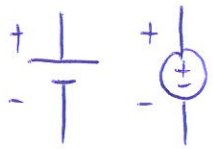
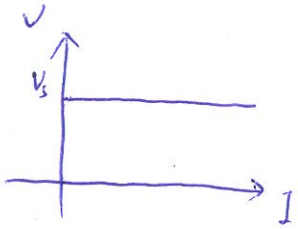
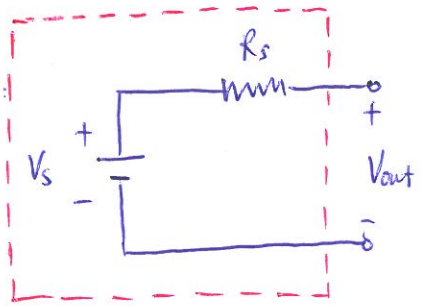
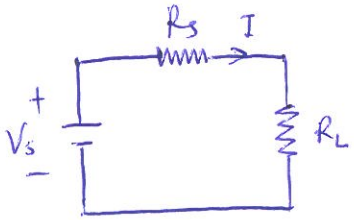
L4. DC Power & Regulation.

1. DC Source:

1) Ideal Case:  $\Rightarrow$ I-V characteristics 

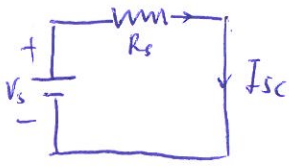
2) Real Case: 

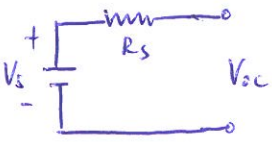
What is the I-V characteristics?

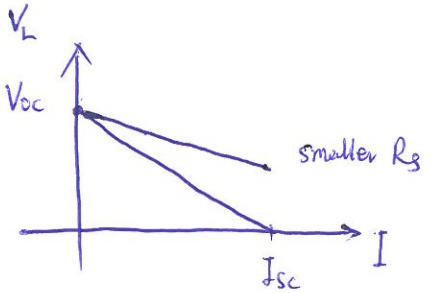


$V_L = V_s - R_s \cdot I$

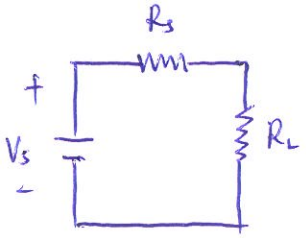
- If $V_L = 0$, then $I = \frac{V_s}{R_s}$
- If $I = 0$, then $V_L = V_s$

$I = \frac{V_s}{R_s}$ Corresponds to the short-circuit current I_{sc} $\Rightarrow$ 

$V_L = V_s$ corresponds to the open-circuit voltage V_{oc} $\Rightarrow$ 

Thus, 

2. Power efficiency & Maximum power consumption



two questions:
- What is the maximum power delivered to R_L?
- What is the maximum power efficiency?

$$I = \frac{V_s}{R_s + R_L} \Rightarrow \begin{cases} P_s = I^2 R_s = \dfrac{V_s^2}{(R_s+R_L)^2} \cdot R_s \\ P_L = I^2 R_L = \dfrac{V_s^2}{(R_s+R_L)^2} R_L \end{cases}$$

Question 1: $\max_{R_L} P_L$

$P_L(R_L) = \dfrac{V_s^2}{(R_s+R_L)^2} R_L$ To maximize P_L, we take the derivative of P_L with respect to R_L

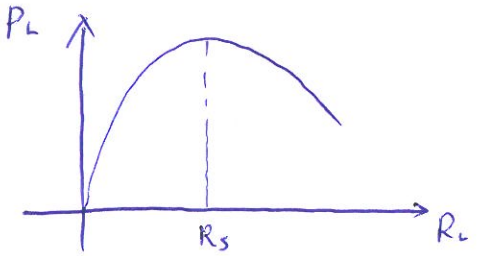
$$\frac{dP_L(R_L)}{dR_L} = \frac{d\left(\frac{V_s^2}{(R_s+R_L)^2} R_L\right)}{dR_L} = \frac{V_s^2(R_s+R_L)^2 - V_s^2 R_L 2(R_s+R_L)}{(R_s+R_L)^4}$$

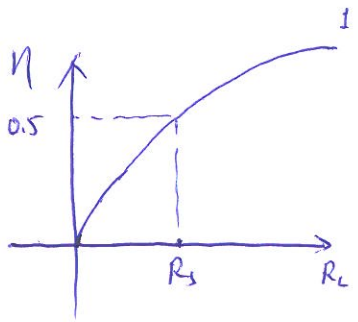
Let $\dfrac{dP_L(R_L)}{dR_L} = 0 \Rightarrow V_s^2(R_s+R_L)^2 = V_s^2 R_L 2(R_s+R_L) \Rightarrow R_s+R_L = 2R_L \Rightarrow R_s = R_L$.

