ECE 320 - Homework #2

Semiconductors, PN Junction. Due Monday, January 23rd

Semiconductors

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

A couple of ways to explain this (any of these are acceptable answers)

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 3300 Ohms? The dimensions of an 1206 resistor are

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

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

$$\rho = \frac{RA}{L} = \frac{(3300\Omega)\cdot(0.16cm)(0.095cm)}{0.32cm} = 156.75\Omega \cdot cm$$

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

$$\sigma = 0.0063796\frac{1}{\Omega \cdot cm} = n_n \cdot (1.6 \cdot 10^{-19}) \cdot (1300)$$

$$n_n = 30.67 \cdot 10^{12}\,\frac{\text{atoms}}{cc}$$

3) Determine the parameters for a ERT-D2FGL332S thermistor

- Digikey Part Number: PNT116-ND

$$R = R_{25} \cdot \exp\left(\frac{B_{25/50}}{T+273} - \frac{B_{25/50}}{298}\right)\Omega$$

From Digikey

- Resistance @ 25C = 3.3k
- B25/50 = 4500K

giving the relationship

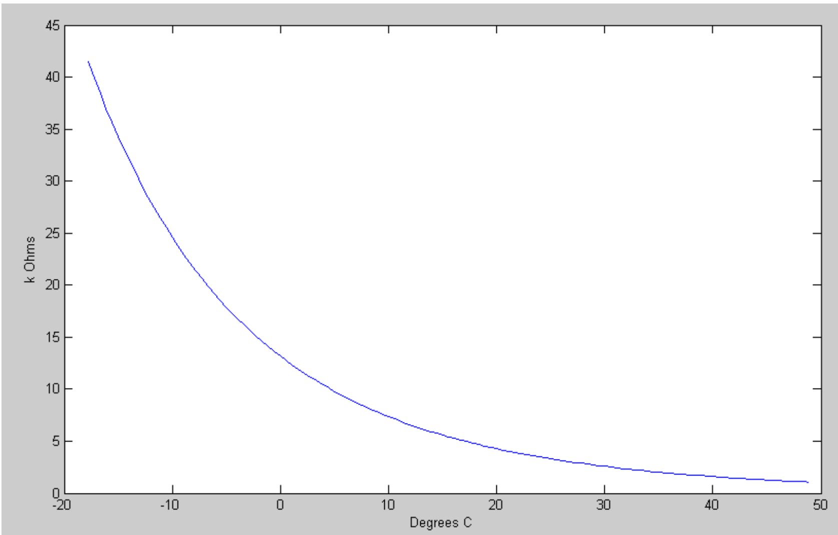
$$R = 3300 \cdot \exp\left(\frac{4500}{T+273} - \frac{4500}{298}\right)\Omega$$

The resistance at different temperatures:

T (F)	T (C)	R	
0F	-17.78C	41.47k Ohms	Recommended temperature of a freezer
+40F	4.444C	10.10k Ohms	Recommended temperature of a refrigerator
+68F	20.00C	4.270k Ohms	Temperature of cold tap water (varies)
+120F	48.89C	1.076k Ohms	Tempeature of hot tap water (varies)

(not asked for): The resistance vs. temperature can be plotted in Matlab

```
>> F = [0:120]';
>> C = (F-32)/1.8;
>> T = (F-32)/1.8;
>> R = 3300 * exp( 4500./(T + 273) - 4500/298 );
>> plot(T,R/1000);
>> xlabel('Degrees C');
>> ylabel('k Ohms');
```



