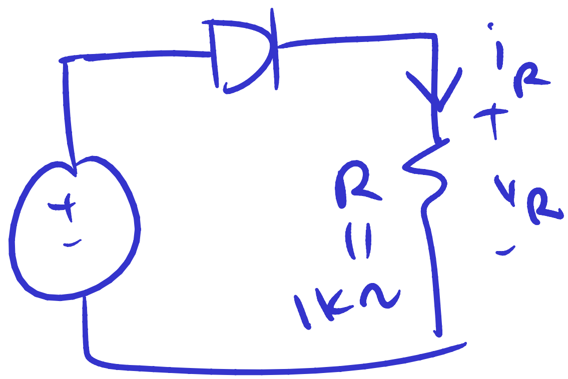
If $v_s(t) > 0$ V, diode is forward biased (else KVL is disobeyed – try it)

If $v_s(t) < 0$ V, diode is reverse biased (else KVL is disobeyed – try it)

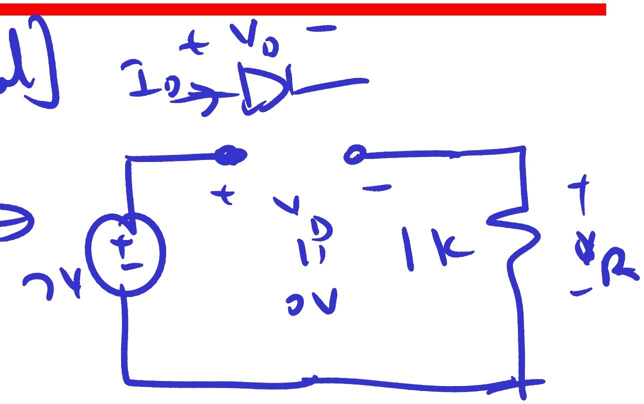
The circuit in the previous slide:

[Assume diode is ideal]

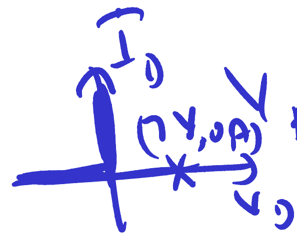
Ex 1



diode off →



Quiescent-point → Q-point

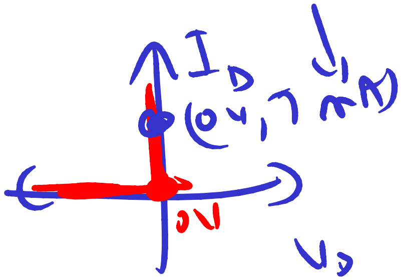


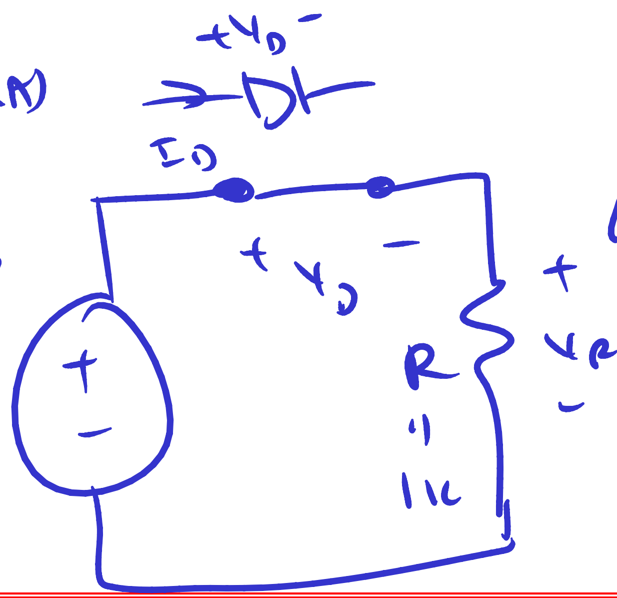
$V_D = 7\,V \Rightarrow$ oops, diode cannot be off

$I_D = 0\,A$

[assumption about diode state is incorrect!]

diode on:



