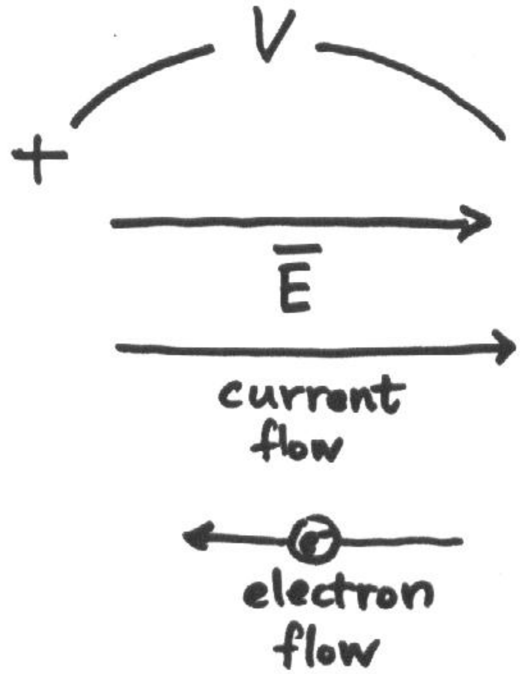
Semiconductor Devices

Reading: Chapter 13

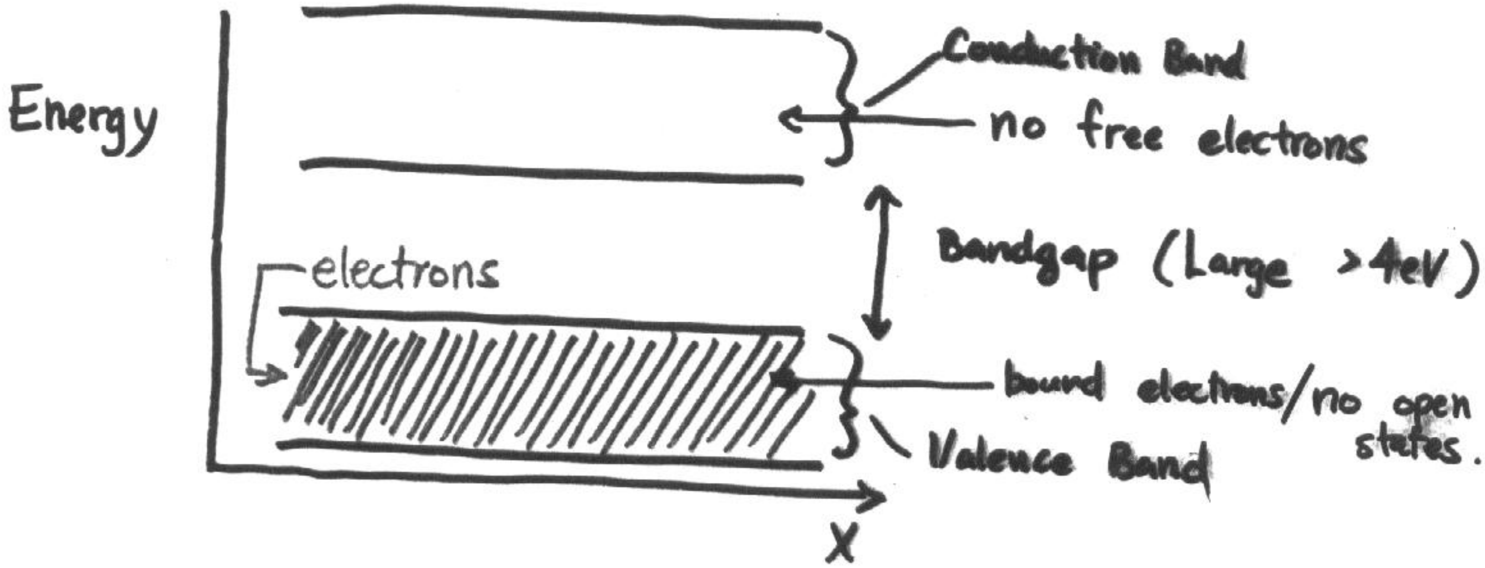
current = flow of charged particles
- ionic current in solution
- beam of charged particles in vacuum
- electric current in metals/semiconductor
  - always carried by e^-
  - e^- is smaller & lighter than proton
  - neutron has no charge



Opposite Current Flow since electron has negative charge (thanks?! to B. Franklin)

Insulators

- glass, rubber
- conducts no current (very, very small)
- no "free electrons" / all electrons are bound.

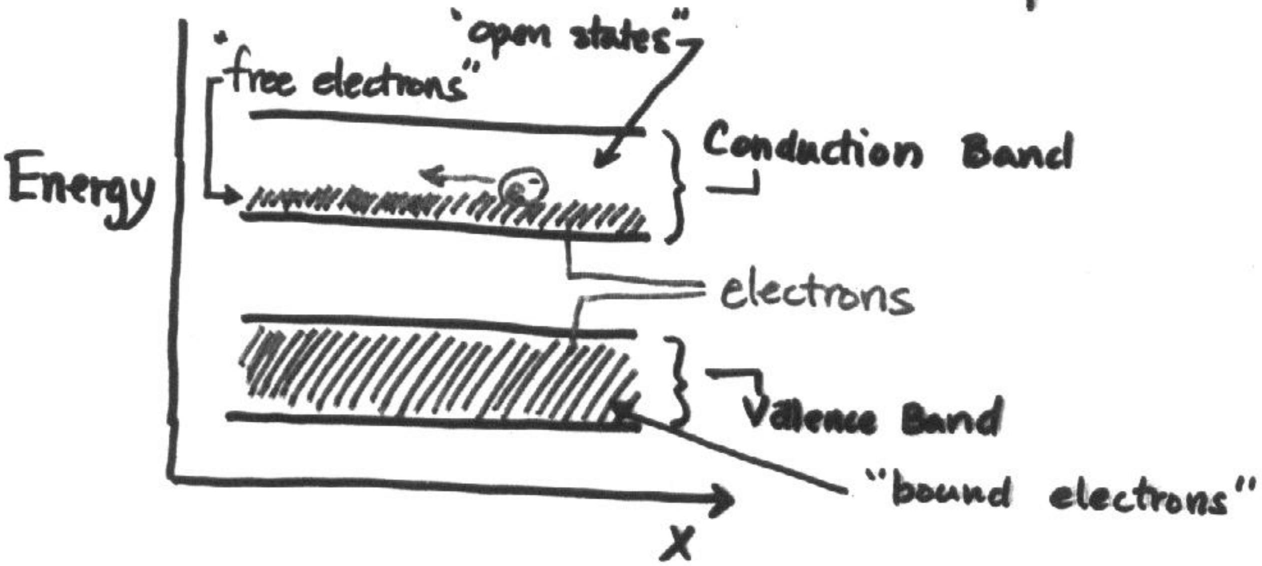


- electrons cannot move
- large bandgap energy (>4eV)
- what happens if bandgap is smaller?

