ECE 320 - Homework #2

Semiconductors, PN Junction, Ideal Diodes. Due Wednesday, September 8th

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

Semiconductors

1) Why does the voltage drop across a pn junction decrease as temperature increases?

As temperature increases, the number of thermal electrons / holes increases. This makes the n-type and p-type materials behave more and more like intrinisic (undoped) silicon. In the limit, when the doping no longer matters, the voltage drop will go to zero.

2) What doping of Boron (p-type) do you need to make an 1206 resistor have a resistance of 2200 Ohms? The dimensions of an 1206 resistor are

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

$$R = \frac{\rho L}{A}$$

$$2200\Omega = \frac{\rho \cdot 0.32cm}{0.16cm \cdot 0.095cm}$$

$$\rho = 104.5\ \Omega \cdot cm$$

$$\sigma = \frac{1}{\rho} = 0.009596 = n_p \cdot q \cdot \mu_p$$

$$0.009596 = n_p \cdot (1.6 \cdot 10^{-19}) \cdot (500)$$

$$n_p = 1.196 \cdot 10^{14} \quad \text{atoms / cc}$$

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

-48F Coldest day in Fargo (Jan 8, 1887)

- T = -44.44C
- R = 53,599 Ohms

0F Recommended temperature of a freezer

- T = -17.78C
- R = 8922.3 Ohms

+40F Recommended temperatuure of a refrigerator

- T = 4.44C
- R = 2640.2 Ohms

+114F Hottest day in Fargo (Jul 6, 1936)

- T = 45.56C
- R = 429.3 Ohms

Diode VI Characteristics

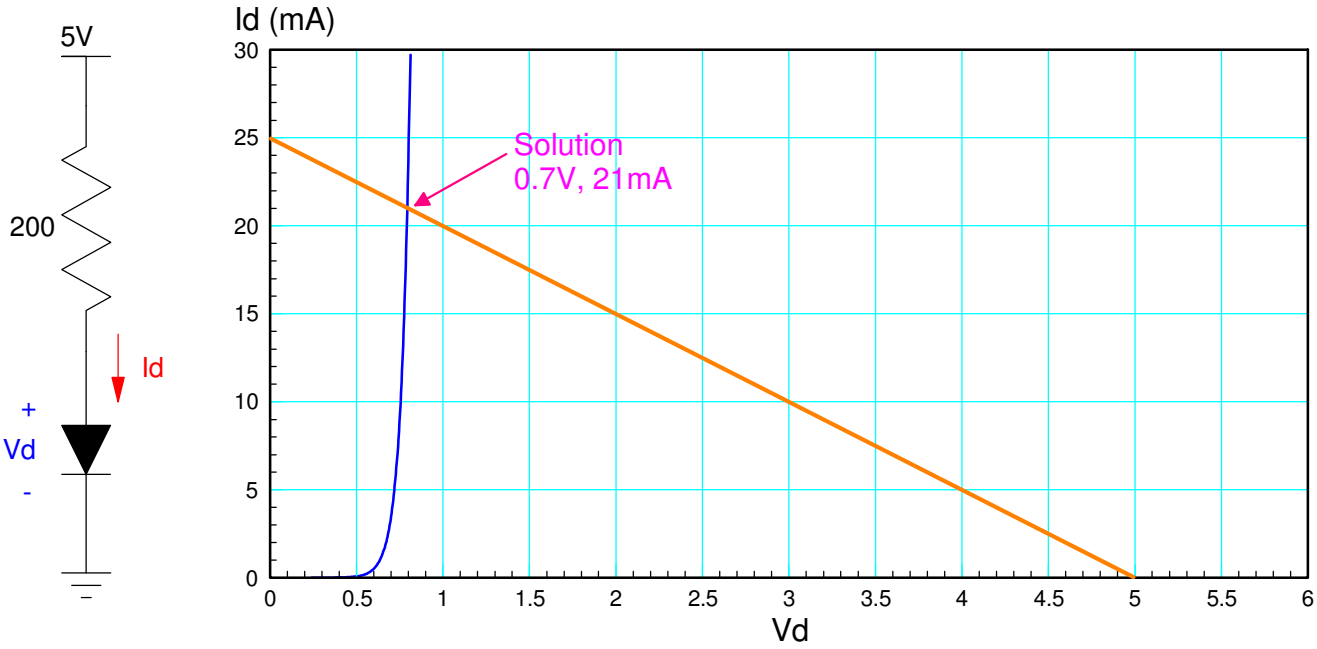
Assume the VI characteristics for a diode are

$$V_d = 0.052 \cdot \ln\left(\frac{I_d}{10^{-8}} + 1\right) \qquad I_d = 10^{-8}\left(\exp\left(\frac{V_d}{0.052}\right) - 1\right)$$

4) For the 1-diode circuit (next page - 200 Ohms is red - black - brown)

a) Draw the load-line for the following circuit (next page). Determine Vd and Id from the graph.

