ECE 320 - Homework #2

Semiconductors, PN Junction. Due Monday, January 24th

Please make the subject "ECE 320 HW#2" if submitting homework electronically to Jacob_Glower@yahoo.com (or on blackboard)

Semiconductors

1) Why does current flow p-to-n but not n-to-p across a pn junction?

Several ways to answer this (any are OK)

Answer 1)

- When current flows p to n, it used majority carriers. A large number of carriers means low resistance.
- When current flows n to p, it uses minority carriers. A small number of carriers means high resistance.

Answer 2) A deplation zone exists across the pn junction. This prevents current flow.

- Voltage p to n decreases the depletion zone. When it goes to zero, current flows (about 0.7V for silicon)
- Voltage n to p increases the depletion zone (blocking current flow)

Answer 3) A potential energy barrier is created across the pn junciton

- Voltage in excess of this barrier (0.7V for silicon) allows current to flow
- Voltage less than this barrier result in no current

2) What doping of phosphorus (n-type) do you need to make an 1206 resistor have a resistance of 1200 Ohms? The dimensions of an 1206 resistor are

L = 3.20mm, W = 1.60mm, H = 0.95mm

$$R = \left(\frac{\rho L}{A}\right)$$

$$1200\Omega = \left(\frac{\rho \cdot 0.32cm}{(0.16cm)(0.091cm)}\right)$$

$$\rho = 54.6\Omega \cdot cm$$

$$\sigma = \frac{1}{\rho} = 0.01832\frac{1}{\Omega \cdot cm} = n_n \cdot q \cdot \mu_n$$

$$0.01832\frac{1}{\Omega \cdot cm} = n_n \cdot (1.6 \cdot 10^{-19}) \cdot (1300)$$

$$n_n = 8.805 \cdot 10^{13}\frac{\text{atoms}}{cc}$$

That seems like a large number, but it's one phosphorous atom for every 1e10 silicon atoms.

3) A thermistor has the following resistance - voltage relationship

$$R = 1000 \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\Omega$$

where T is the temperature in degrees C. What is the resistance at

0F Recommended temperature of a freezer

- -17.778C
- 8992 Ohms

+40F Recommended temperature of a refrigerator

- 4.444C
- 2640 Ohms

+68F Temperature of cold tap water (varies)

- 20.000C
- 1250 Ohms

+120F Tempeature of hot tap water (varies)

- 48.49C
- 378 Ohms

Note that there is a large change in resistance with respect to temperature for thermistors.

Diode VI Characteristics

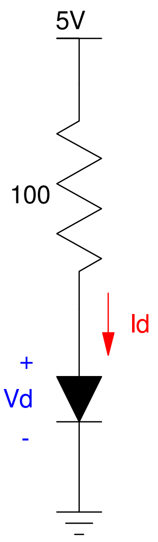
Assume the VI characteristics for a diode are (1N4004 diode in CircuitLab)

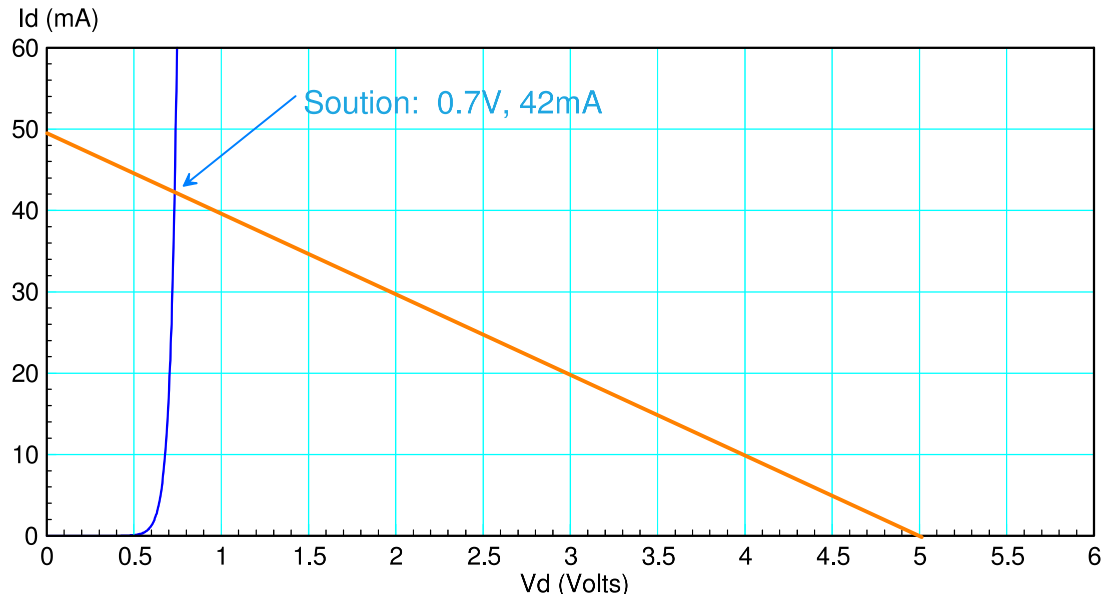
- n = 1.45
- n Vt = 0.0377
- Idss = 7.69e-11