⇒ Semiconductor

Conductors

- Gold, Silver, Copper, Aluminum, Iron, Tungsten
- conducts current freely
- many "free electrons" and "open states"



- amount of current that flows depends on

depends on material property { - "free electron" concentration
- average velocity of electrons

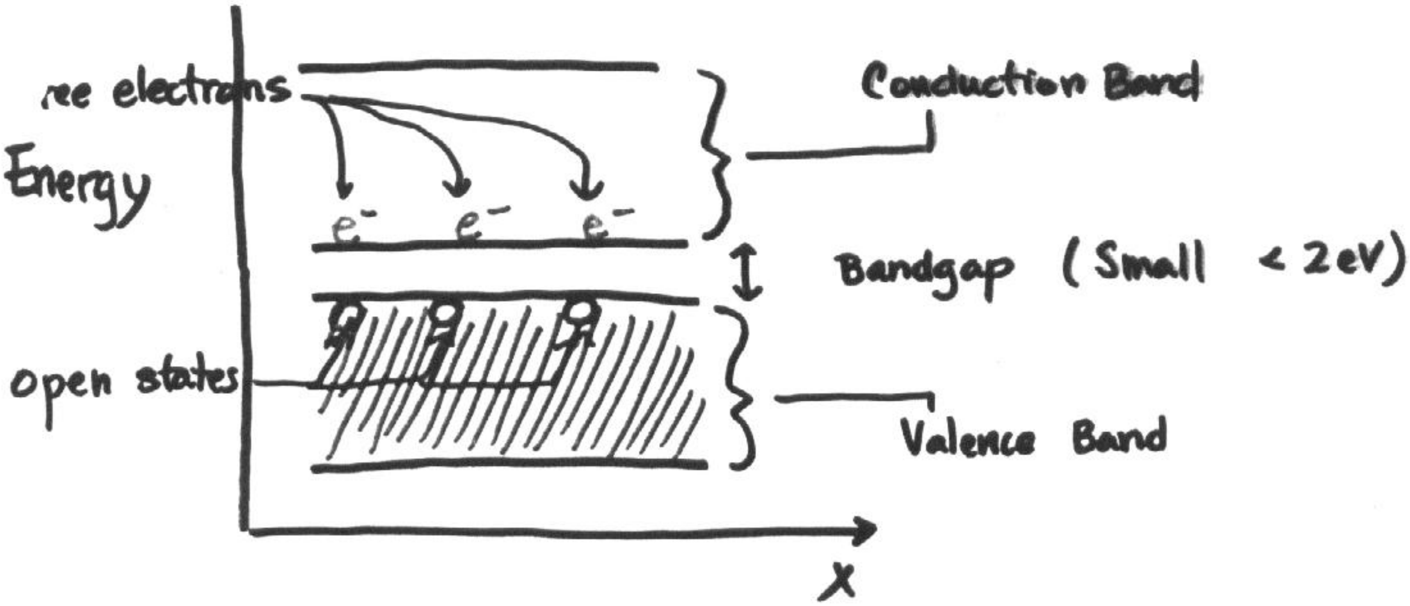
- voltage/electric field (Ohm's Law)

Semiconductor

IV A — Silicon, Germanium, Carbon (diamond)

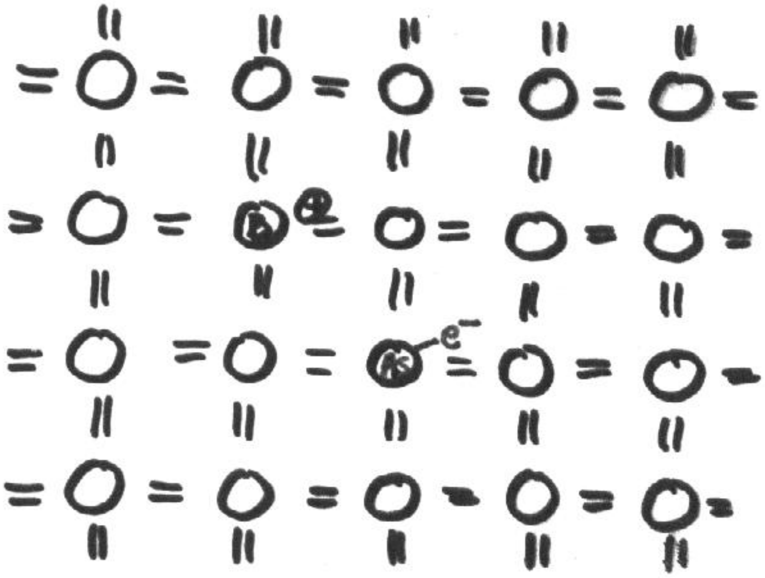
III-V, II-VI — Gallium Arsenide, Indium Phosphide, Cadmium Telluride
Compound Semiconductors

- conducts current depending on
  - precise chemical composition
  - electric, magnetic field
  - temperature, incident photo radiation



- small number of "free electrons" in Conduction Band (electrons) and "open states" in Valence Band (holes)