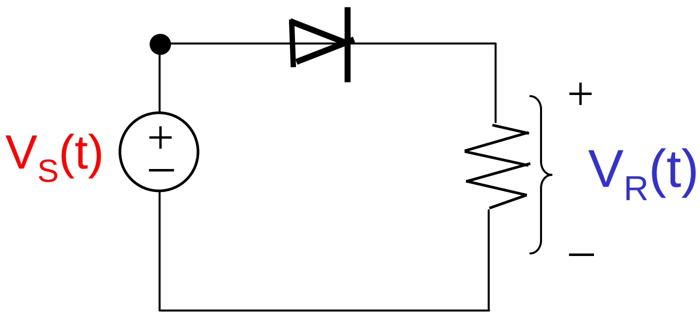


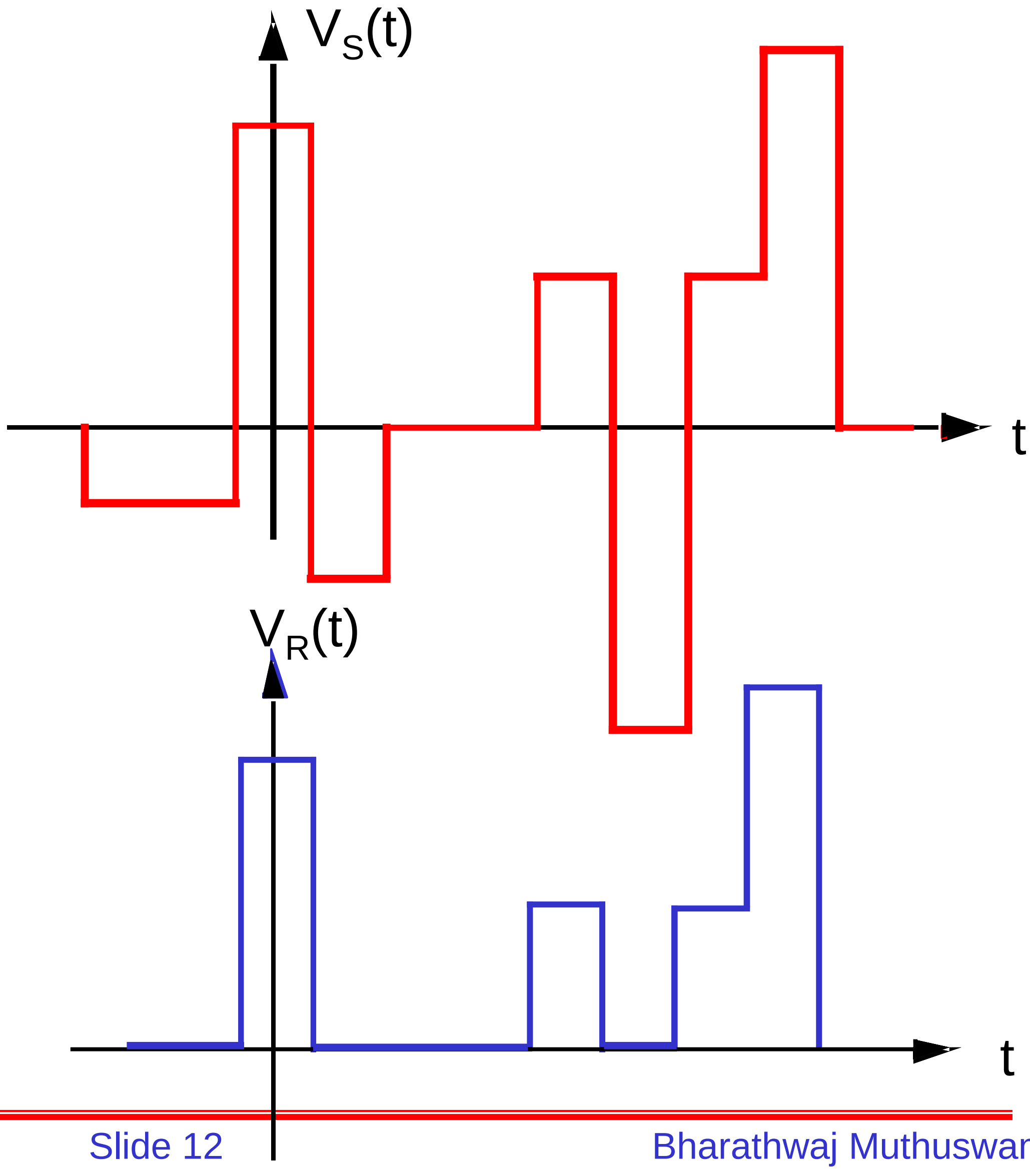
$V_D = 0\,V$

$$I_D = \frac{7}{1k} = 7\,mA$$

Rectifier Circuit

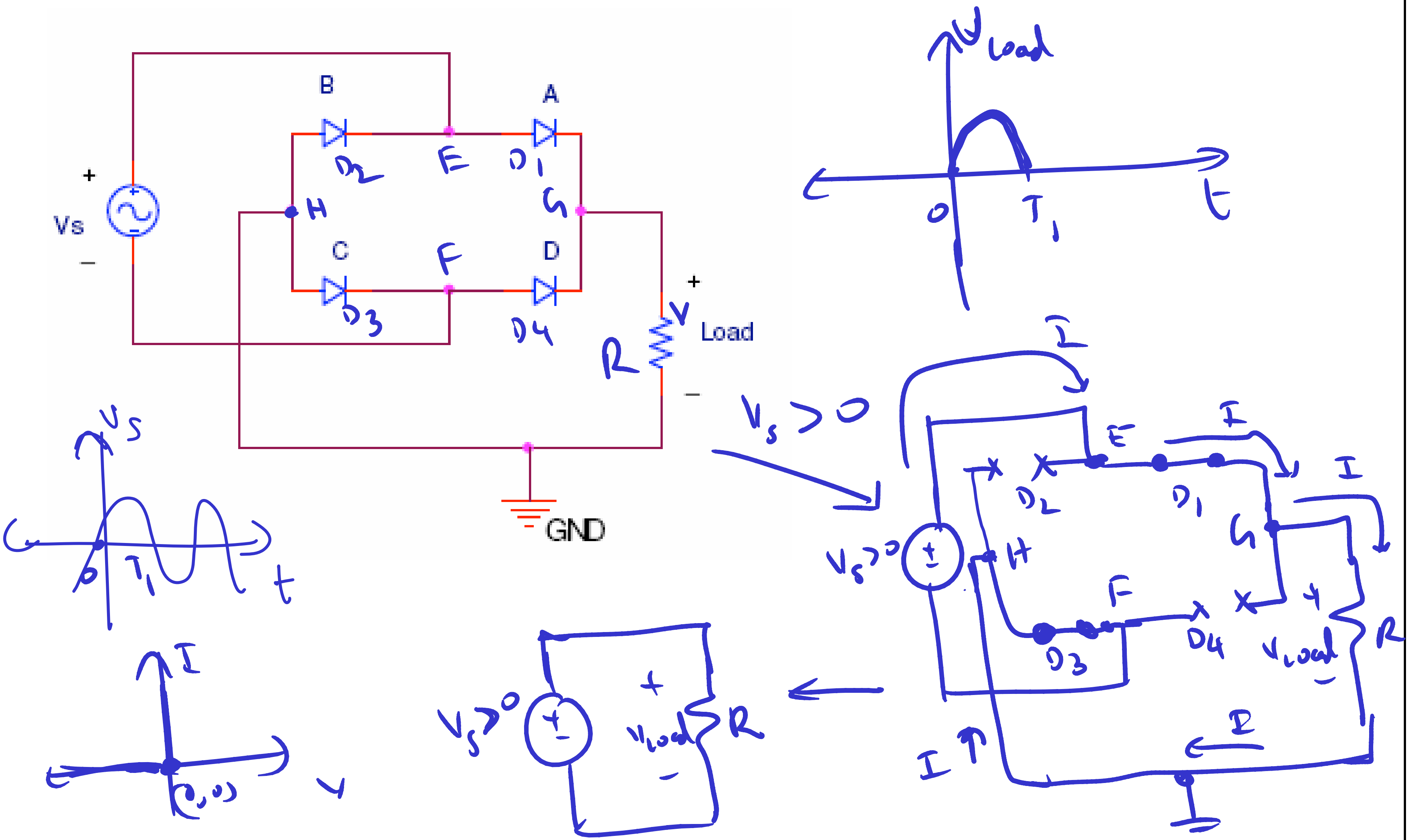
Assume the ideal (perfect rectifier) model.



