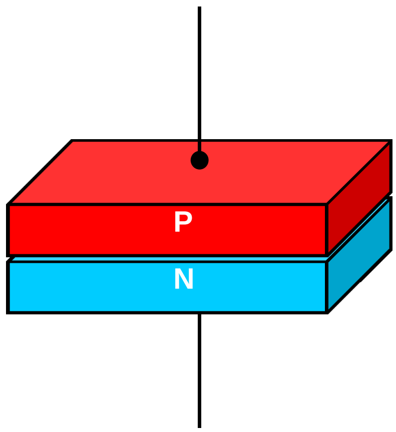
EET-225 Homework #1

Sr. Professor Wheeler

18 points possible

1. What is a diode? Draw a diagram showing the construction of a semiconductor diode. (1 point)

   A diode is a two-terminal device. A semiconductor diode is built with two differently-doped layers of semiconductor material (such as silicon or germanium). A classical junction type diode is constructed as follows:



2. What material is most commonly used for constructing diodes? Why? (1 point)

   Silicon is most commonly used because it is inexpensive and plentiful.

3. What are the majority carriers in P and N type silicon? (1 point)

   In *P* silicon, the majority carriers are holes. A hole is present when an atom has a missing electron, giving it a net positive charge. P-type silicon is doped with an acceptor impurity that causes the silicon atoms to be short of electrons.

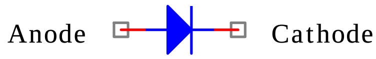
   In *N* silicon, the majority carriers are electrons. N-type silicon is produced by doping pure silicon with a *donor impurity*, resulting in extra valence electrons and a net negative charge.

4. Explain the difference between conventional and electron current. Which is used in engineering? (1 point)

   Electron current follows electrons as unit charges, while conventional current follows the direction of hole flow. Engineering arbitrarily uses conventional current flow.

   Tip: In most semiconductor device symbols, arrows indicate the direction of conventional current flow.

5. Draw the schematic diagram of a diode. What is the *ideal behavior* of a diode? (1 point)



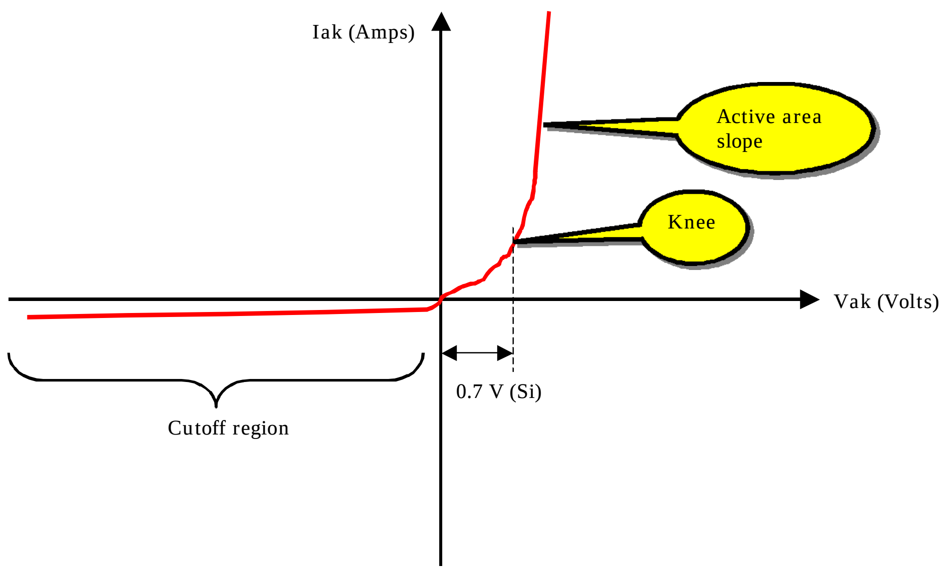
The ideal behavior of a diode is to allow current to flow in the direction of the arrow. In other words, a diode allows current to flow in only *one* direction.

6. Explain the conditions necessary for a diode to be (a) Forward-Biased and (b) Reverse-Biased. (1 point)

(a) For a diode to be forward-biased, the anode must be positive with respect to the cathode. For the diode to conduct significantly when forward biased, the positive potential must approach the *barrier potential* of the junction, which is about 0.7 V (at room temperature) for silicon junctions.