- When Id = 0, Vd = 5V
- When Vd = 0, Id = 5V / 200 Ohms = 25mA



b) Write the voltage node equations and solve for Vd and Id assuming the VI equations above

There are 2 unknowns (Vd, Id). We need 2 equations for 2 unknowns. One is the diode equation

$$V_d = 0.052 \cdot \ln\left(\frac{I_d}{10^{-8}} + 1\right)$$

The second is a current loop equation (voltage nodes also works)

$$V_d + 200 I_d = 5$$

Solving using fminsearch in Matlab. First, create a function where you

- Guess Vd
- From Vd, comptue the Id using the blue and orange line
- Return the squre of the distance between the two

```
function [ J ] = Diode1( z )

 Vd = z(1);
 Idss = 1e-8;
 nVt = 0.052;
 Id1 = Idss* exp( Vd/nVt - 1 );
 Id2 = (10 - Vd) / 200;
 e1 = (Id1 - Id2)*1000;  % mA
 J = (e1)^2;
 disp([z, log10(J)])
 pause(0.1);
end
```

Solving using fminsearch() in Matlab:

```
>> [V, e] = fminsearch('Diode1',2)
    2.0000   22.5387
    2.1000   24.2090
    1.9000   20.8683
    1.8000   19.1980
    1.6000   15.8572
    1.4000   12.5165
     :
     :
    0.8496   -1.8885
    0.8495   -3.5884
    0.8494   -2.4549
    0.8495   -4.5133
    0.8495   -3.1325
    0.8495   -4.5574

V =    0.8495
e =  2.7705e-005
```

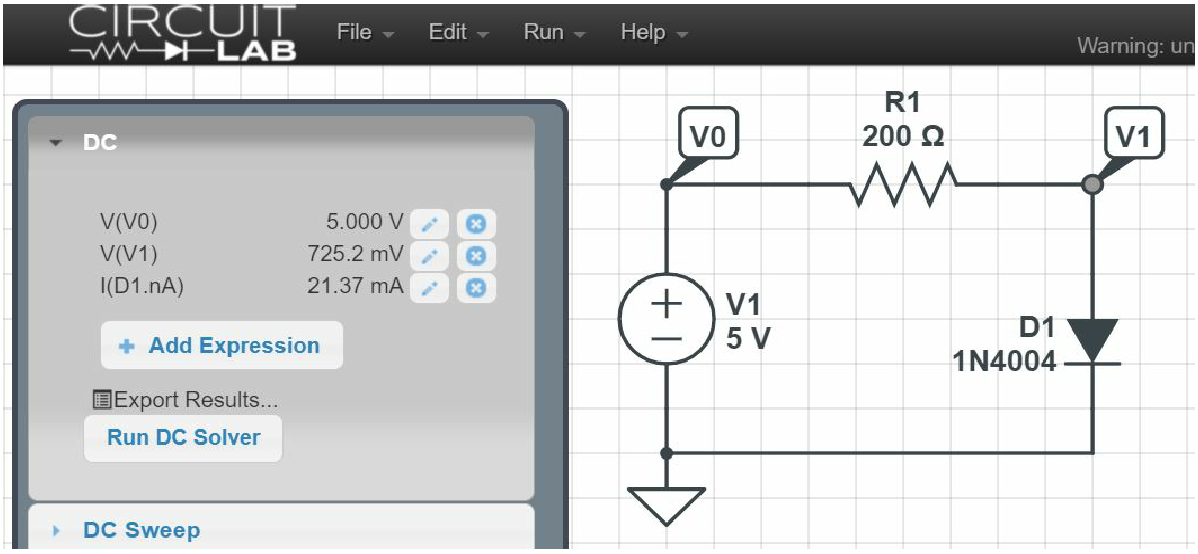
ans: V2 = 0.8495V

5) Determine Vd and Id assuming an ideal silicon diode (Vf = 0.7V)