$$V_d = 0.0377 \cdot \ln\left(\frac{I_d}{7.69 \cdot 10^{-11}} + 1\right) \qquad I_d = 7.69 \cdot 10^{-11}\left(\exp\left(\frac{V_d}{0.0377}\right) - 1\right)$$

4) For the 1-diode circuit (next page - 100 Ohms is brown - black - brown)

- a) Draw the load-line for the following circuit (next page). Determine Vd and Id from the graph.
- b) Write the voltage node equations and solve for Vd and Id assuming the VI equations above





Numerical Solution

$$V_d = 0.0377 \cdot \ln\left(\frac{I_d}{7.69 \cdot 10^{-11}} + 1\right)$$

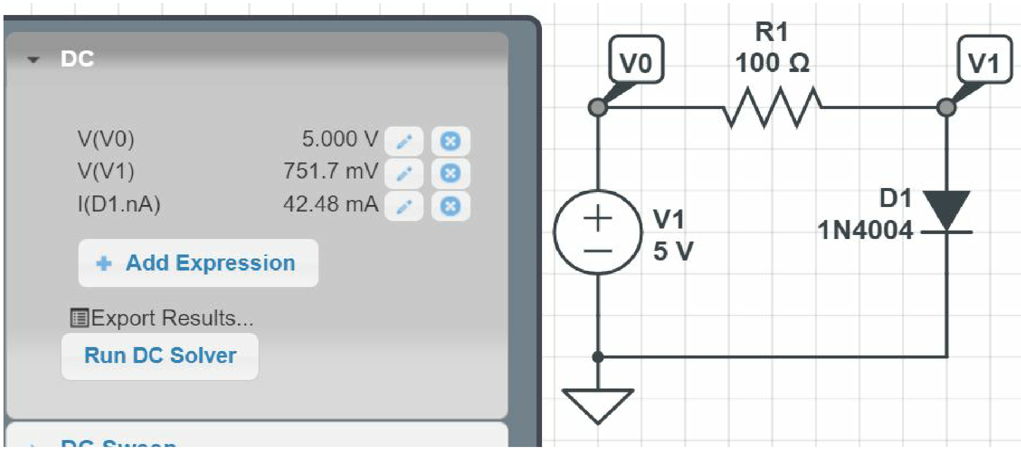
$$V_d + 100 I_d = 5$$

Solving:

Id = 42.4117mA

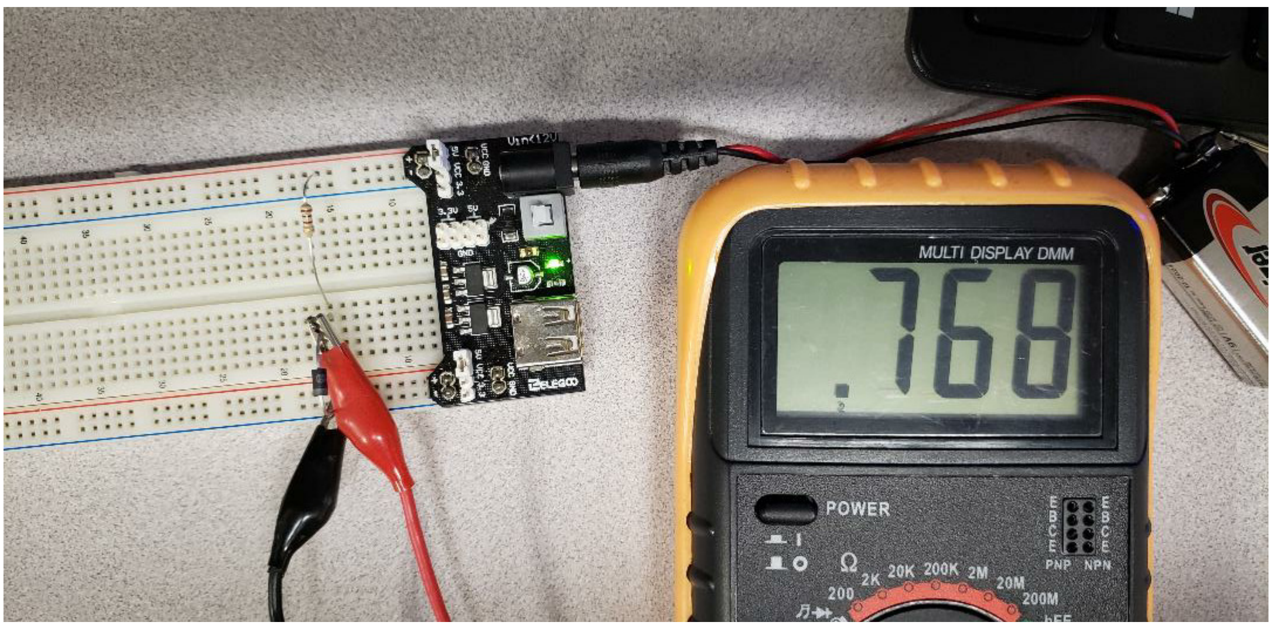
Vd = 0.7588V

5) Build this circuit in CircuitLab and solve for Vd and Id. (Use a 1N4004 diode)



6) Build this curcuit on your breadboard and measure Vd. From this, compute Id

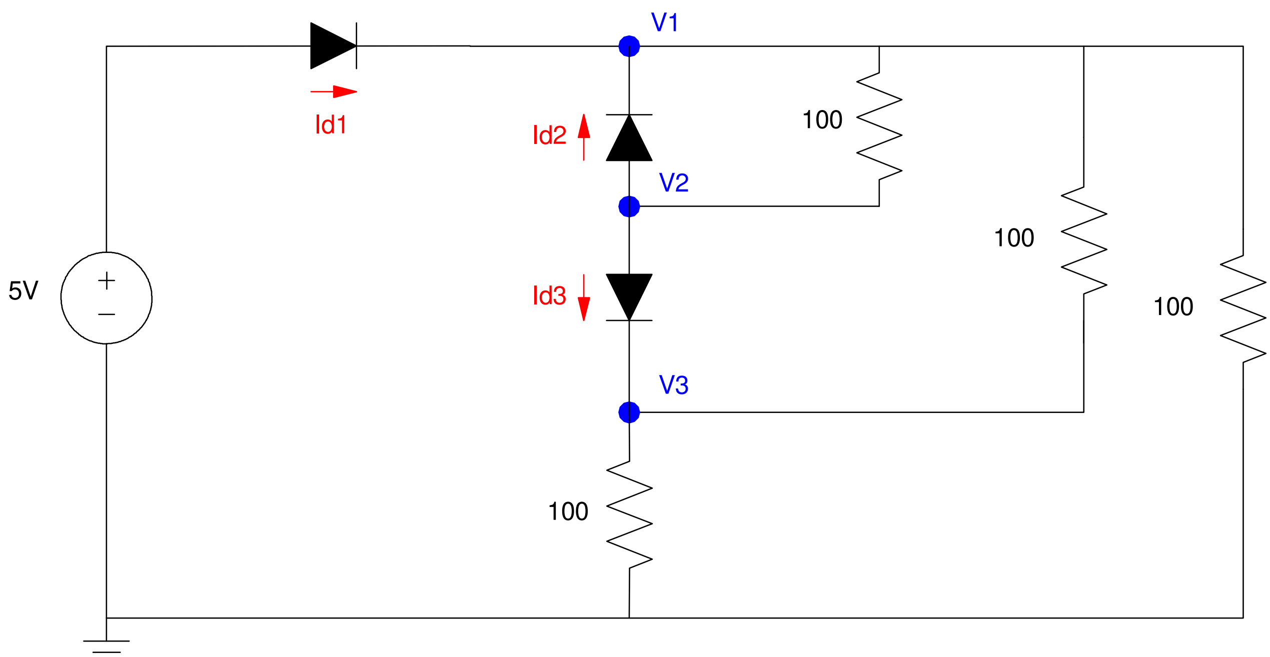
- Include a photo to receive credit for this problem