(b) A diode is reverse-biased when the anode-cathode potential is either *zero* or *negative*. Ideally, no current flows in a reverse-biased diode.

7. Draw a characteristic curve for a typical silicon diode, labeling the following clearly on the graph: (a) Knee ; (b) Cutoff; (c) Active area slope (2 points)



Optional note (not required of the student): The shape of the right-hand portion of the diode curve is given by the Ebers-Moll equation:

$$I = Is(e^{\left(\frac{Vq}{KT}\right)} - 1)$$

Where I is the diode current, Is is the saturation current (reverse bias leakage current or zero-voltage current), V is the anode-cathode voltage on the diode, K is Boltzmann's constant (1.38 x 10^-23 J/K), and T is absolute temperature.

For a silicon junction at room temperature (q/KT) is about 40, and the equation becomes:

$$I = Is(e^{(40V)} - 1)$$

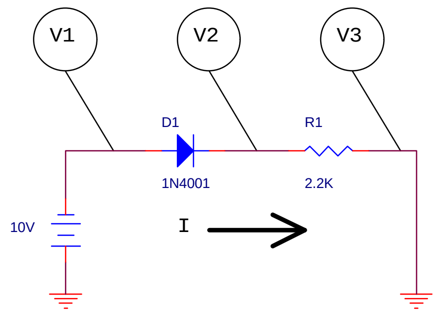
The current *Is* can be found on the data sheet for a particular device.

The equivalent resistance of the diode junction is the derivative of the diode voltage with respect to the diode current:

$$r'd = \frac{dV}{dI} \approx \frac{KT}{qI} \approx \frac{0.025V}{I}$$ when (q/KT) = 40 (silicon)

8. What is the knee voltage for these diode types? (1 pt)
   a) Silicon: <u>0.7 V</u>
   b) Germanium: <u>0.3 V</u>
   c) Gallium Arsenide: <u>2.0 V</u>
   d) Schottky (Hot Carrier): <u>0.1 V</u>

9. Calculate the currents and voltages for each circuit shown below. State clearly whether the diode(s) are in conduction or cutoff. (6 points, one per sub-problem)

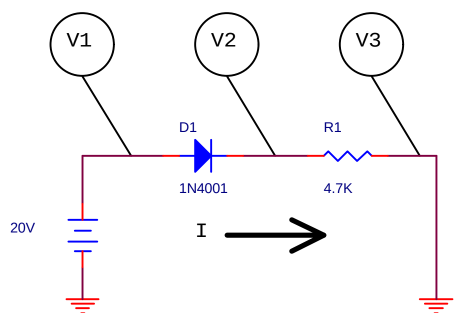


V1 = -10 V by inspection (Vcc power potential)

V2 = 10 V - V(D1) = 10 V - 10 V = 0 V **(Diode is reverse biased)**

V3 = 0 V by inspection (Grounded)

I = V(R1) / R1 = (V2-V3)/R1 = (0 V - 0 V) / 2.2 K = 0 mA (Diode is reverse biased)

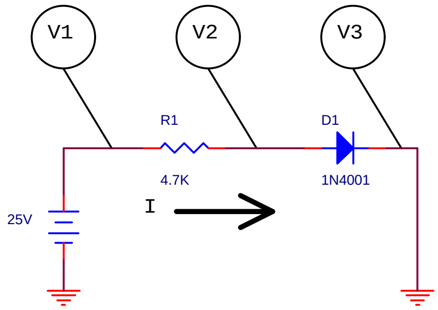


V1 = 20 V by inspection

V2 = V1 - V(D1) = 20 V - 0.7 V = 19.3 V

V3 = 0 V (ground) by inspection

I = V(R1)/R1 = (V2 - V3)/R1 = 19.3 V / 4.7 K = 4.1 mA

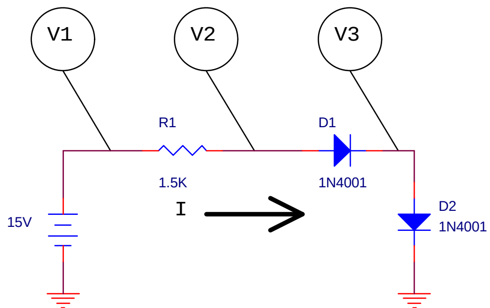


V1 = <u>25 V</u> by inspection

V3 = <u>0 V</u> by inspection

V2 = V3 + V(D1) = 0 V + 0.7 V = <u>0.7 V</u> (Diode is forward biased)