It is refered to as Load Match.

Question 2: What is the maximum efficiency?

$\eta = \dfrac{P_L}{P_s+P_L} = \dfrac{I^2R_L}{I^2R_s+I^2R_L} = \dfrac{R_L}{R_s+R_L} = \dfrac{1}{\frac{R_s}{R_L}+1}$ is an increasing function of R_L.





3. Battery Characteristics

Battery voltage is not a constant

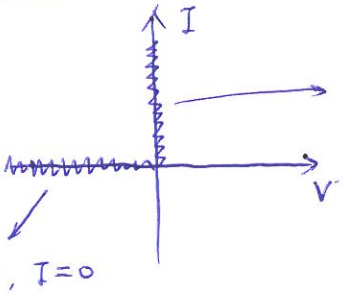
How can we stablize the voltage of a battery?

4. Diode / Zener Diode / Regulator.

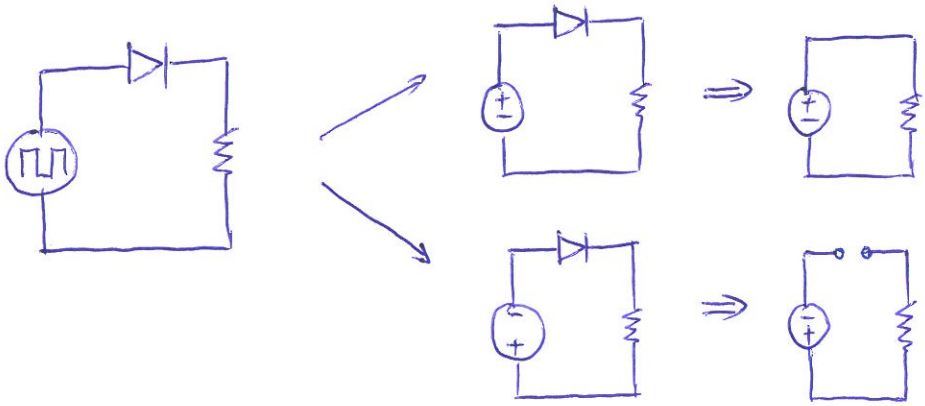
1) Diode : a device that only allows current to flow in one direction.

※ Circuit model : 

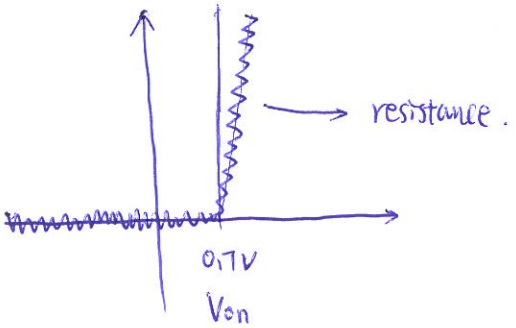
Ideal I-V characteristics :



example :



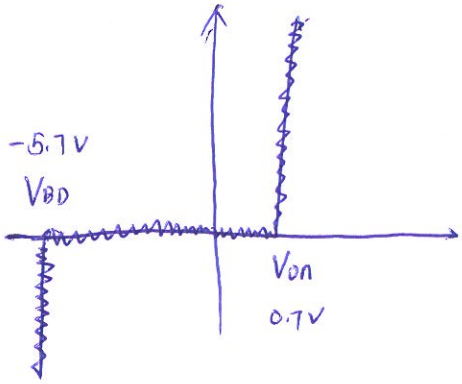
※ Real diode :



2) Zener Diode :