	Vd	Id
4a) Graphical solution	0.7V	42mA
4b) Numeric Solution	0.7588V	42.4117mA
5) Simulation (CircuitLab)	0.7517V	42.483mA
6) Lab (experimental)	0.768V	42.32mA (calculated from Vd)

Problem 8 - 10: *Note: If you don't have four 100 Ohm resistors (brown - black - brown), replace the resistors with ones you *do* have - ideally all the same and close to 100 Ohms. Do problems 8 - 10 using the resistors you use for the experimental results (problem #10).*

8) Write the voltage node equations assuming nonlinear diodes. Solve for {V1, V2, and V3} using Matlab.



$$I_{d1} = 7.69 \cdot 10^{-11}\left(\exp\left(\frac{5-V_1}{0.0377}\right) - 1\right)$$

$$I_{d2} = 7.69 \cdot 10^{-11}\left(\exp\left(\frac{V_2-V_1}{0.0377}\right) - 1\right)$$

$$I_{d3} = 7.69 \cdot 10^{-11}\left(\exp\left(\frac{V_2-V_3}{0.0377}\right) - 1\right)$$

$$-I_{d1} - I_{d2} + \left(\frac{V_1-V_2}{100}\right) + \left(\frac{V_1-V_3}{100}\right) + \left(\frac{V_1}{100}\right) = 0$$

$$I_{d2} + I_{d3} + \left(\frac{V_2-V_1}{100}\right) = 0$$

$$-I_{d3} + \left(\frac{V_3}{100}\right) + \left(\frac{V_3-V_1}{100}\right) = 0$$