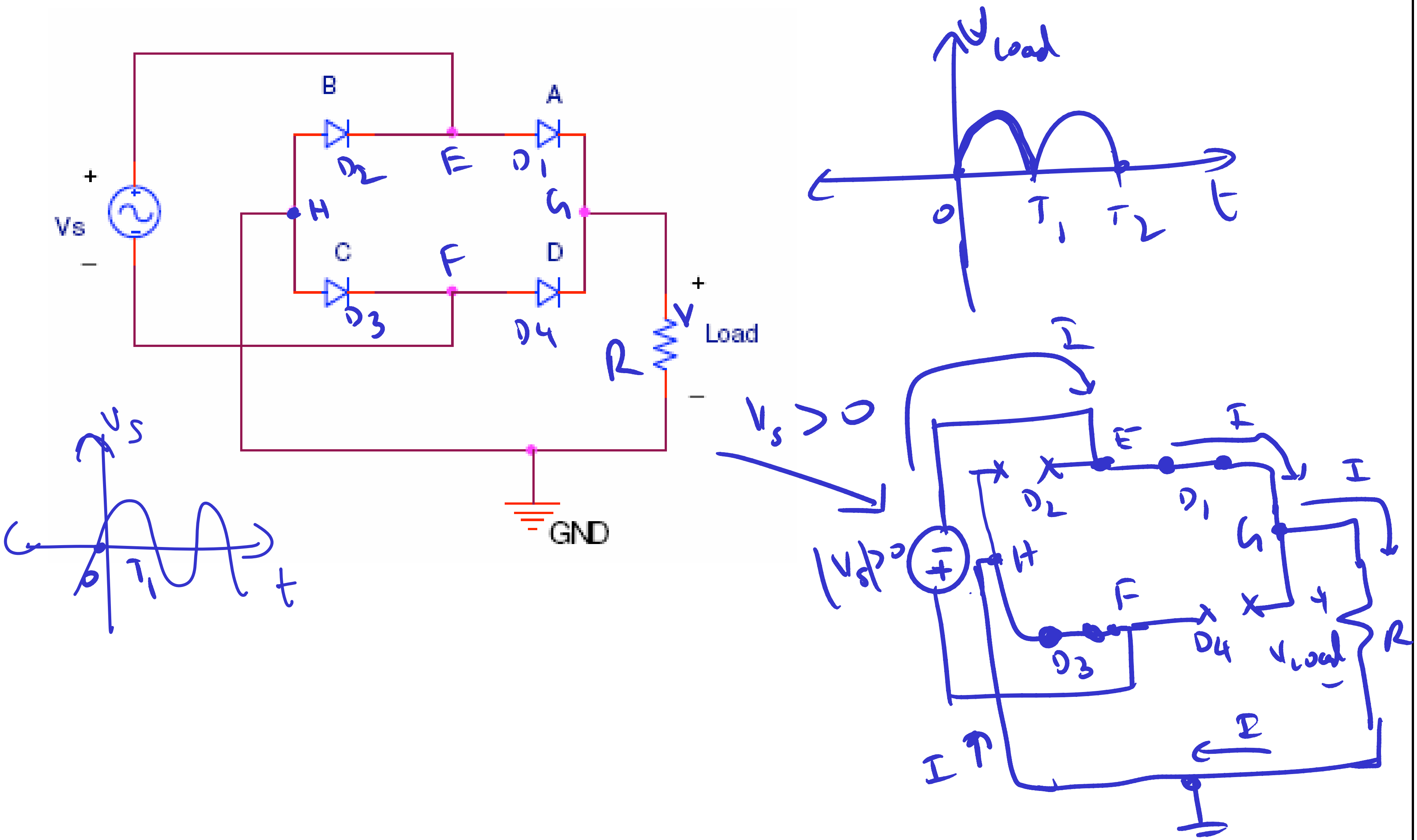


"rectified" version of input waveform

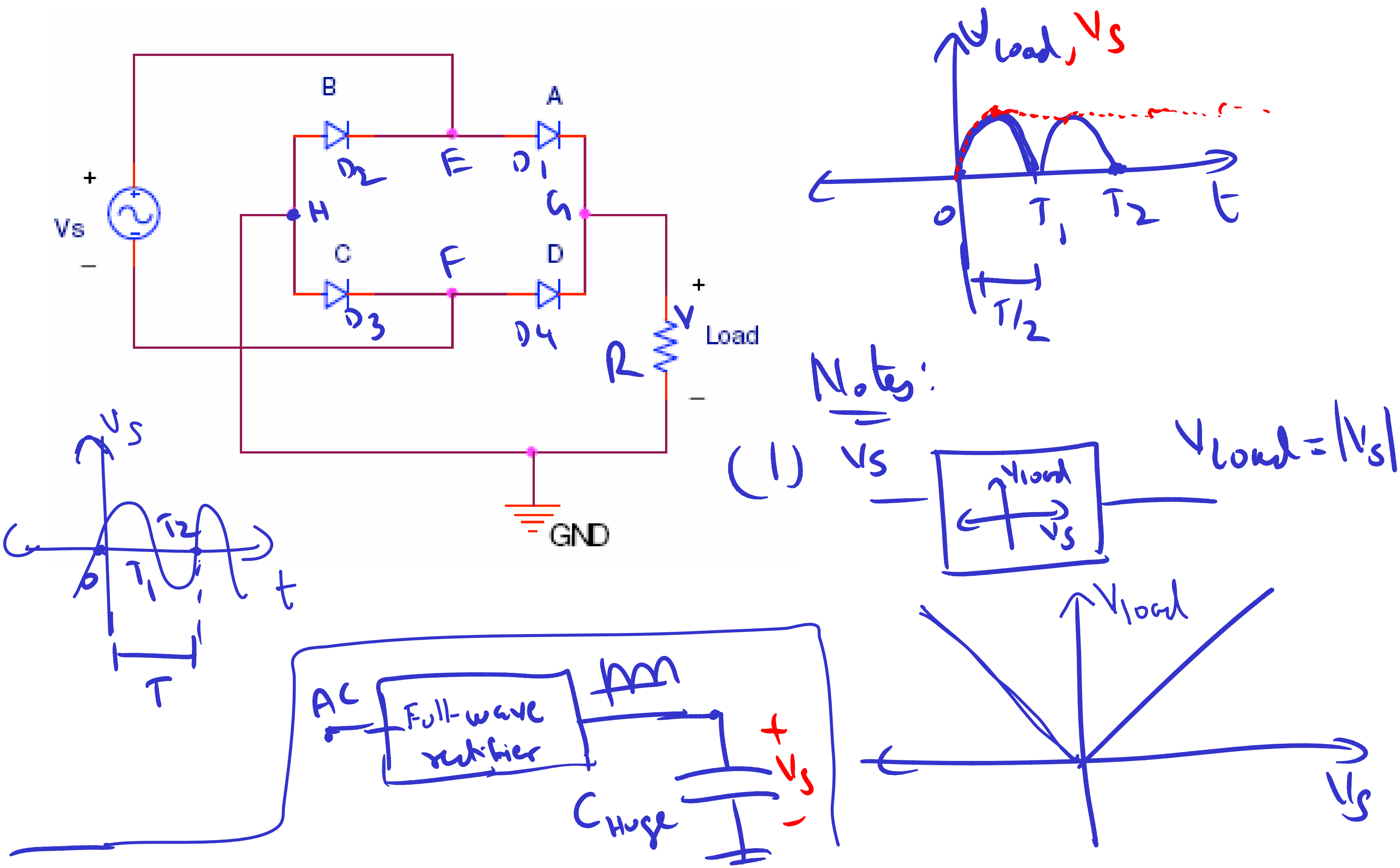
Full Wave Rectifier & AC-DC converter



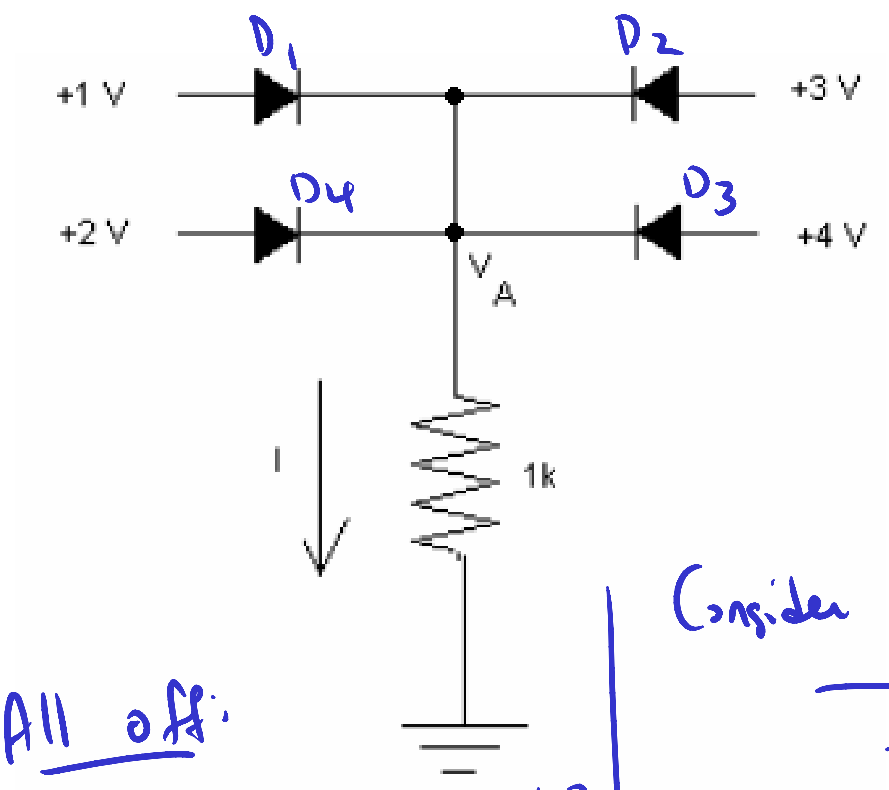