- small bandgap energy



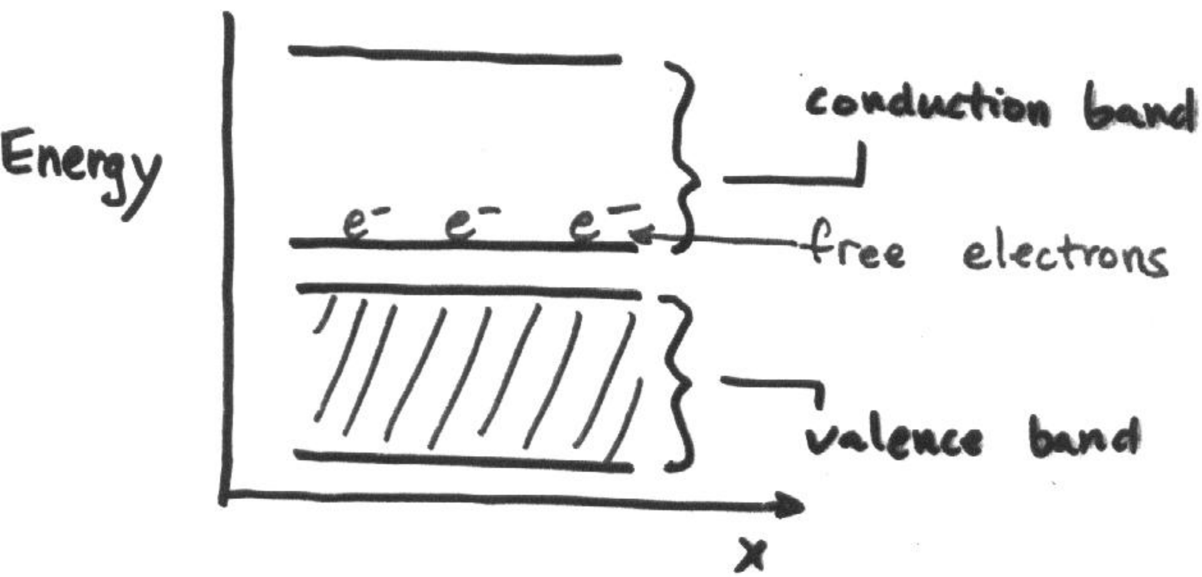
Covalently Bonded Crystal Matrix

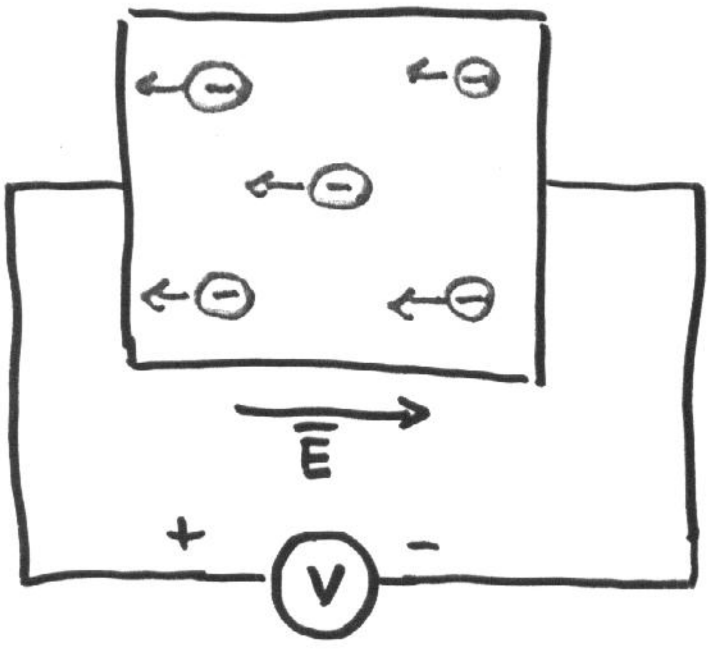
Chemical Doping: 10^{23} atoms/cm^3 density of crystal
$10^{14} - 10^{20}$ atoms/cm^3 doping concentration

replace IV Si with [III B] (Boron) introduces
"hole" or "open state" in valence band
p-type semiconductor

replace IV Si with [V P] (Phosphorus) or [V As] (Arsenic)
introduces "free electron" in
conduction band
n-type semiconductor

n-type semiconductor



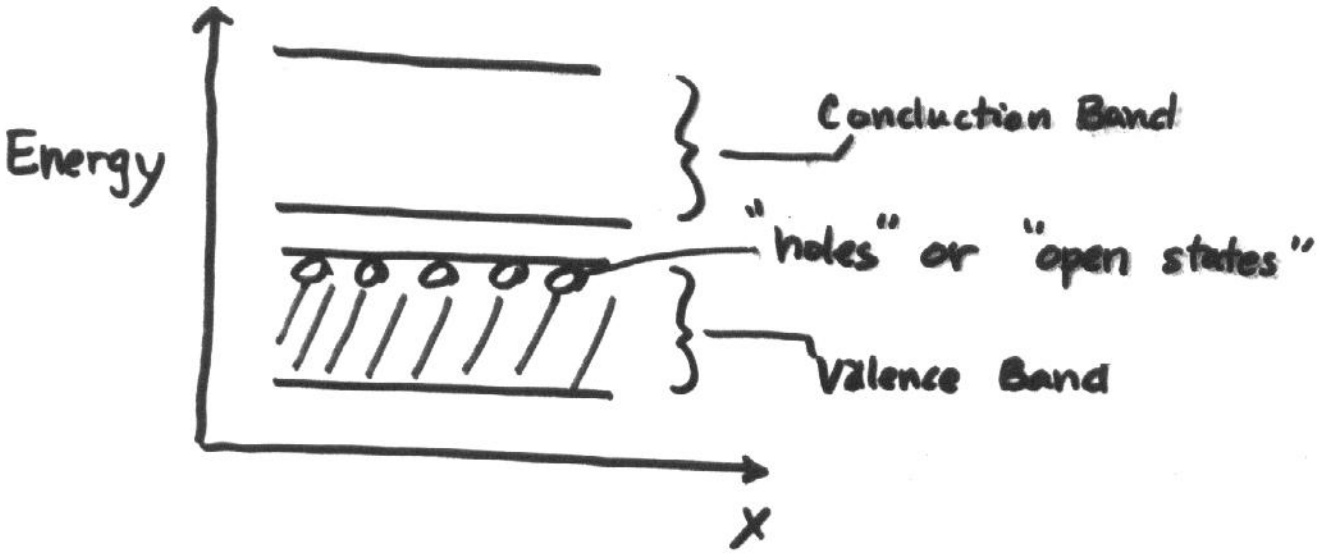


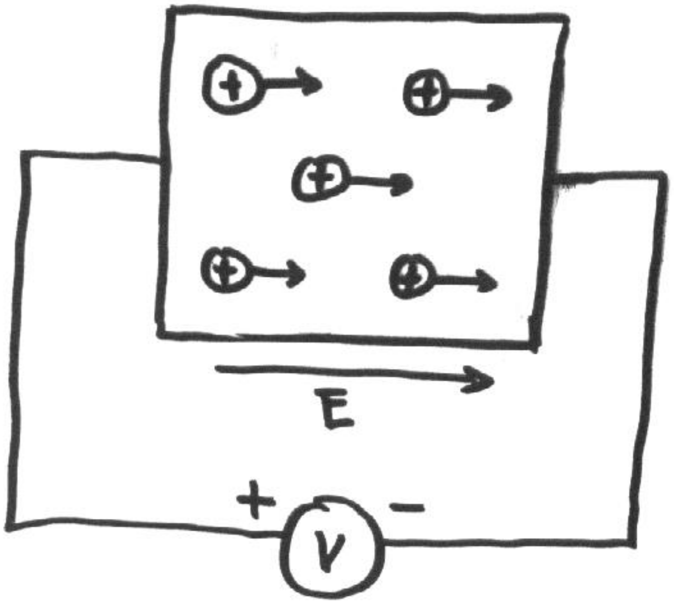
current conduction by electrons in conduction band

