

ECE 320 - Solution #2

Semiconductors, PN Junction, Diode VI Characteristics. Due Wednesday, January 23rd, 2019

Semiconductors

1) Why does the resistance of silicon decrease as temperature goes up?

As temperature goes up, more and more electrons escape their covalent bonds creating free electrons and holes (both charge carriers). As the number of charge carriers goes up, the resistance goes down.

2) What doping of Boron (p-type) do you need to make an 0805 resistor have a resistance of 300 Ohms? The dimensions of an 0805 resistor are

$$L = 2.0\text{mm}, W = 1.25\text{mm}, H = 0.95\text{mm}$$

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

$$300\Omega = \left(\frac{\rho \cdot 0.2\text{cm}}{(0.125\text{cm})(0.095\text{cm})} \right)$$

$$\rho = 17.182 \Omega \cdot \text{cm}$$

$$\sigma = \frac{1}{\rho} = 0.0561 \frac{1}{\Omega \cdot \text{cm}} = qp\mu_p$$

$$0.0561 = (1.6 \cdot 10^{-19} \text{C})(p)(500)$$

$$p = 7.017 \cdot 10^{14} \frac{\text{atoms}}{\text{cc}}$$

3) A thermistor has the following resistance - voltage relationship

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

where T is the temperature in degrees Kelvin. What is the resistance you'll read at

+34C	-31C	0C
681 Ohms	20,745 Ohms	3320 Ohms

Sample Calculation: At +34C

$$T = 34C + 273C = 307K$$

$$R = 1000 \left(\frac{3905}{307K} - \frac{3905}{298K} \right) \Omega = 681\Omega$$

PN Junction

4) Why can current flow p to n but not n to p?

Any of the following explanations are OK

Answer 1: p to n you are using majority carriers so the resistance is small. n to p you are using minority carriers, so the resistance is large.

Answer 2: Applying voltage p to n results in the depletion zone be reduced in size. If reduced to zero, current flows. Applying voltage n to p just makes the depletion zone bigger.

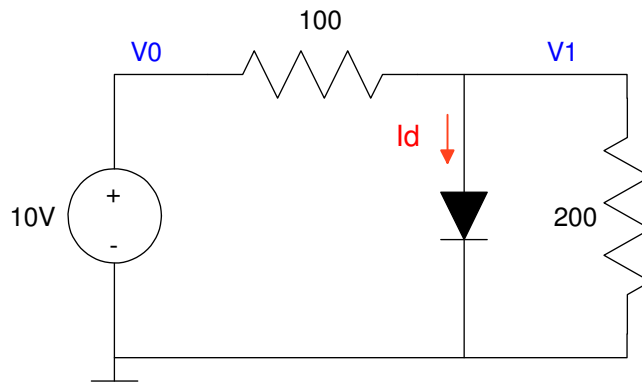
Answer 3: If you have enough voltage to overcome the potential energy barrier (0.7V for silicon), current flows. If you don't, current doesn't (it doesn't have enough energy to overcome the potential energy barrier).

Diode VI Characteristics

Assume the VI characteristics for a diode are

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

5) Write the voltage node equations for the following circuit. Solve for V1



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

$$\left(\frac{V_1 - 10}{100} \right) + I_d + \left(\frac{V_1}{200} \right) = 0$$

To solve, set up a function in Matlab and solve with fminsearch()

```
function [ J ] = diode1( X )  
    V1 = X(1);  
    Id = 1e-8 * ( exp( (V1) / 0.052 ) - 1 );  
    E1 = (V1 - 10)/100 + Id + V1/200;  
    J = E1^2;  
end
```