Diode VI Characteristics

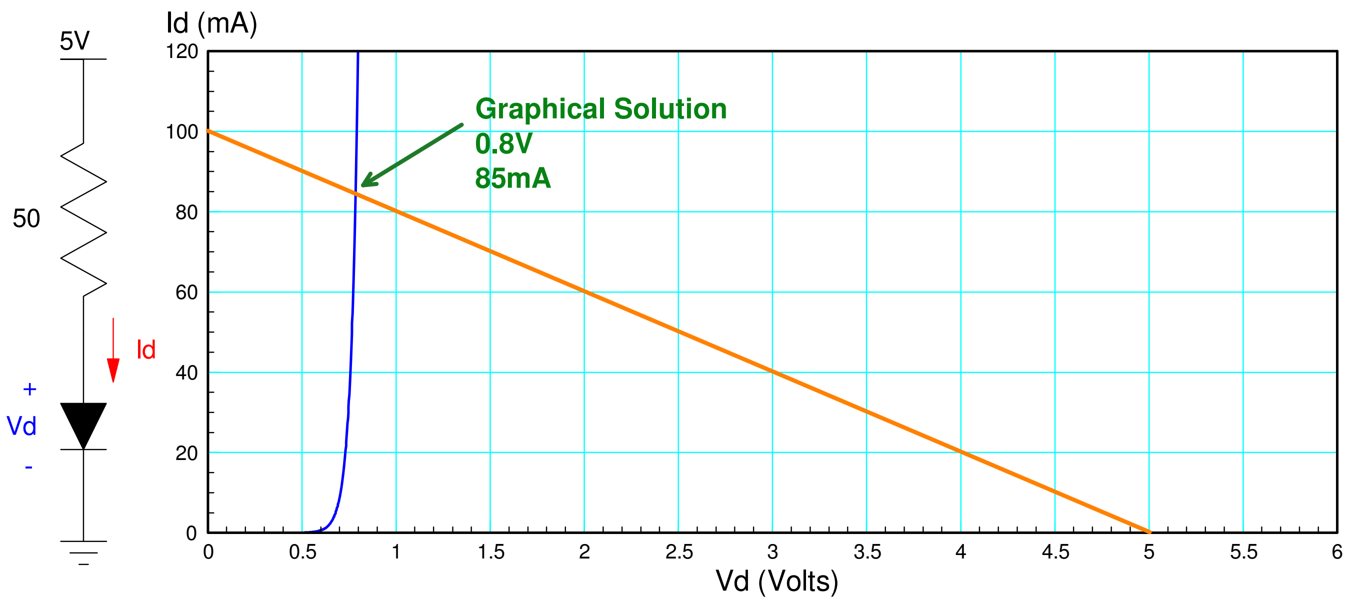
Assume the VI characteristics for a diode are (1N4004 diode in CircuitLab)

- 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 - use two 100-Ohm resistors in parallel for the 50 Ohm resistor)

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

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

$$V_d + 50 I_d = 5V$$

Solve using *fminsearch* in Matlab

First, write an m-file which

- Receives a guess for Vd, and
- Computed Id based upon the diode equation, and
- Returns the error in the second equation

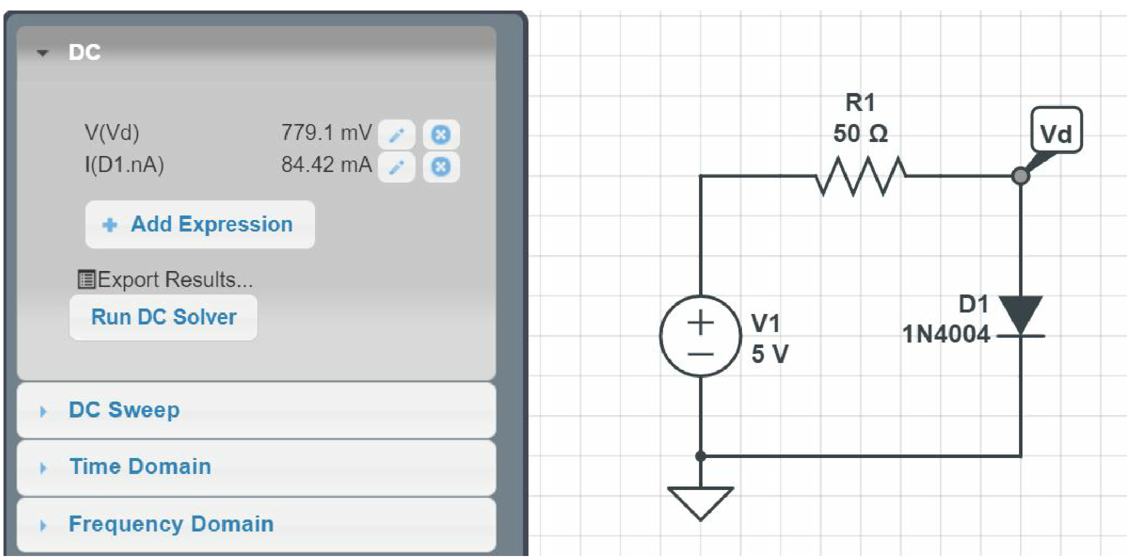
```
function [ J ] = Diode1( z )

 Vd = z(1);
 Idss = 7.69e-11;
 nVt = 0.0377;
 Id = Idss* exp( Vd/nVt - 1 );
 e1 = Vd + 50*Id - 5;
 J = (e1)^2;
 disp([z, log10(J)])
 pause(0.1);
end
```