$$V_d = 0.7V$$

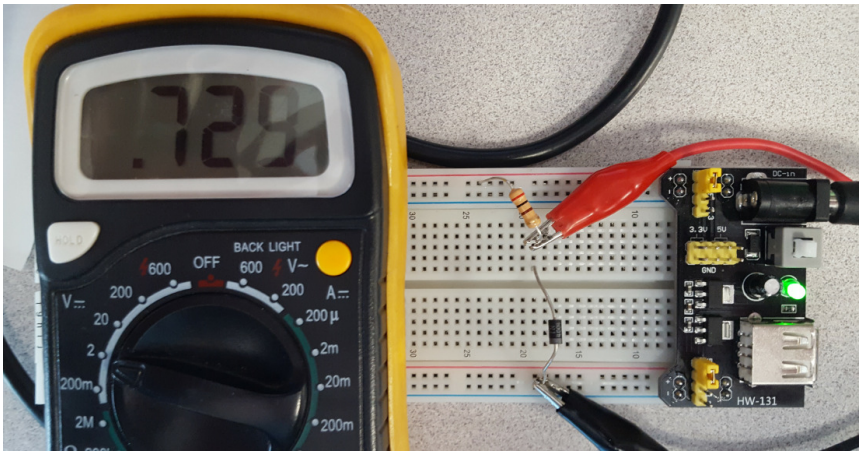
$$I_d = \left(\frac{5V - 0.7V}{200\Omega}\right) = 21.5mA$$

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



7) 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**	**21mA**
4b) Numeric Solution	**0.8495 V**	**20.75mA**
5) Ideal Diode	**0.7V**	**21mA**
6) Simulation (CircuitLab)	**0.7252V**	**21.37mA**
7) Lab (experimental)	**0.729 V**	**21.36mA**

Problem 4 to 7

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 - 11 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.

$$I_{d1} = 10^{-8}\left(\exp\left(\frac{V_1 - V_2}{0.052}\right) - 1\right)$$

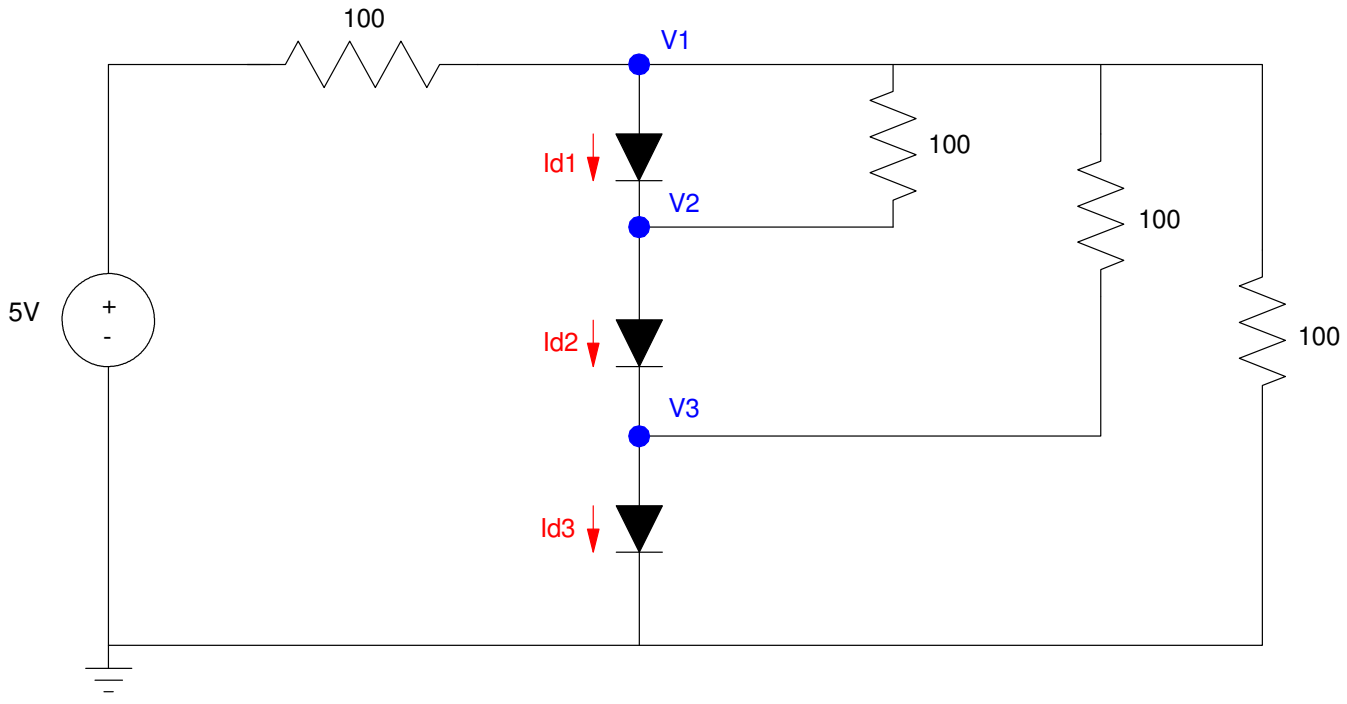
$$I_{d2} = 10^{-8}\left(\exp\left(\frac{V_2 - V_3}{0.052}\right) - 1\right)$$