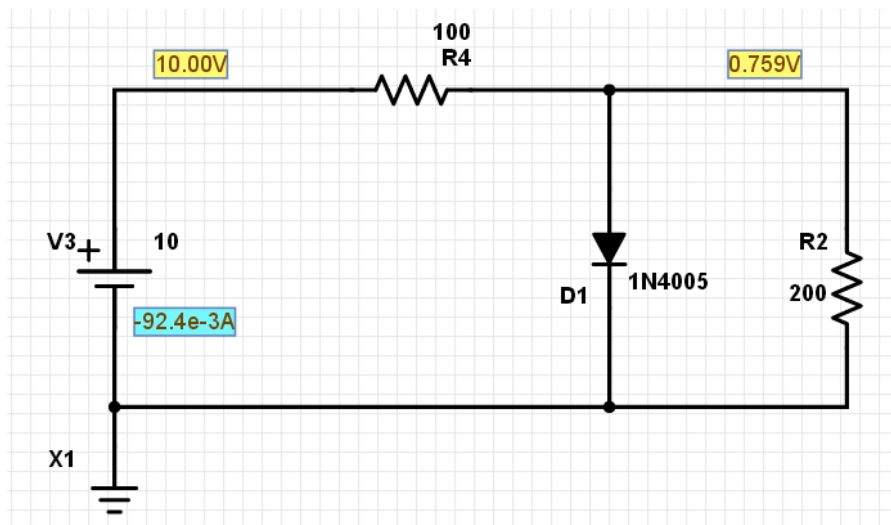
Running this in Matlab

```
[V,e] = fminsearch('diode1',0.7)
```

V = 0.8313

e = 3.2940e-009

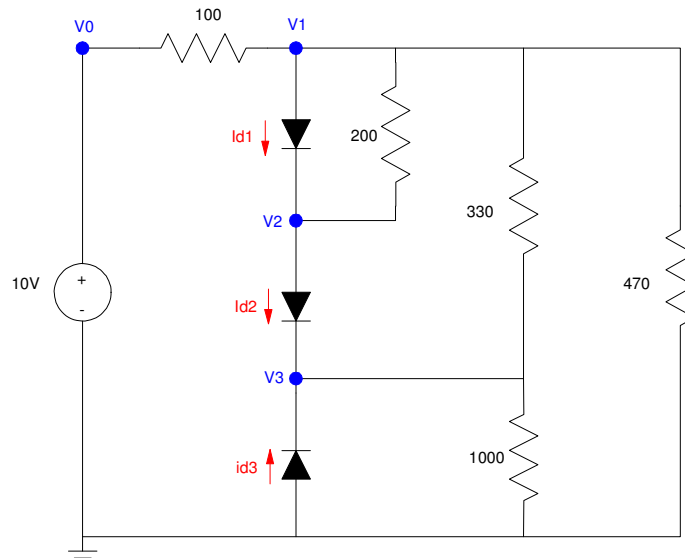
6) Check your answer in PartSim. (use Fairchild, Rectifier Diode, 1N4005)



Comparing calculations to simulations:

	Calculated Problem 5	Simulated Problem 6	Measured Problem 7
V	0.8313 V	0.759 V	0.7876 V

8) Write the voltage node equations for the following circuit. Solve for V1, V2, and V3



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

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

$$I_{d3} = 10^{-8} \left(\exp \left(\frac{0 - V_3}{0.052} \right) - 1 \right)$$

$$\left(\frac{V_1 - 10}{100} \right) + I_{d1} + \left(\frac{V_1 - V_2}{200} \right) + \left(\frac{V_1 - V_3}{330} \right) + \left(\frac{V_1}{470} \right) = 0$$

$$-I_{d1} + I_{d2} + \left(\frac{V_2 - V_1}{200} \right) = 0$$

$$-I_{d2} - I_{d3} + \left(\frac{V_3 - V_1}{330} \right) + \left(\frac{V_3}{1000} \right) = 0$$