Valence band electrons are bound

- number of free electrons determines resistance

p-type semiconductor



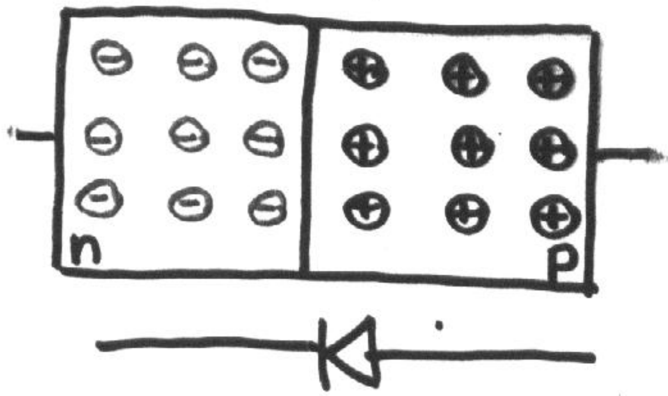


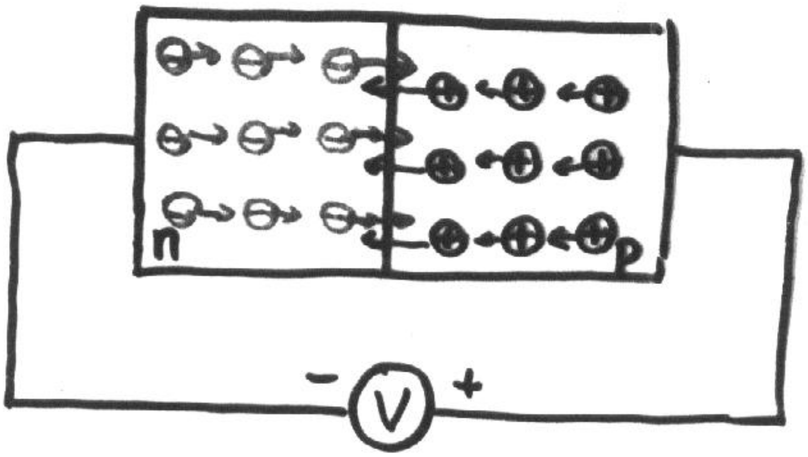
current conduction by virtual holes

really it is the electrons that are moving

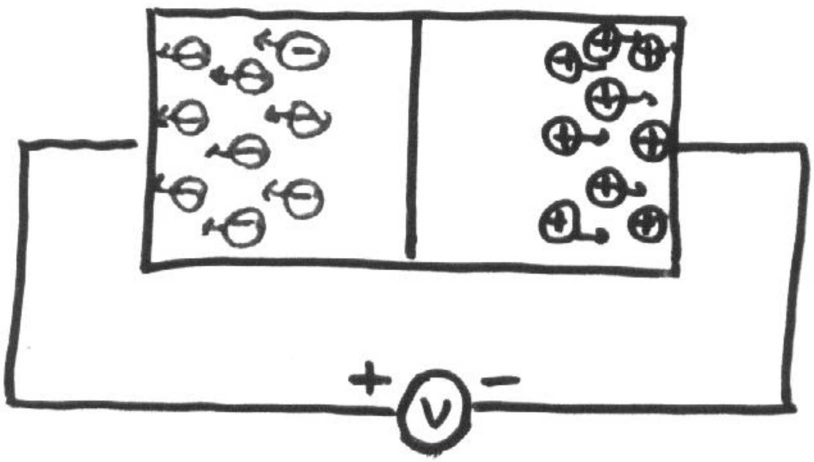
- number of holes determines resistance

PN Junction or Diode





- Current flow freely
- electrons injected from n to p recombine with holes
- holes injected into n fromp recombine with electrons.



- current does not flow!

In detail,

$$I_D = I_S \left(e^{V_D/V_T} - 1\right)$$

I_S = saturation current which is constant factor determined by size and composition

V_T = thermal voltage = $\frac{kT}{q}$

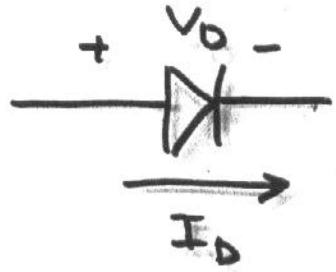
T = temperature in °Kelvin
k = Boltzman's constant
q = charge on electron =

= 25.84 mV at $T = 300°K$
= 26mV at room temp

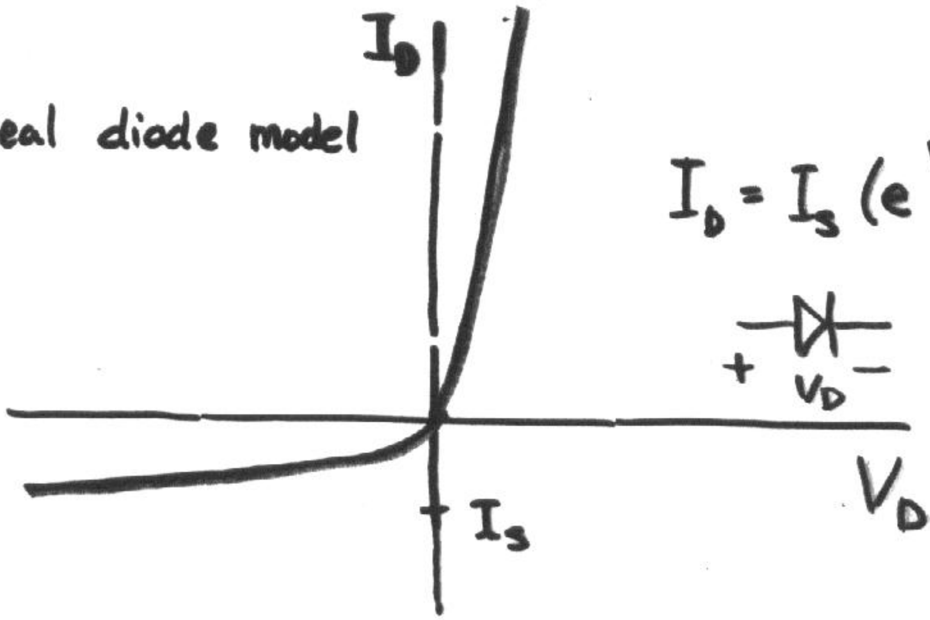
I_D = current in diode

V_D = voltage across diode

Diode Characteristics and Models

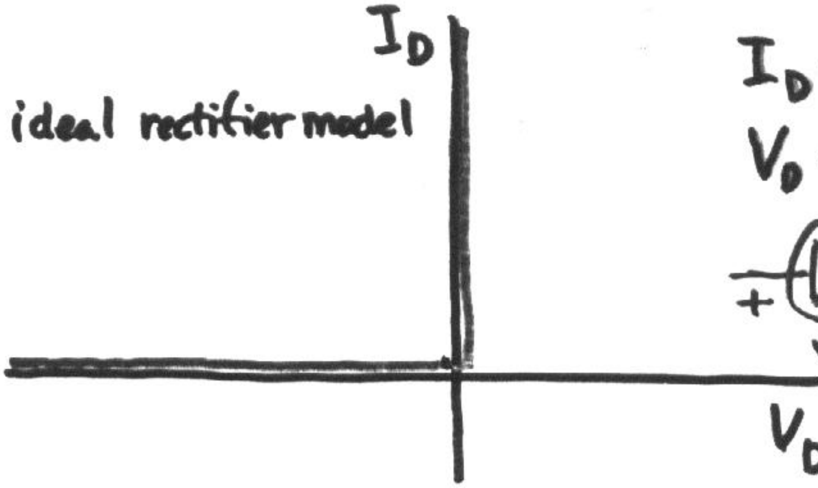


ideal diode model



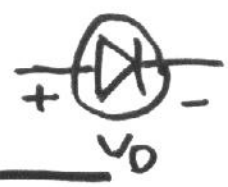
$$I_D = I_S\left(e^{V_D/V_T} - 1\right)$$