Full Wave Rectifier & AC-DC converter



Full Wave Rectifier & AC-DC converter



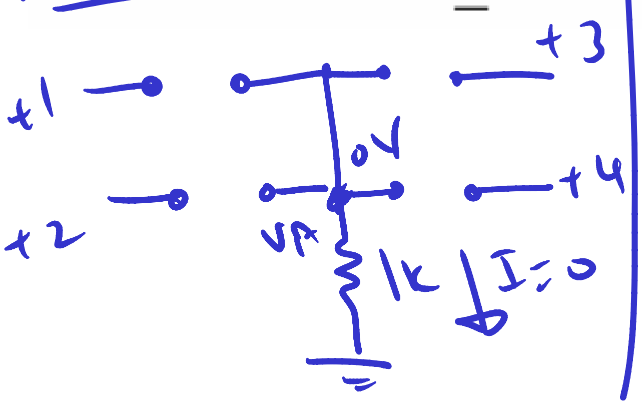
Another Example Circuit



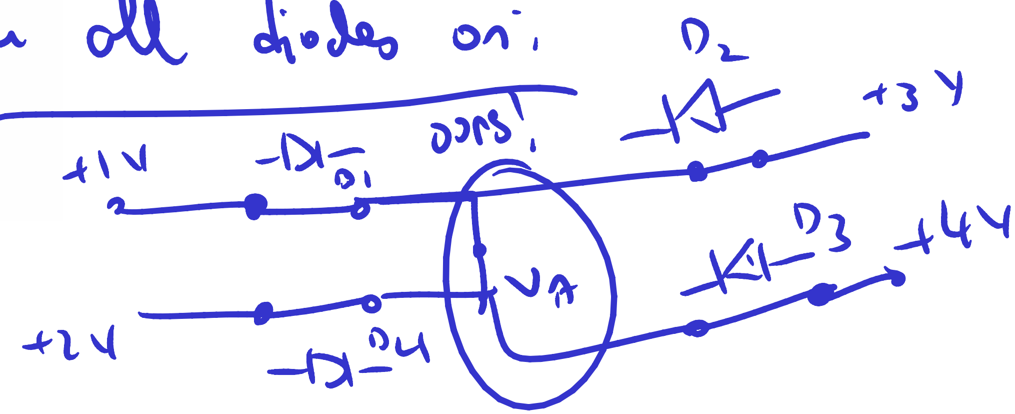
Assume D_1, D_2, D_3 & D_4 are ideal, find V_A & I.