Create an m-file to return the sum-squared error of each equation

```
function [ J ] = diode3( X )

V1 = X(1);
V2 = X(2);
V3 = X(3);

Id1 = 1e-8 * ( exp( (V1 - V2) / 0.052 ) - 1 );
Id2 = 1e-8 * ( exp( (V2 - V3) / 0.052 ) - 1 );
Id3 = 1e-8 * ( exp( (0 - V3) / 0.052 ) - 1 );

E1 = (V1 - 10)/100 + Id1 + (V1 - V2)/200 + (V1 - V3)/330 + V1/470;
E2 = -Id1 + Id2 + (V2 - V1)/200;
E3 = -Id2 - Id3 + (V3 - V1)/330 + V3/1000;

J = E1^2 + E2^2 + E3^2;

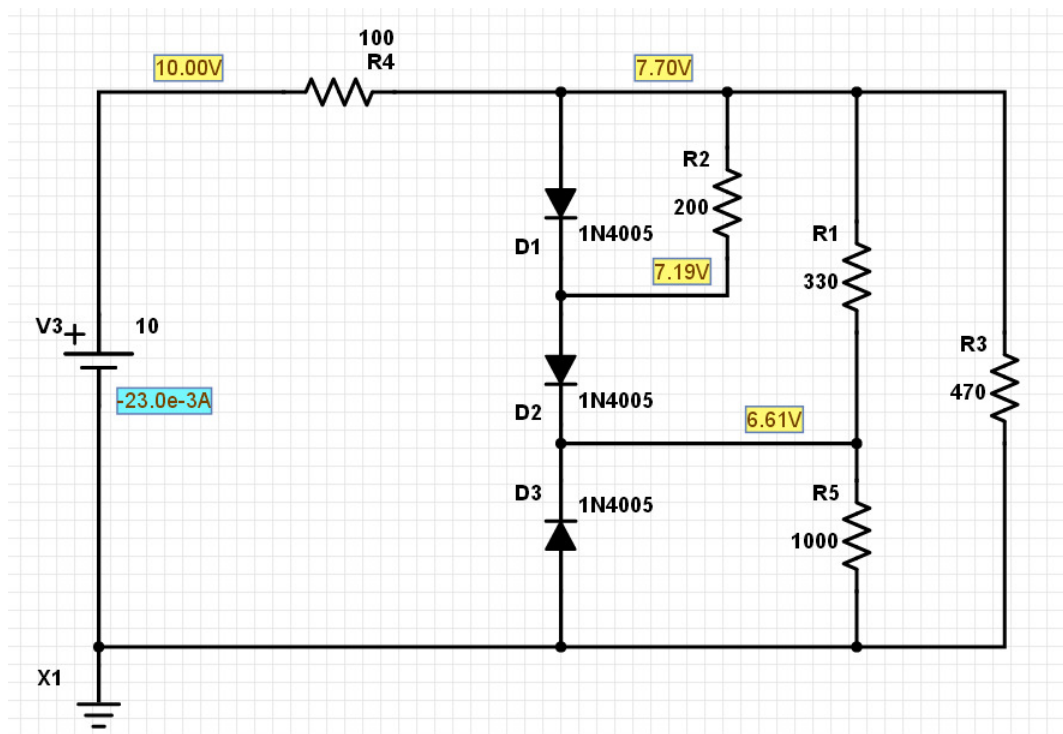
end
```

```
>> [V,e] = fminsearch('diode3',[3,2,1])
```

```
V =      V1      V2      V3
      7.7078    7.1766    6.5221
```

```
e = 1.0940e-013
```

9) Check your results in PartSim. (use Fairchild, Rectifier Diode, 1N4005)



10) Build this circuit and measure the voltages V1, V2, and V3. Use a 4004 diode (in room 211 - or any silicon diode)

note: there is no separate lab write-up in this class. Just collect data in the lab and compare the results to your calculations and simulation results. Tables like the one below are a convenient way to compare these results.

Problem 7, 8, 9

	Calculated (problem 7)	Simulation Results (problem 8)	Lab Results (problem 9)
V1	7.7078 V	7.70 V	7.714 V
V2	7.1766 V	7.19 V	7.171 V
V3	6.5221 V	6.61 V	6.554 V