Solving using fminsearch()

```
>> [V,e] = fminsearch('Diode1',1)
```

```
V =     0.8221
e =   9.2820e-006
```

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

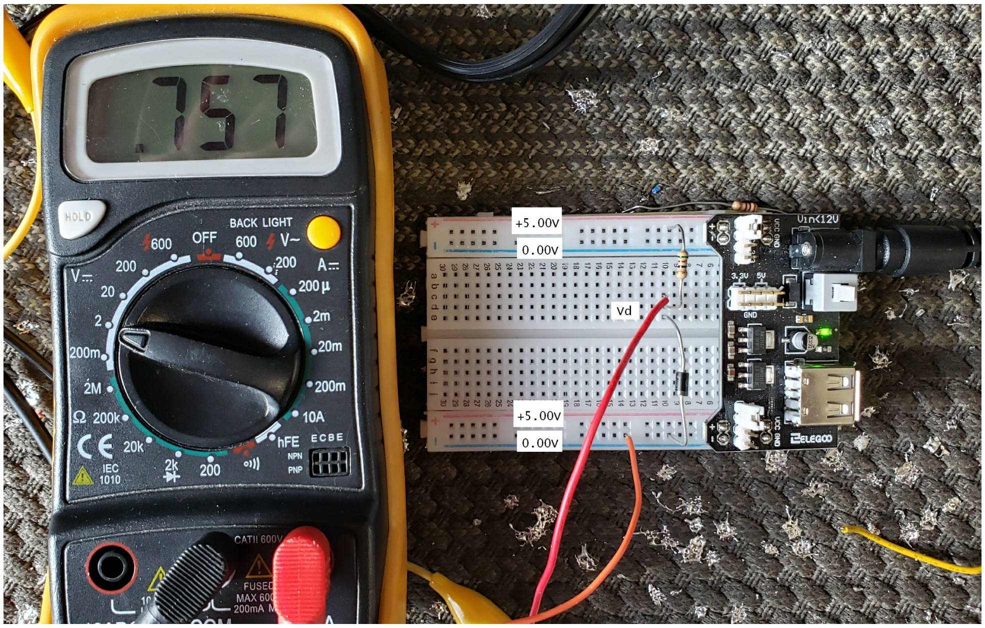


6) Build this curcuit on your breadboard and measure Vd. From this, compute Id

- Include a photo to receive credit for this problem

  Vd = 0.757V

$$I_d = \left(\frac{5.00V - 0.757V}{51\Omega}\right) = 83.20mA$$

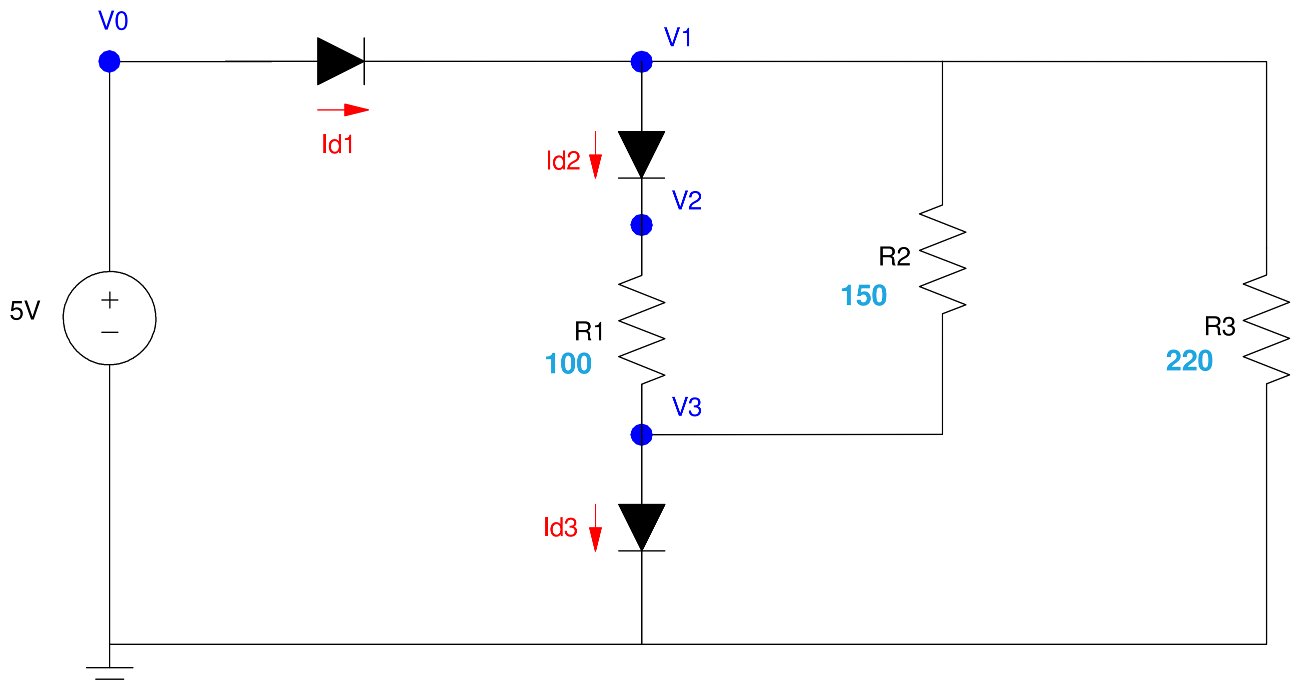


	Vd	Id
4a) Graphical solution	800mV	85mA
4b) Numeric Solution	821.1mV	83.58mA
5) Simulation (CircuitLab)	779.1mV	84.42mA
6) Lab (experimental)	757mV	83.20mA

Problem 4 to 6

Problem 8 - 10: Pick three resistors for R1, R2, R3 in the range of 100 Ohms to 330 Ohms. They can all be the same.

R1	R2	R3