ideal rectifier model

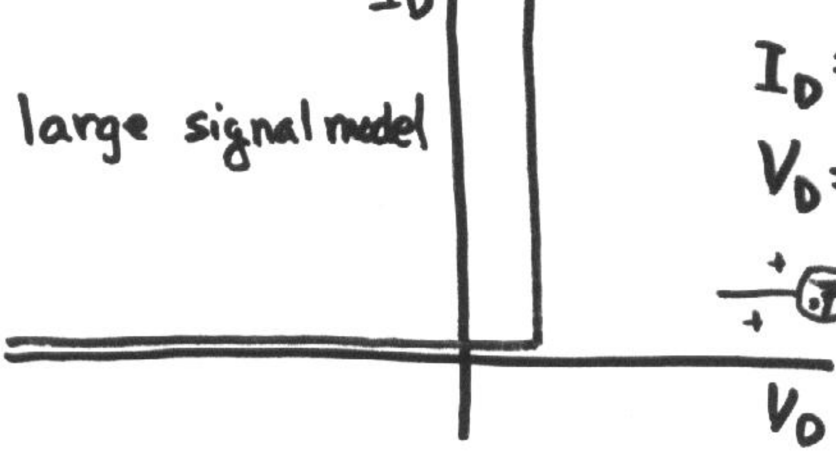


$I_D = 0$ if $V_D < 0$

$V_D = 0$ if $I_D > 0$

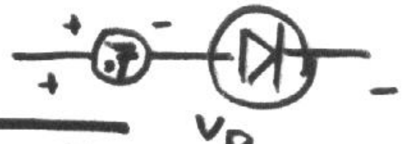


large signal model

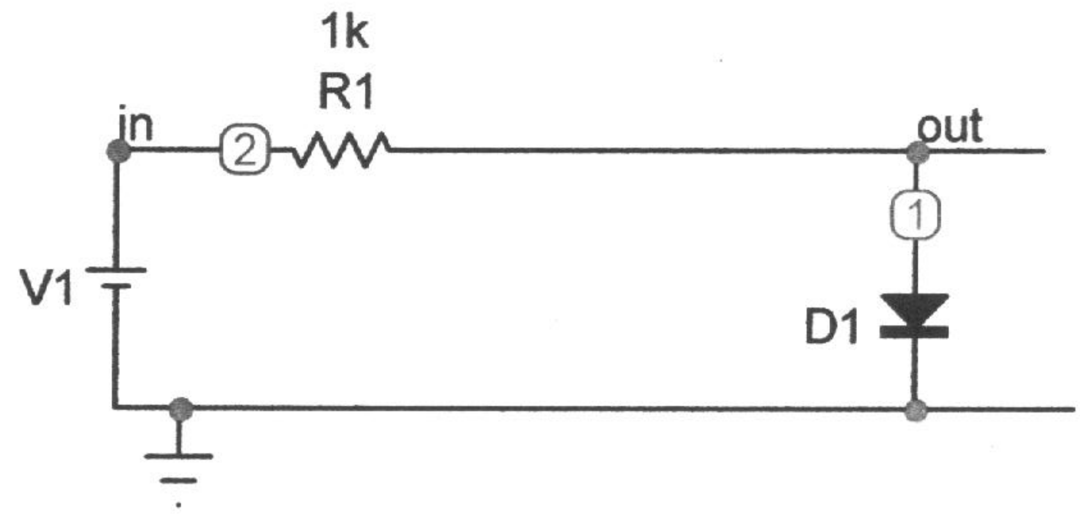


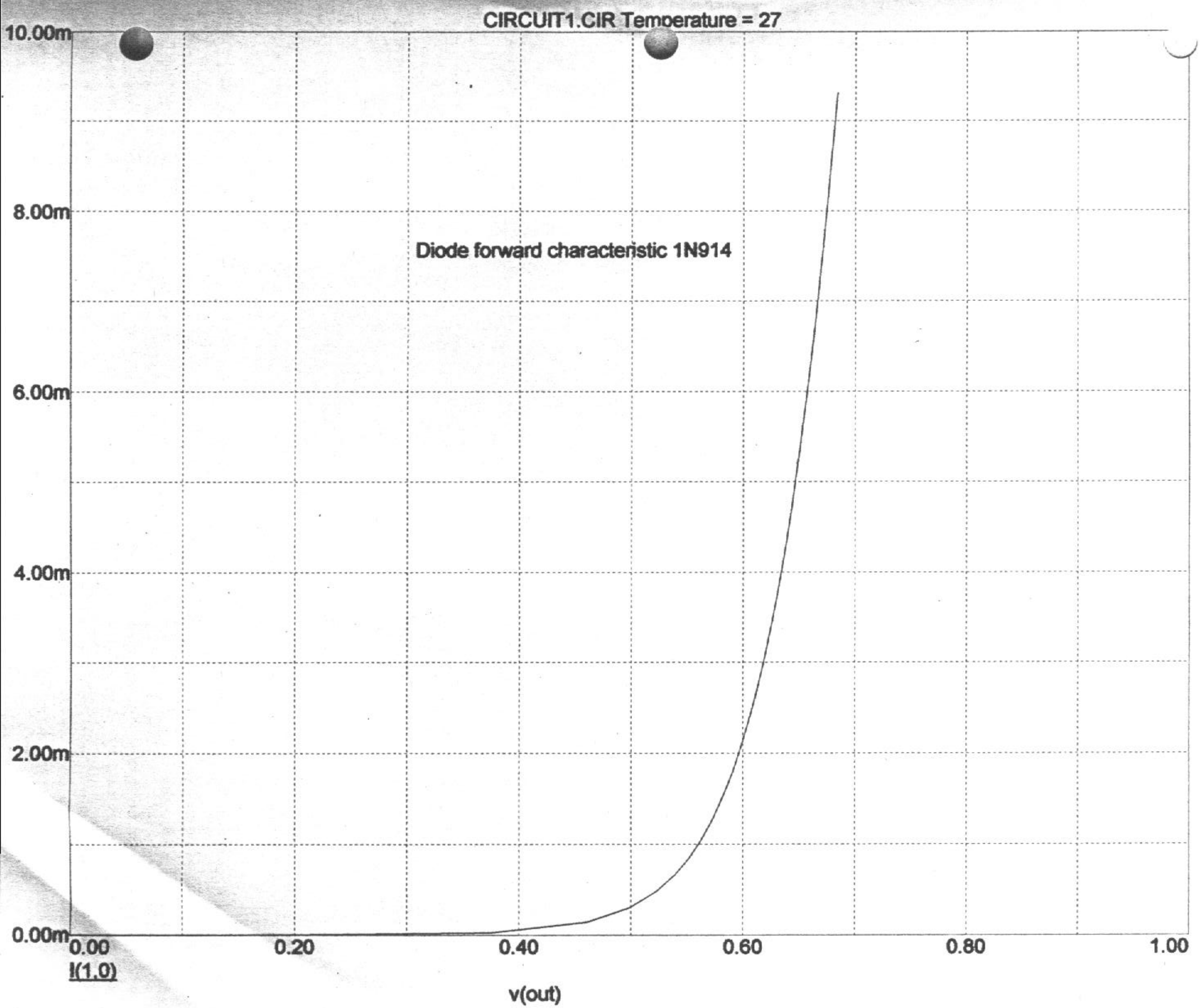
$I_D = 0$ if $V_D < 0.7v$

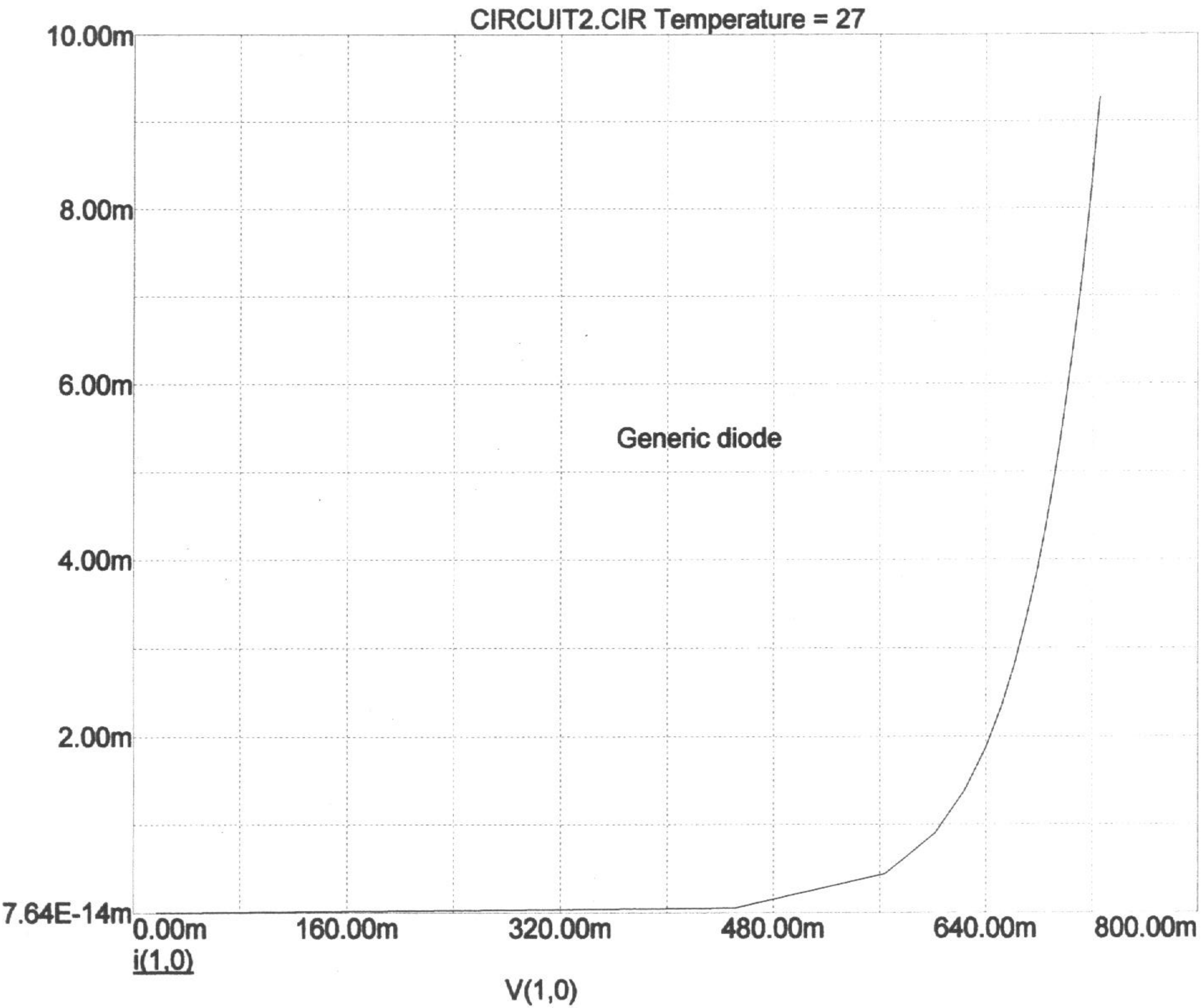
$V_D = 0.7v$ if $I_D > 0$



Diode forward characteristic 1N914




CIRCUIT1.CIR Temperature = 27
Diode forward characteristic 1N914
10.00m
8.00m
6.00m
4.00m
2.00m
0.00m
0.00
0.20
0.40
0.60
0.80
1.00
I(1,0)