$$I_{d3} = 10^{-8}\left(\exp\left(\frac{V_3}{0.052}\right) - 1\right)$$

$$\left(\frac{V_1 - 5}{100}\right) + I_{d1} + \left(\frac{V_1 - V_2}{100}\right) + \left(\frac{V_1 - V_3}{100}\right) + \left(\frac{V_1}{100}\right) = 0$$

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

$$-I_{d2} + I_{d3} + \left(\frac{V_3 - V_1}{100}\right) = 0$$



Solve using Matlab. First, create a function

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

 Idss = 1e-8;
 nVt = 0.052;

 Id1 = Idss* exp( (V1 - V2)/nVt - 1 );
 Id2 = Idss* exp( (V2 - V3)/nVt - 1 );
 Id3 = Idss* exp( (V3 - 0)/nVt - 1 );

 e1 = (V1 - 5)/100 + Id1 + (V1-V2)/100 + (V1-V3)/100 + (V1/100);
 e2 = (V2-V1)/100 - Id1 + Id2;
 e3 = (V3-V1)/100 - Id2 + Id3;

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

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

end
```

Solve for {V1, V2, V3} using fminsearch() in Matlab

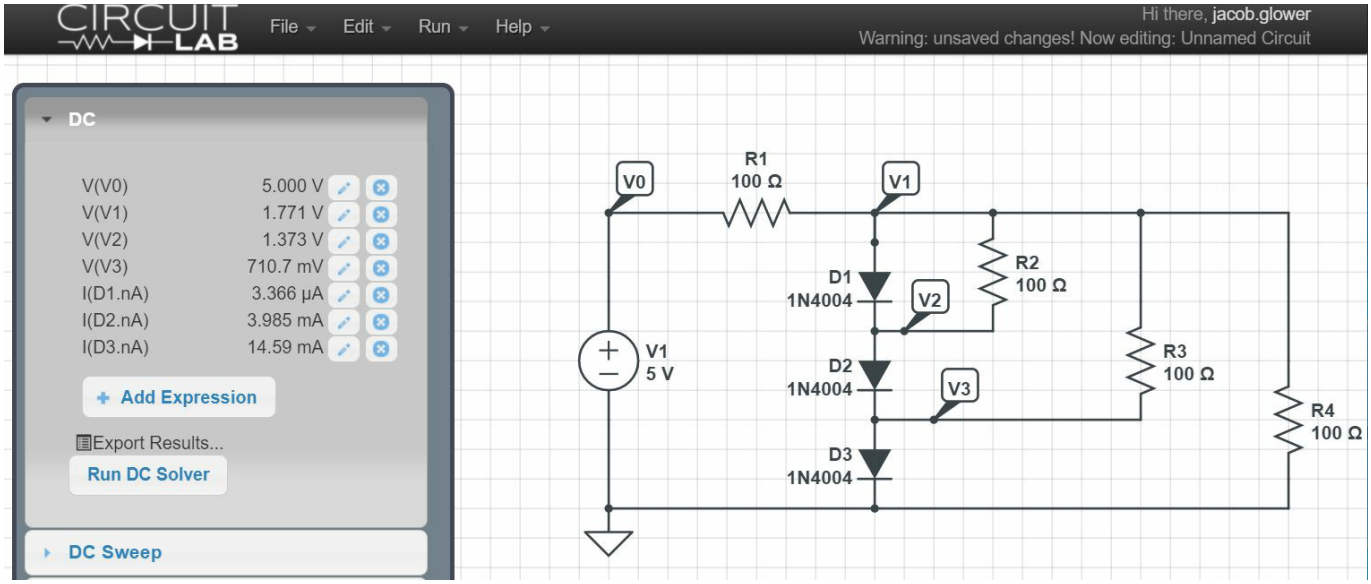
```
>> [V,e] = fminsearch('Diode3',[3,2,1])