$V_A = 4\ V$

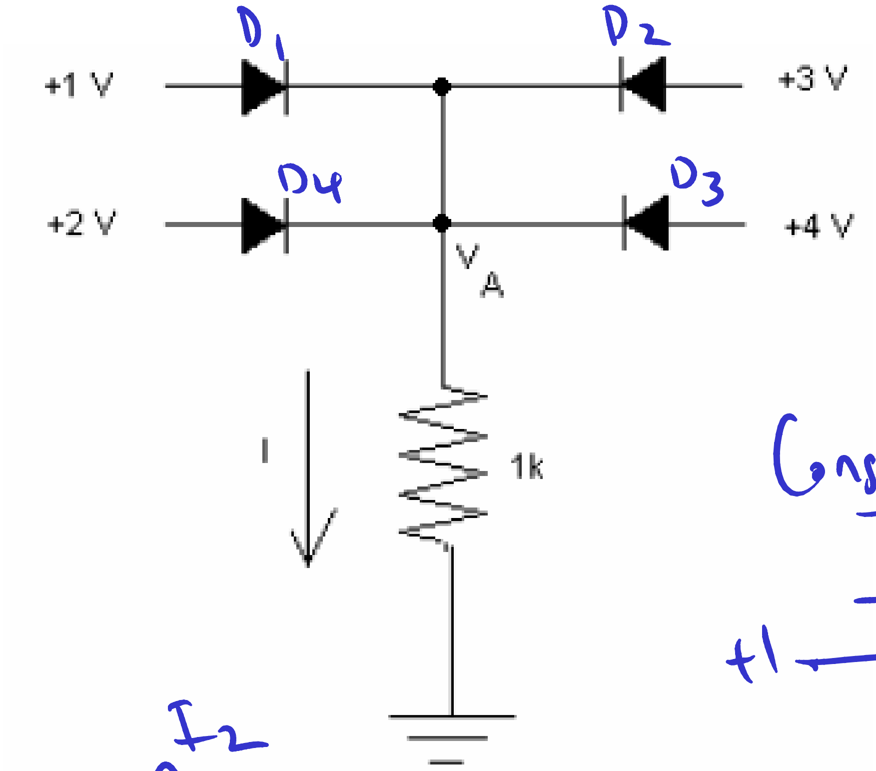
All off:



Consider all diodes on:

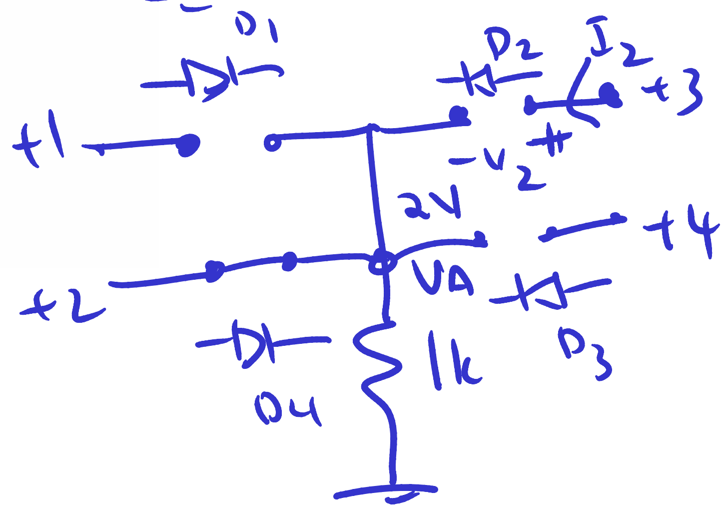


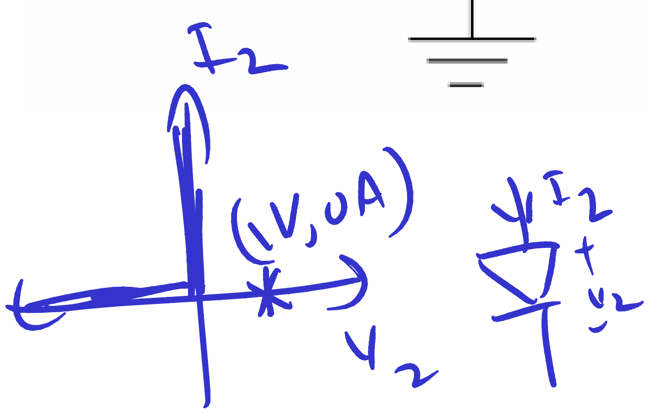
Another Example Circuit



Assume D_1, D_2, D_3 & D_4 are ideal, find V_A & I.

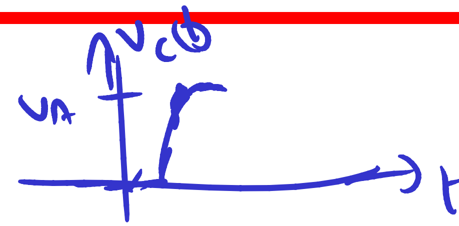
Consider: D_4 on, all others off:

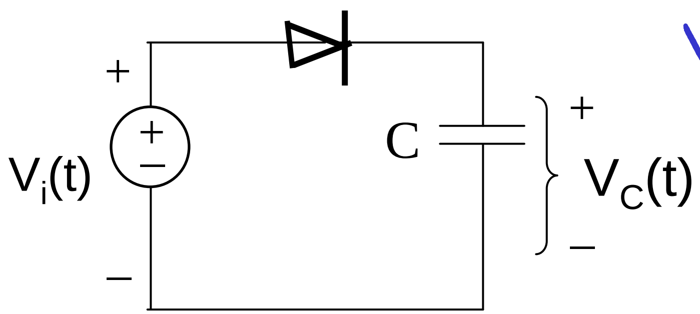




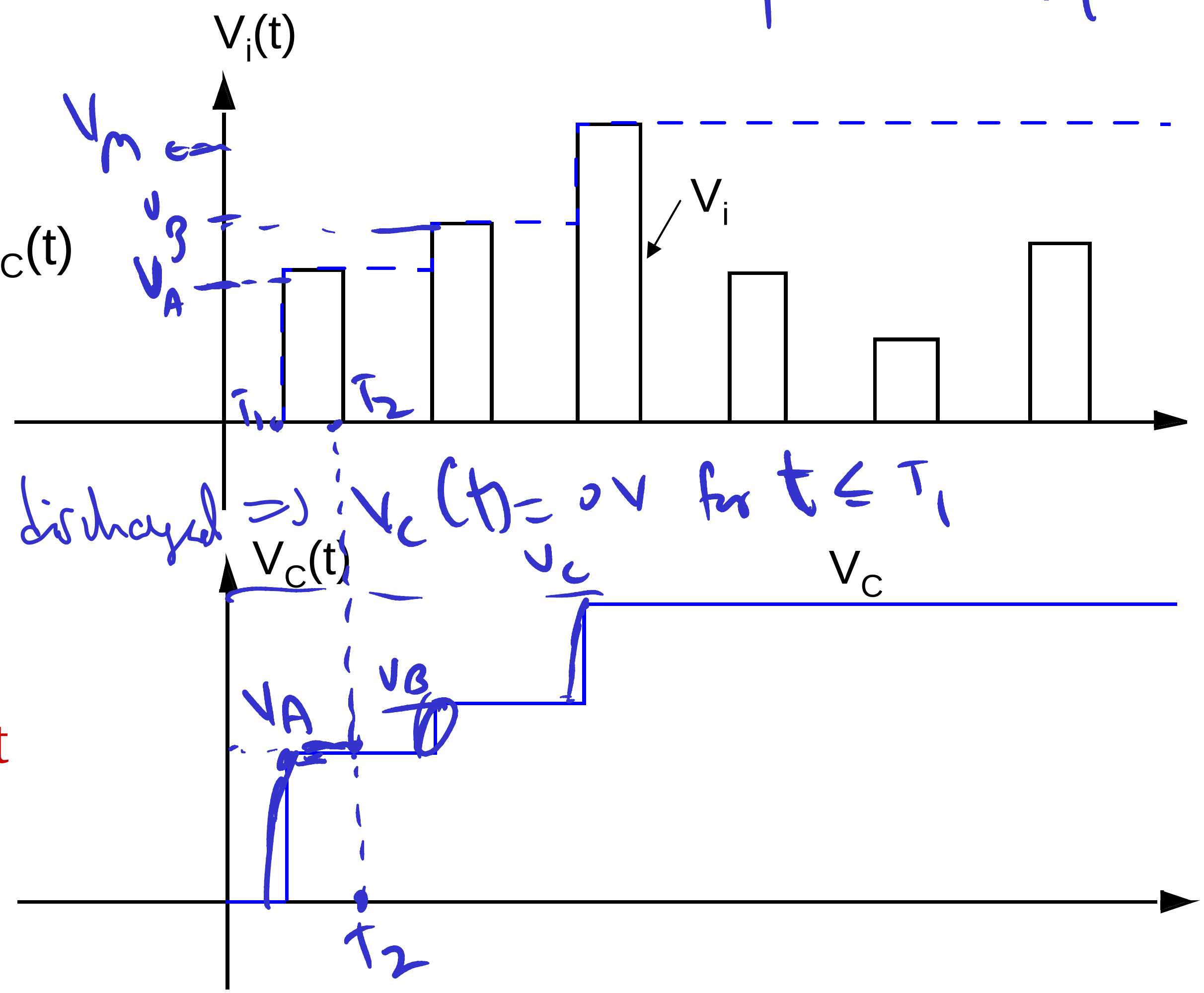
Peak Detector Circuit

Assume the ideal (perfect rectifier) model.





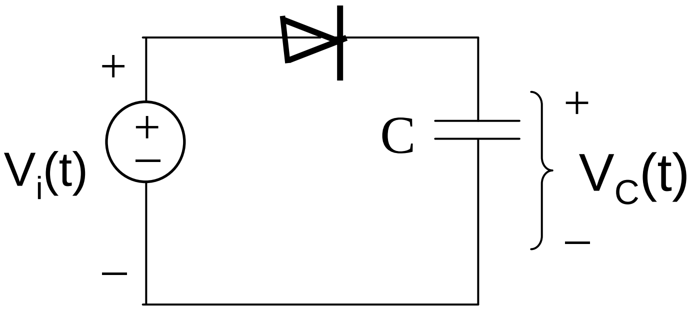
Assume C is initially discharged ⇒ $V_c(t) = 0V$ for $t \leq T_1$

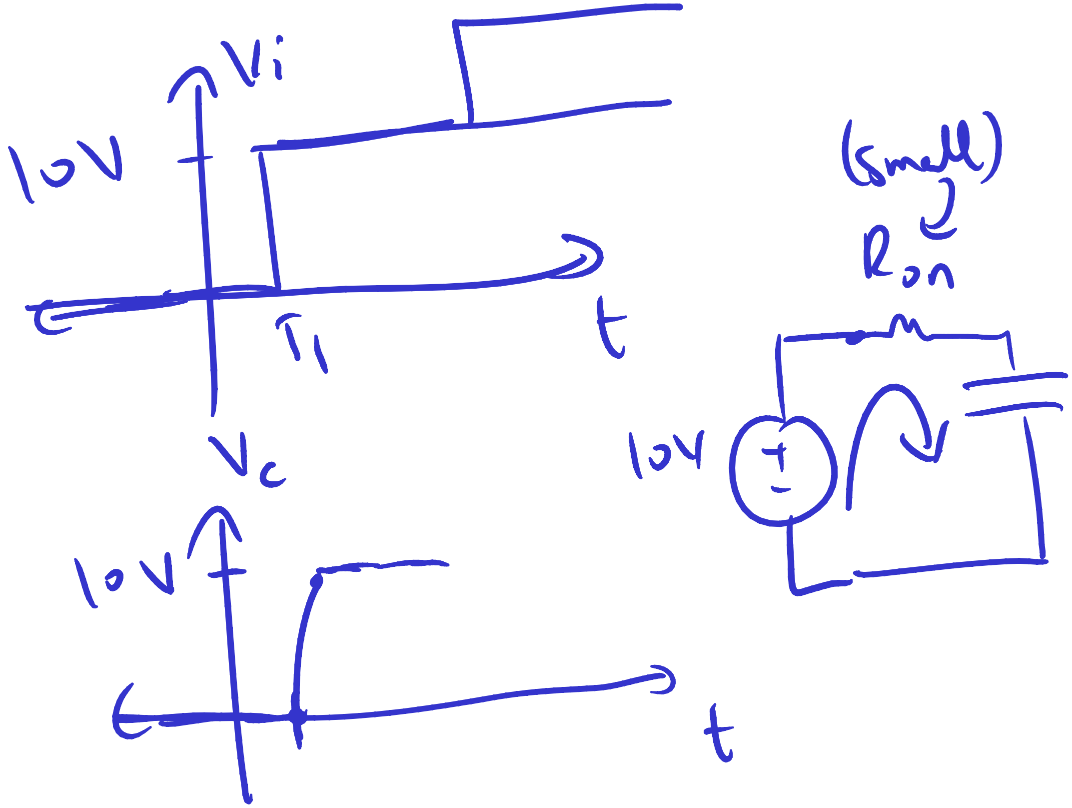


Key Point:
The capacitor charges due to one way current behavior of the diode.