v(out)


CIRCUIT2.CIR Temperature = 27
10.00m
8.00m
6.00m
4.00m
2.00m
7.64E-14m
Generic diode
0.00m
160.00m
320.00m
480.00m
640.00m
800.00m
i(1,0)
V(1,0)

Getting started with MC6

– A step by step example for ES50 (fall 2001)

1. In this tutorial, we will create a simple circuit called ES50-freq-RLC-par using Microcap 6 and do some analysis on it. Figure 1 is a screen capture of the circuit and AC analysis.

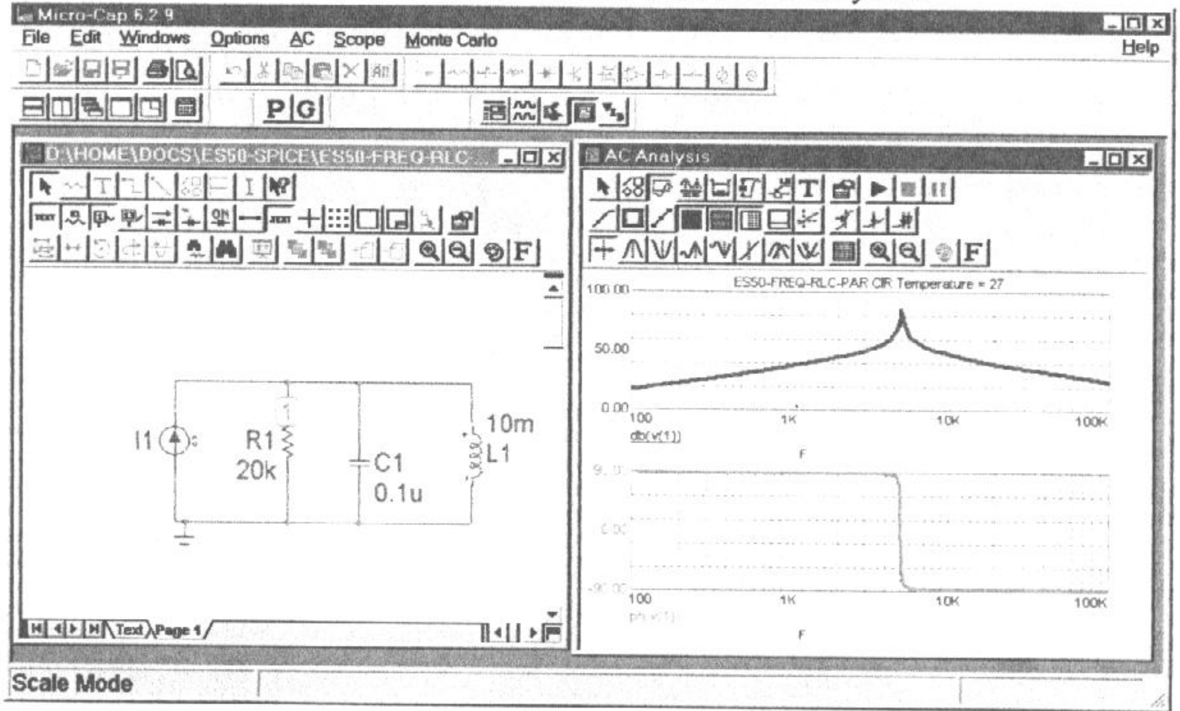
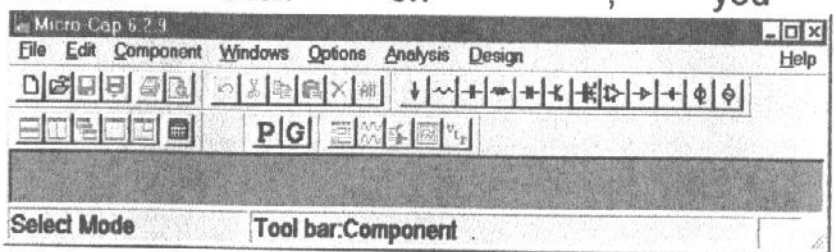
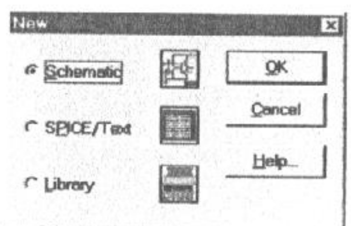