100 Ohms brown - black - brown	150 Ohms brown - green - brown	220 Ohms red - red - brown



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

$$I_{d1} = 7.69 \cdot 10^{-11}\left(\exp\left(\frac{V_0 - V_1}{0.0377}\right) - 1\right)$$

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

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

Node Equations

$$-I_{d1} + I_{d2} + \left(\frac{V_1 - V_3}{150}\right) + \left(\frac{V_1}{220}\right) = 0$$

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

$$\left(\frac{V_3 - V_2}{100}\right) + \left(\frac{V_3 - V_1}{150}\right) + I_{d3} = 0$$

Create an m-file which

- Receives your gues for V1, V2, V3, and
- Computes the sum-squared error in the current equations

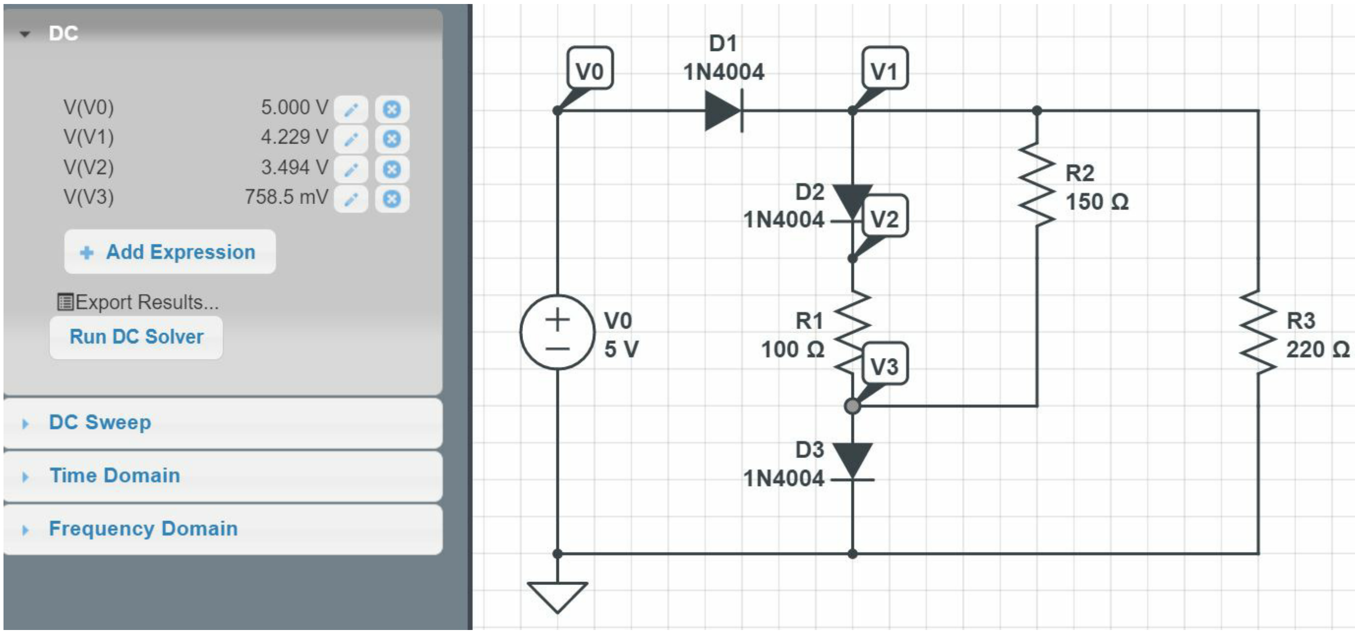
Matlab Code:

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

 V0 = 5;
 V1 = z(1);
 V2 = z(2);
 V3 = z(3);

 Idss = 7.69e-11;
 nVt = 0.0377;

 Id1 = Idss* exp( (V0-V1)/nVt - 1 );
 Id2 = Idss* exp( (V1-V2)/nVt - 1 );
 Id3 = Idss* exp( (V3)/nVt - 1 );

 e1 = -Id1 + Id2 + (V1-V3)/150 + (V3)/220;
 e2 = -Id2 + (V2-V3)/100;
 e3 = (V3-V2)/100 + (V3-V1)/150 + Id3;

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

 disp([z, log10(J)])
 pause(0.1);
end
```

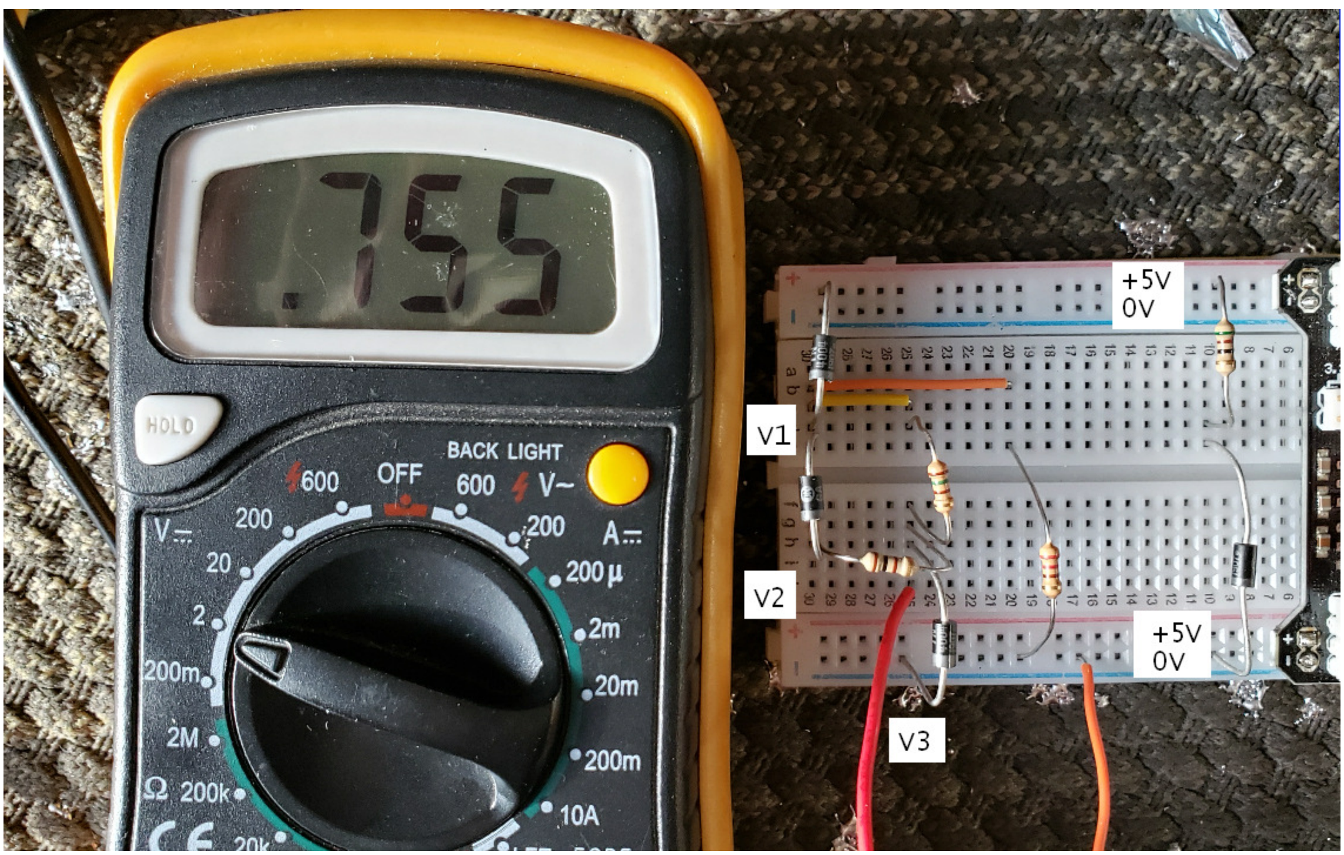
Solving using fminsearch()

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

          V1        V2         V3
V =    4.1955    3.4172    0.8018

e =  5.5499e-010
```