Peak Detector Circuit

Assume the ideal (perfect rectifier) model.

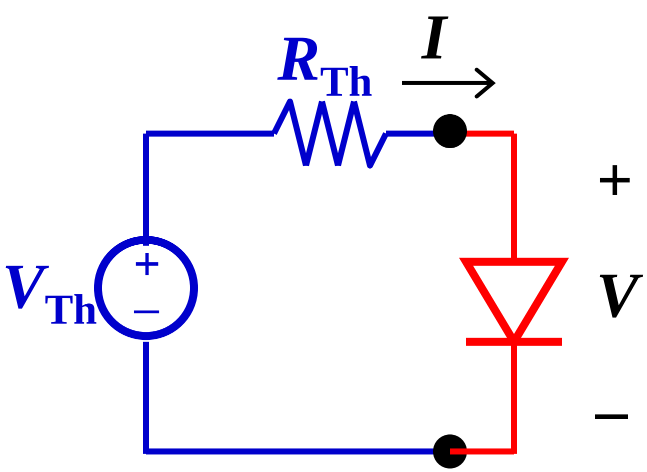


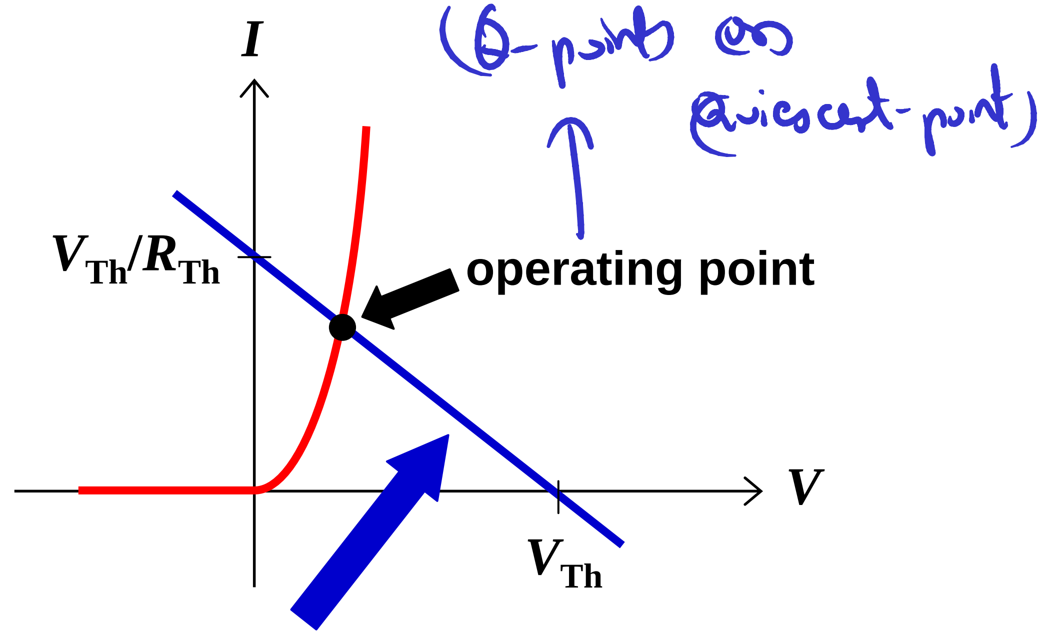


Key Point:
The capacitor charges due to one way current behavior of the diode.

Load Line Analysis Method

1. Graph the *I*-*V* relationships for the non-linear element and for the rest of the circuit
2. The operating point of the circuit is found from the intersection of these two curves.





The *I*-*V* characteristic of all of the circuit except the non-linear element is called the ***load line***

Load Line Analysis Method

Notice: (1) We are using the non-ideal diode model
(2) Thevenize the linear subcircuit across the diode

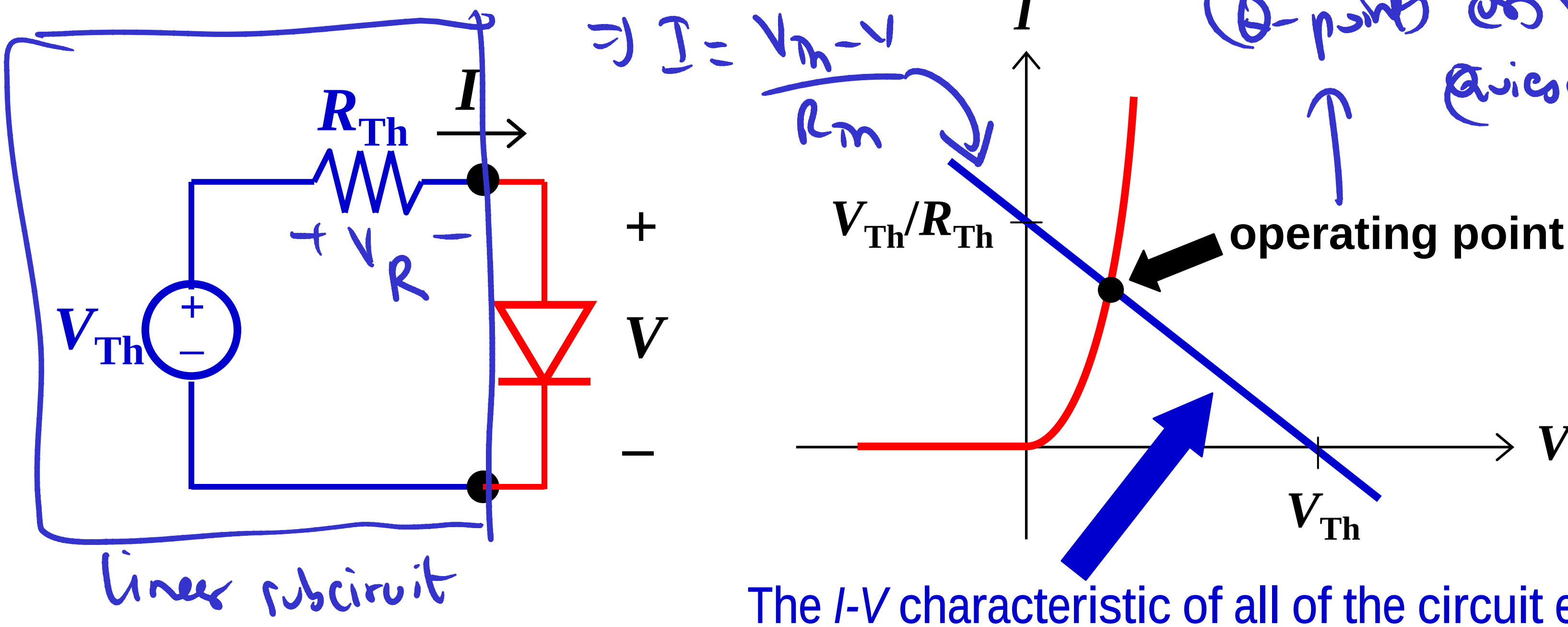
How does it work: KVL: $V_{Th} = V_R + V$