Figure 1

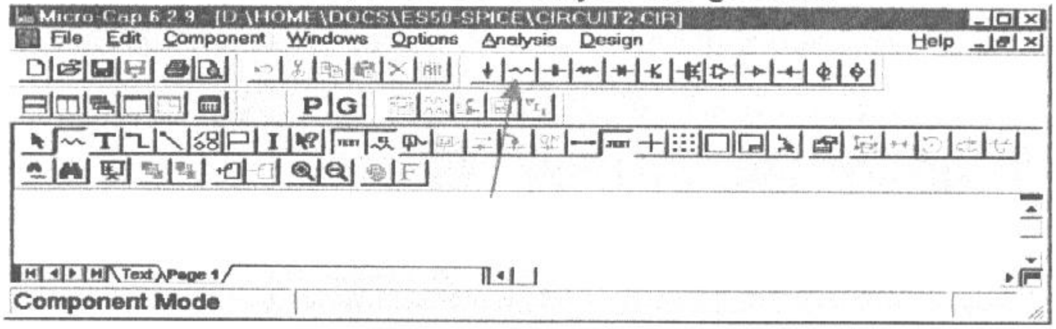
2. Double click on , you will get:



Click on File, New,

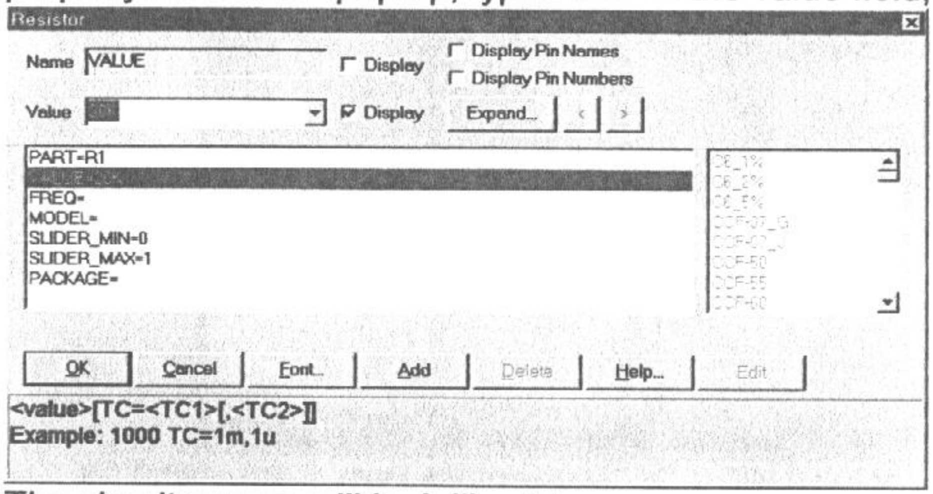


Select Schematic, click on OK, you will get this:

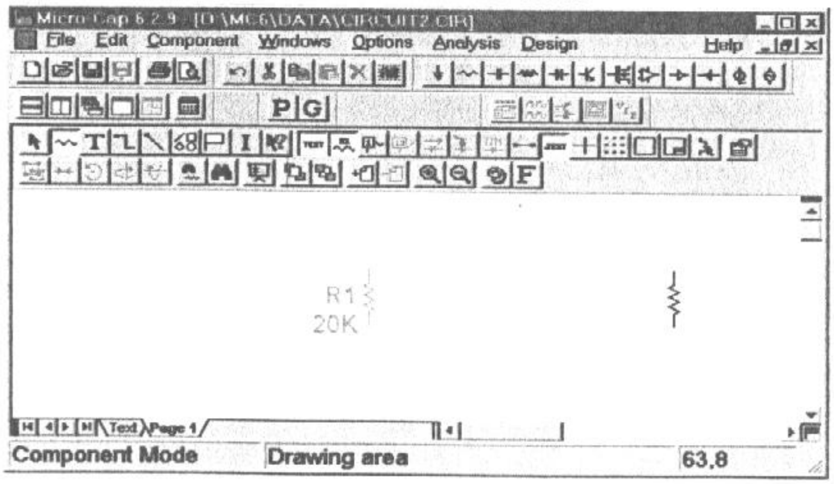


3. Adding the 20KΩ resistor in the schematic:

   Click on the resistor button, move the cursor to the desired position in the schematic editing window, press the right mouse button while holding down the left mouse button (to rotate the part to the desired direction, release the left mouse button, the resistor property screen will pop up, type "20K" in the value field, click on OK.