Circuit model 

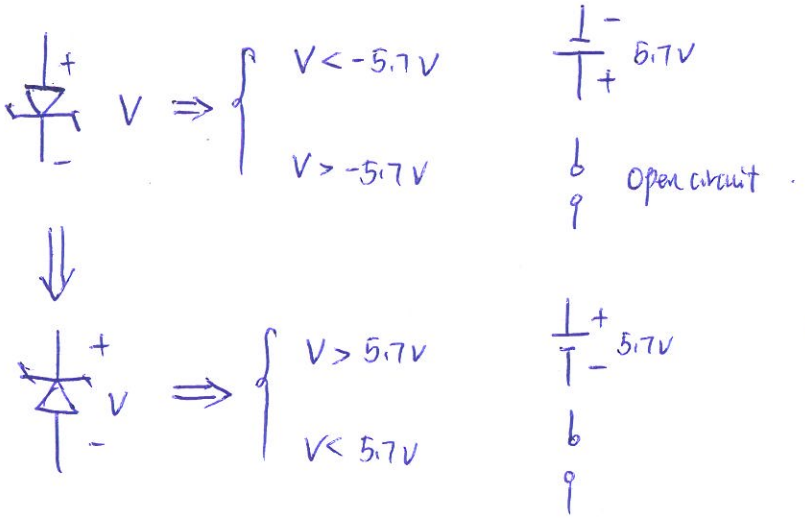
I-V characteristics



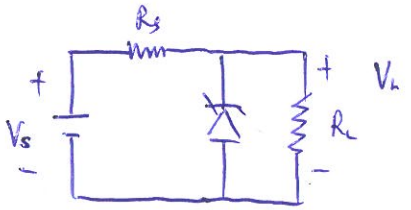
$-V_{BD} < V < V_{on}$ $I = 0$

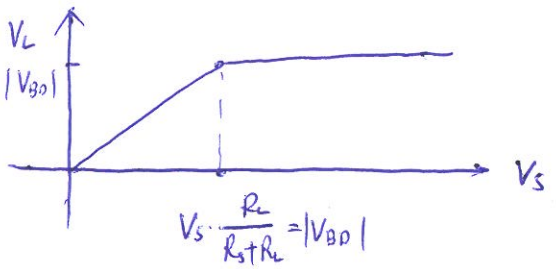
$\begin{cases} V \geq V_{on} \\ V \leq -V_{BD} \end{cases}$ $I =$ anything

Normally, zener diode works in the breakdown region

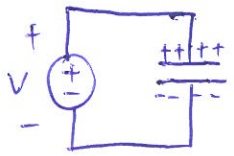


3) Regulator

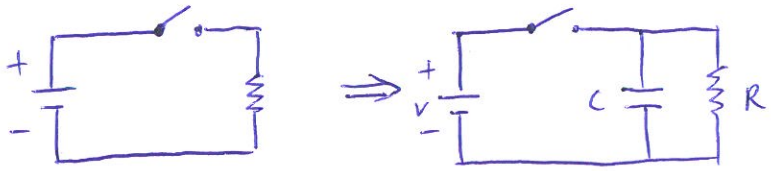




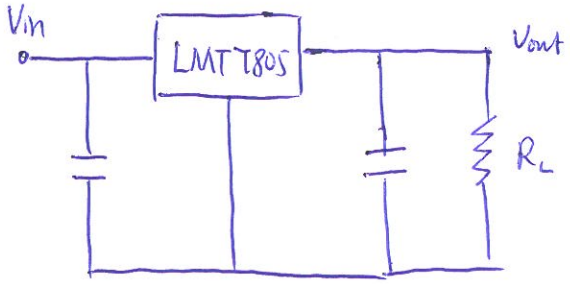
5. Capacitor : a device that stores energy in an electrical field.



$Q = CV \Rightarrow C = \frac{Q}{V} = \frac{\text{Coulomb}}{\text{Volt}}$ # of changes that can be stored if 1 Volt is applied.

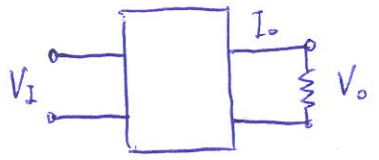


6. Regulator circuit



We have two parameters to measure the performance of a regulator.

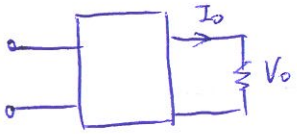
a. Line Regulation : $\frac{\Delta V_o}{\Delta V_I}$



$\frac{\Delta V_o}{\Delta V_I}$ How stable the output voltage is with respect to the input voltage ?

Ideally, it is 0.

b. Load Regulation : $\frac{\Delta V_o}{\Delta I_o}$



How stable the output voltage is with respect to the output current ?

Ideally, it is 0

Example : $7V \le V_{in} \le 25V$

$V_o = 5.0016V$ when $V_{in} = 7V$.

$V_o = 4.9976V$ when $V_{in} = 25V$.

What is the line regulation ?

$$\frac{\Delta V_o}{\Delta V_I} = \frac{5.0016 - 4.9976}{25 - 7} = \frac{0.004}{18} \approx 0.00022$$