Solve in Matlab

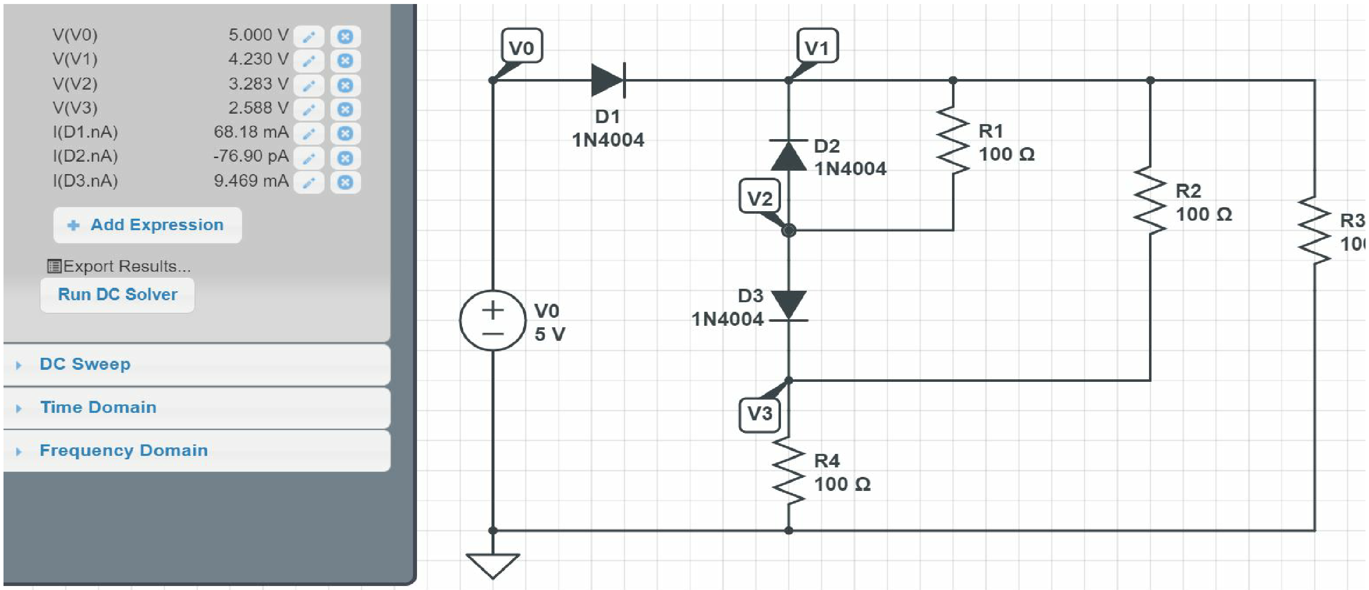
Create an m-file where you guess {V1, V2, V3} and it returns how good your guess was

```
function [ J ] = Diode3( z )
 V1 = z(1);
 V2 = z(2);
 V3 = z(3);

 Idss = 7.69e-11;
 nVt = 0.0377;

 Id1 = Idss* exp( (5 -  V1)/nVt - 1 );
 Id2 = Idss* exp( (V2 - V1)/nVt - 1 );
 Id3 = Idss* exp( (V2 - V3)/nVt - 1 );

 e1 = -Id1 - Id2 + (V1-V2)/100 + (V1-V3)/100 + V1/100;
 e2 = Id2 + Id3 + (V2-V1)/100;
 e3 = -Id3 + V3/100 + (V3-V1)/100;

 J = (e1)^2 + (e2)^2 + (e3)^2;

 disp([V1, V2, V3, log10(J)])
 pause(0.1)

end
```

Solve using fminsearch()

```
>> [Z,e] = fminsearch('Diode3',[3,2,1])
    3.0000    2.0000    1.0000  138.9076

    3.1500    2.0000    1.0000  135.4790

:
:
    4.1861    3.2828    2.5446  -10.9365

    4.1861    3.2829    2.5447  -12.3080


         V1         V2        V3
Z =    4.1861    3.2829    2.5447


e =

  4.9206e-013

>>
```

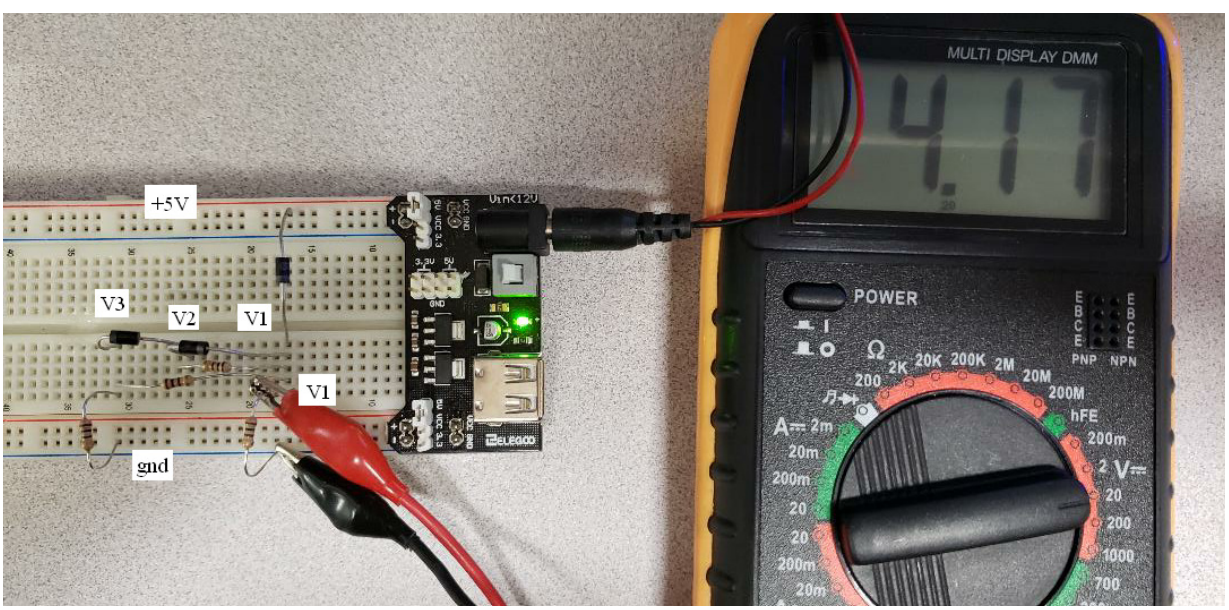
9) Simulate this circuit in CircuitLab to determine {V1, V2, and V3}