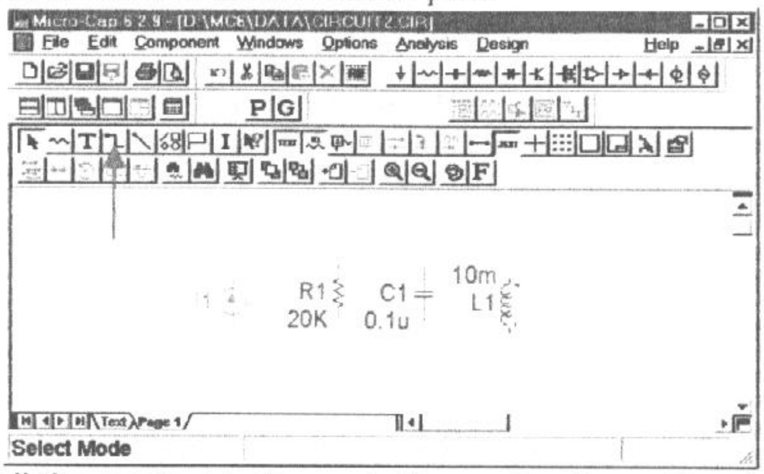


The circuit screen will look like this:

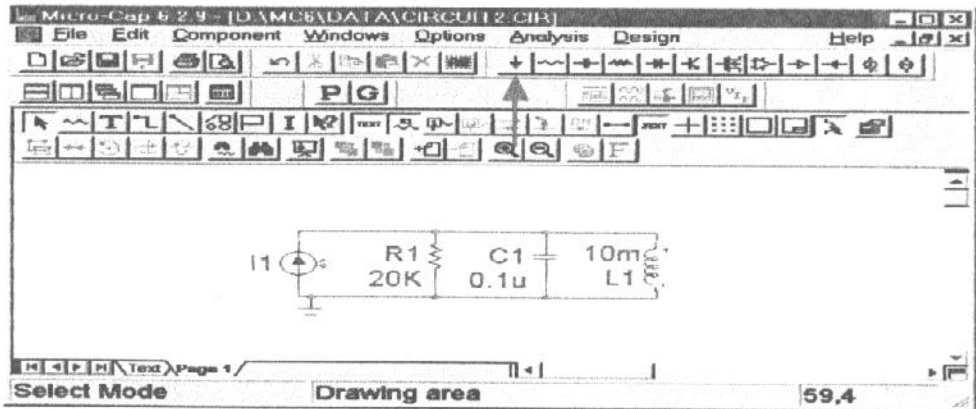


7. Connecting the parts:

   Click on the wiring button, move the cursor to one end of a part, press and hold the left button, move to one end of another part, then release the left button to connect the two parts.



   Connect all the parts as shown in figure 1 schematic window, then add the GROUND too!

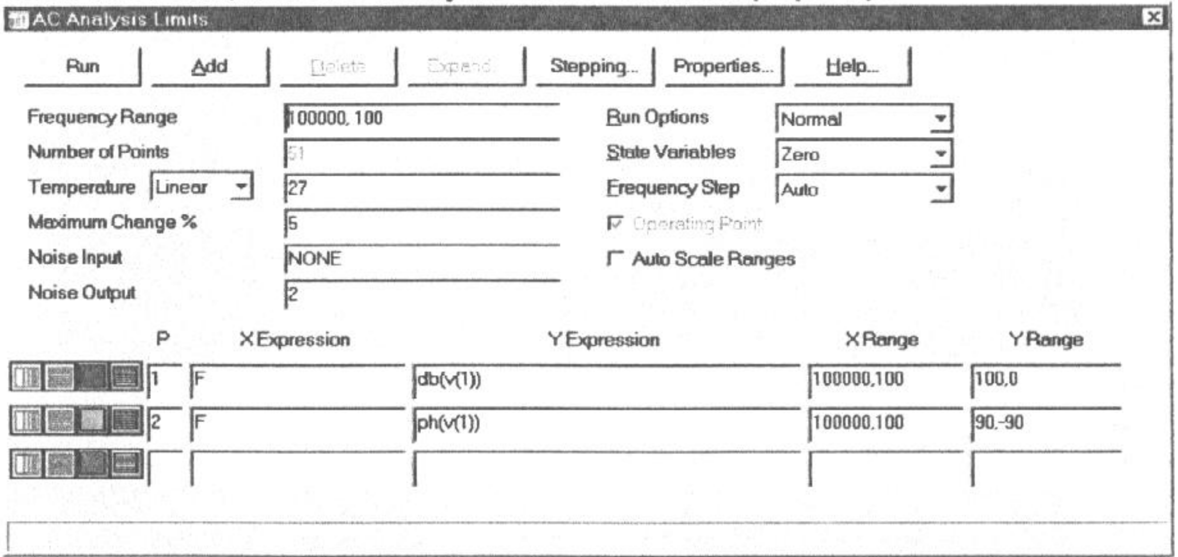


8. Click on File, Save As, type the name of the file you want to save to in the pop up window, click on save.

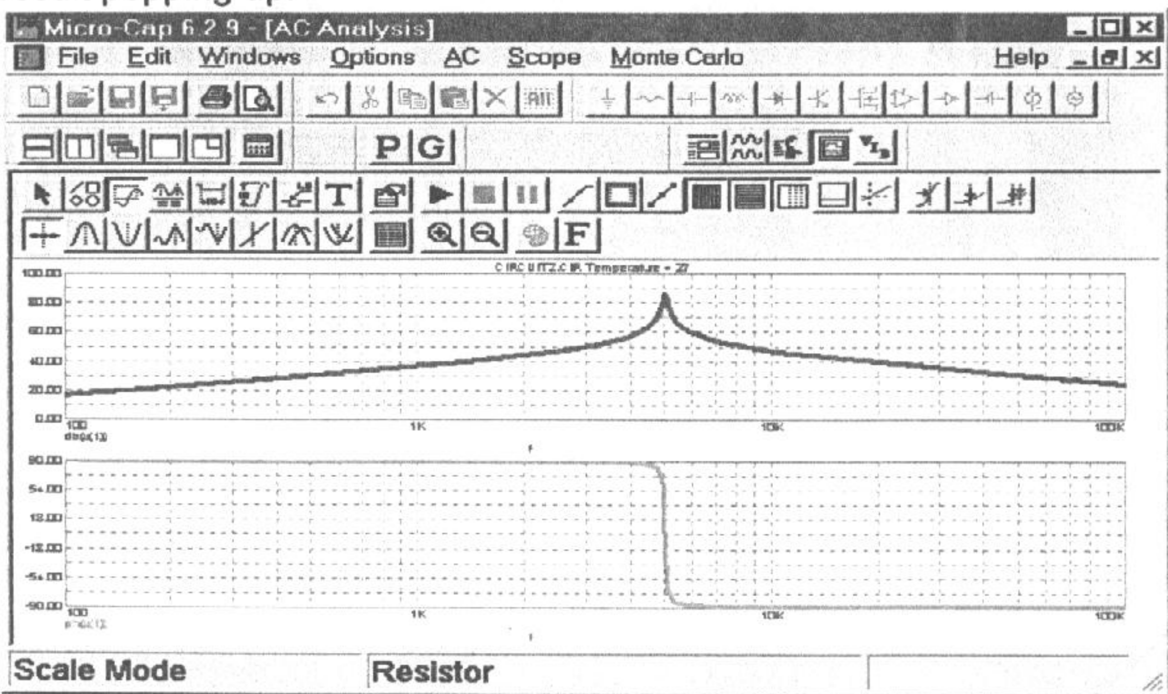
   Now you have just finished editing your schematic by using Microcap 6. Good job!

   Next, is to do some simulation analysis:

9. Click on Analysis on the top bar menu while the circuit is open, then click on AC..., the AC analysis limits window pops up.



Modify the X range, Y range, and frequency range, as shown above. Click on the Run button, you will see your very first frequency analysis result popping up.



Congratulations!

Remember, the more you use it, the more skillful you get with it. This is just to get you started with Microcap 6. Happy Spice!