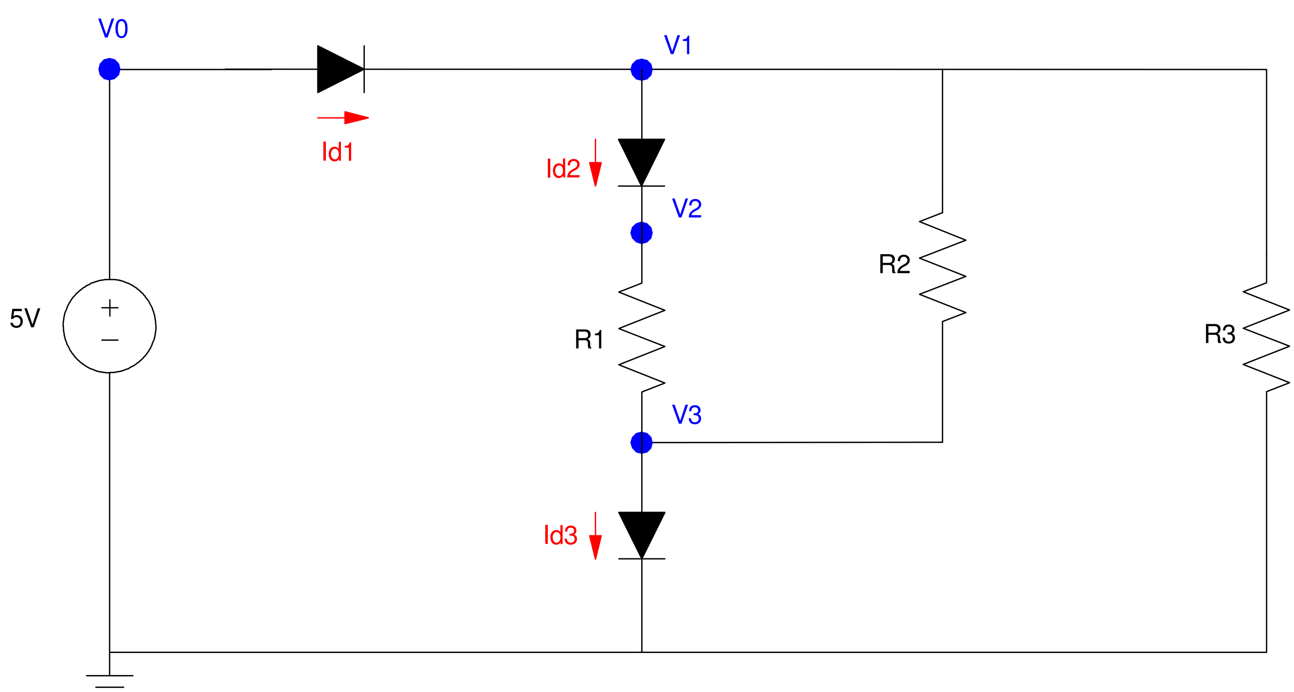
9) Simulate this circuit in CircuitLab to determine {V1, V2, and V3}



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



	V0	V1	V2	V3
8) Numeric Solution	5.00V	4.1955V	3.4172V	801.8mV
9) Simulation (CircuitLab)	5.00V	4.229V	3.494V	758.5mV
10) Lab (experimental)	4.92V	4.14V	3.40V	755mV



Problem 8-10. R1, R2, and R3 are in the range of 100-330 Ohms (your pick)