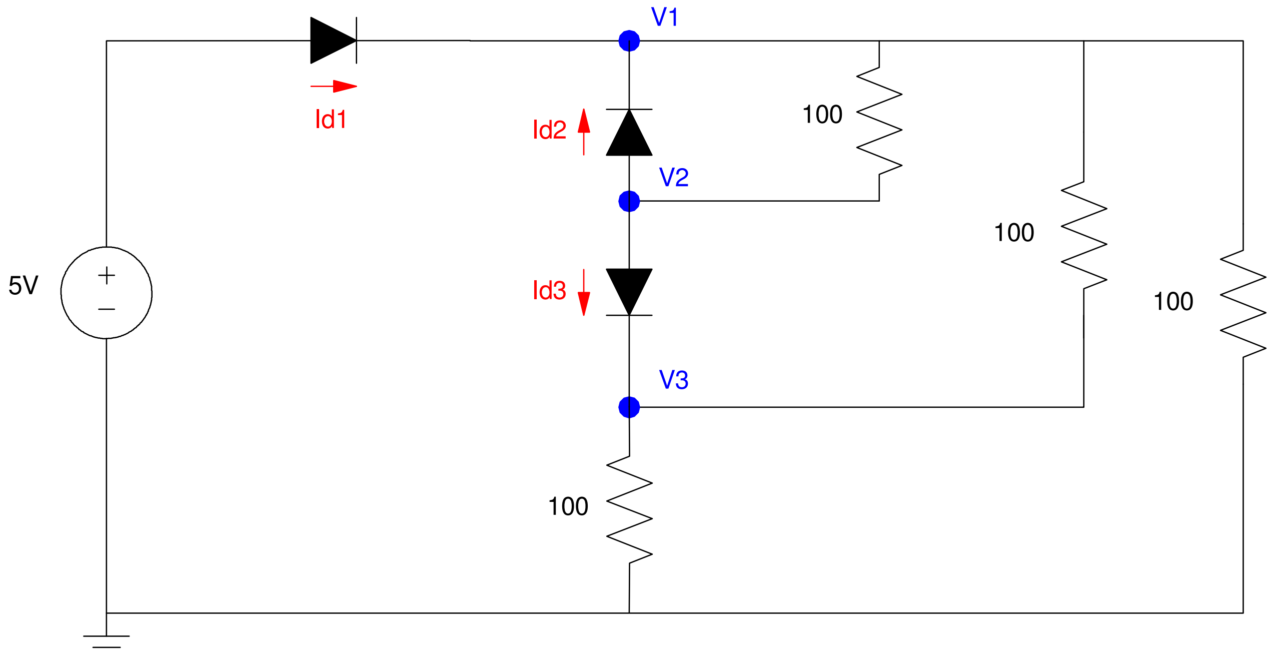


10) Build this circuit with your breadboard and measure {V1, V2, V3} +5V   V1   V2   V3   gnd

- Include a photo to receive credit for problem #10

	V1	V2	V3
8) Numeric Solution	4.1861 V	3.2829 V	2.5447 V
9) Simulation (CircuitLab)	4.230 V	3.283 V	2.588 V
10) Lab (experimental)	4.17 V	3.25 V	2.55 V





Problem 8-11. Change the resistors if you don't have four 100 Ohm resisotrs available