     V1        V2         V3     log10(error)
   3.0000    2.0000    1.0000   -0.2200
   3.1500    2.0000    1.0000    2.6161
   3.0000    2.1000    1.0000    1.7326
   :
   :
   2.5962    1.7348    0.8697   -8.8025
   2.5962    1.7349    0.8697   -9.4757


          V1        V2        V3
V =    2.5962    1.7349    0.8697


e =  3.3442e-010
```

9) Assume ideal silicon diodes. (Vf = 0.7V). Determine {V1, V2, and V3}.

Assume all diodes are on. Then

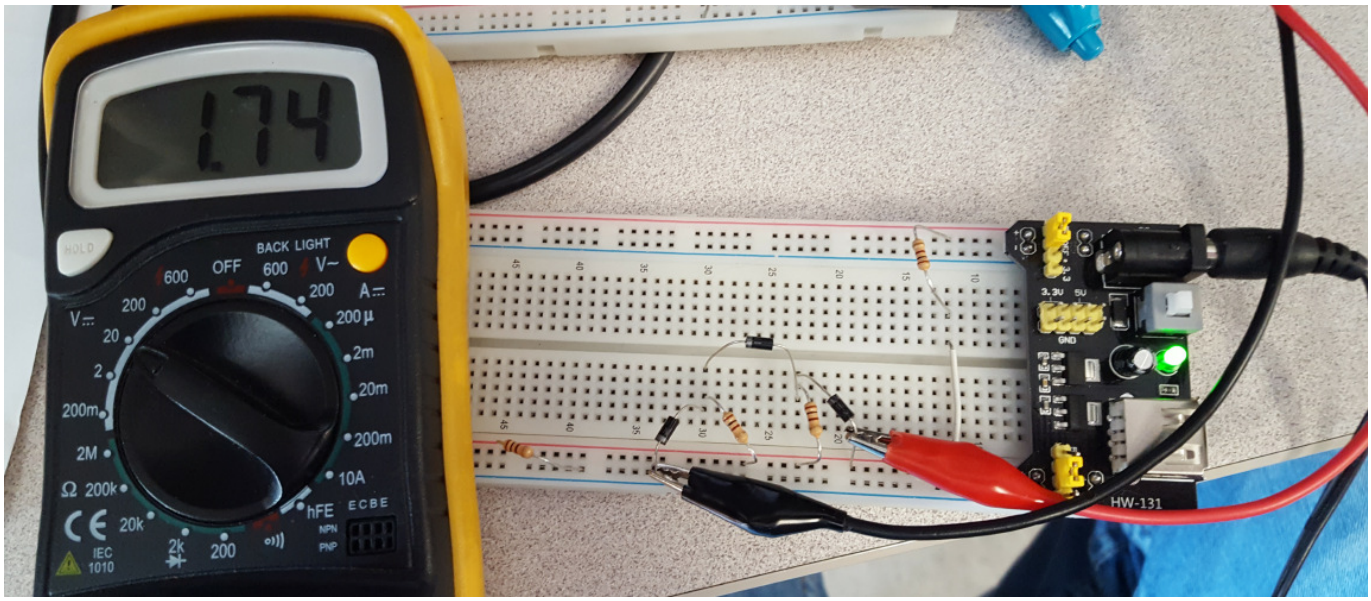
- V3 = 0.7V
- V2 = 1.4V
- V3 = 2.1V

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



11) Build this circuit with your breadboard and measure {V1, V2, V3}

- Include a photo to receive credit for problem #11



	V1	V2	V3
8) Numeric Solution	**2.5962 V**	**1.7349 V**	**0.8697 V**
9) Ideal Diode	**2.1 V**	**1.4 V**	**0.7 V**
10) Simulation (CircuitLab)	**1.771 V**	**1.373 V**	**0.710 V**
11) Lab (experimental)	**1.73V**	**1.359V**	**0.707V**