$\Rightarrow V_{Th} = I \cdot R_{Th} + V$

$\Rightarrow I = \frac{V_{Th} - V}{R_{Th}}$

(Load-lines work best for circuit with one nonlinear element)

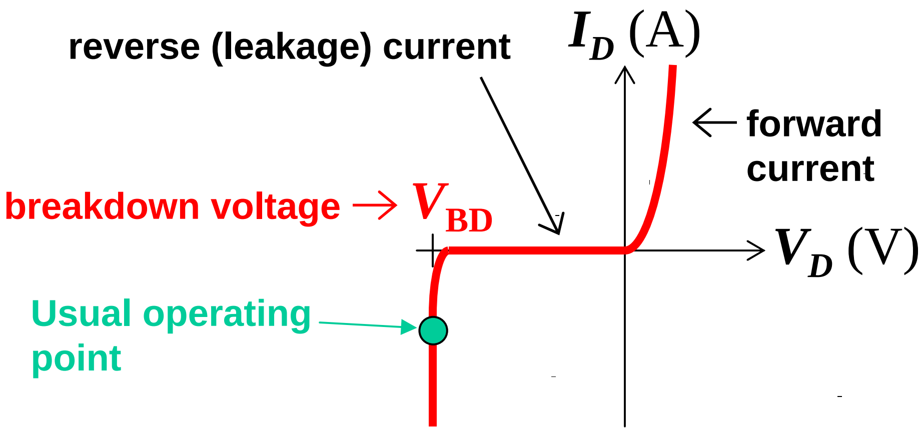
(Q-point or quiescent-point)



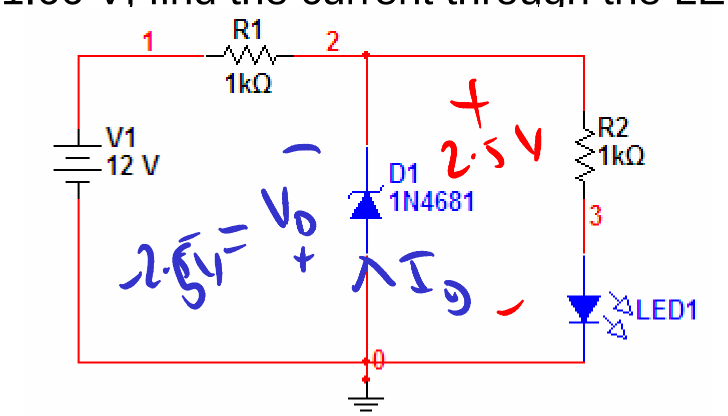
The *I-V* characteristic of all of the circuit except the non-linear element is called the *load line*

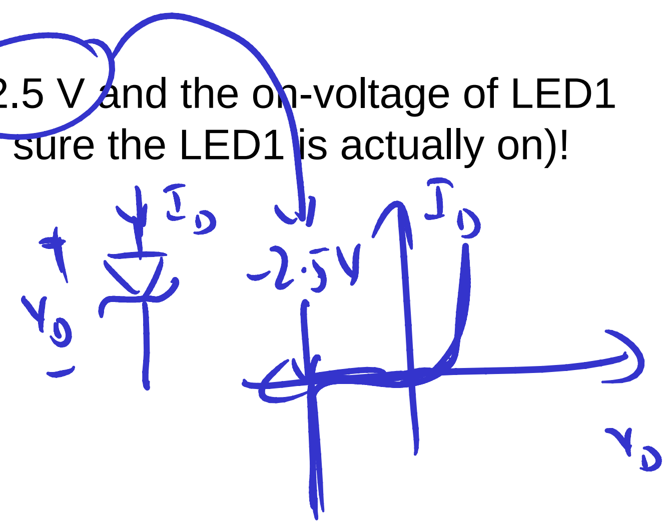
Zener Diode

A ***Zener diode*** is designed to operate in the breakdown mode. They are usually used to produce constant output voltages.

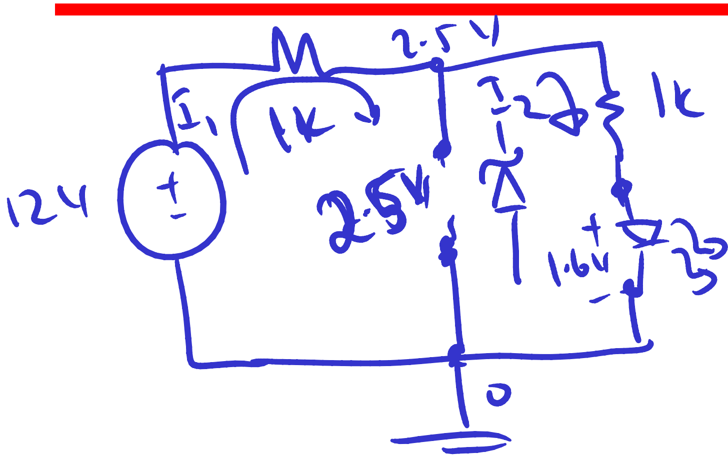


Example: Assuming reverse breakdown voltage of zener is -2.5 V and the on-voltage of LED1 is 1.66 V, find the current through the LED1 (of course, make sure the LED1 is actually on)!





Zener Diode



$$I_1 = \frac{12 - 2.5V}{1K} = 9.5\ mA$$

$$I_2 = \frac{2.5 - 1.6}{1k} = 0.9\ mA$$

<u>Example</u>: Assuming reverse breakdown voltage of zener is -2.5 V and the on-voltage of LED1 is 1.66 V, find the current through the LED1 (of course, make sure the LED1 is actually on)!