I = V(R1) / R1 = (V1 - V2)/ R1 = (25V-0.7V)/4.7K = <u>5.2 mA</u>

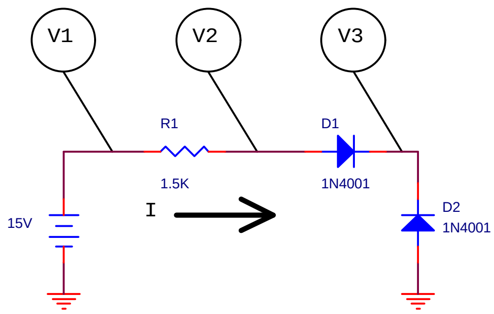


V1 = <u>15 V</u> by inspection

V3 = 0 V + V(D2) = 0 V + 0.7 V = <u>0.7 V</u>

V2 = V3 + V(D1) = 0.7 V + 0.7 V = <u>1.4 V</u>

I = (V1-V2)/R1 = (15 V - 1.4 V)/1.5K = <u>9.07 mA</u>

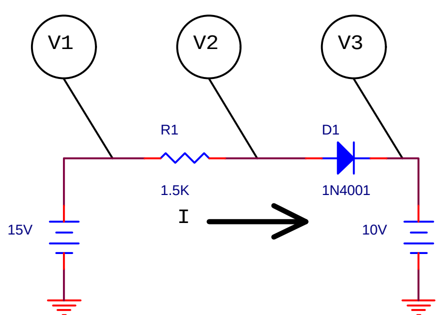


V1 = 15 V by inspection

I = 0 mA by inspection (notice that D1 and D2 are in opposing directions, so that no current can flow in either direction because one the diodes will always be "blocking.")

V2 = V1 - I R1 = 15 V - (0 mA)(1.5K) = 15 V

V3 will be approximately equal to V2 because the diode current in D1 will be zero; V3 = 15 V by inspection. (In reality, V3 will be determined by the leakage current of D1 and D2 dropped across R1).



V1 = 15 V by inspection

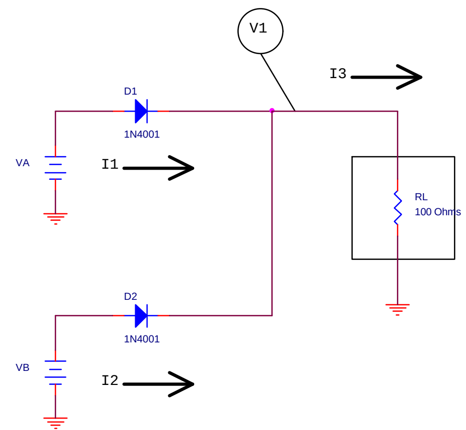
V3 = 10 V by inspection

V2 = V3 + V(D1) = 10 V + 0.7 V = 10.7 V

I = (V1 - V2) / R1 = (15 V - 10.7 V)/ 1.5K = 2.9 mA

10. Below is an interesting diode circuit that will let a device be powered from either the "A" or "B" battery, depending on which battery is the strongest. Calculate the voltage V1 and all currents in the circuit under the following conditions: (3 points, 1 per sub-problem)

a) VA = 10 V, VB = 0 V
b) VA = 10 V, VB = 15 V
c) VA = 0 V, VB = 10 V



a) V1 = VA - V(D1) = 10 V - 0.7 V = 9.3 V
I1 = V1 / RL = (VA - V(D1)) / RL = (10 V - 0.7 V)/100 Ohms = 9.3 V / 100 = 93 mA
I2 will be 0 mA by inspection since VB < V1 reverse biases D2.
I3 = I1 = 93 mA

b) V1 = VB - V(D2) = 15 V - 0.7 V = 14.3 V
I1 = 0 mA by inspection because D1 is reverse biased
I2 = I3 = V1 / RL = 14.3 V / 100 Ohms = 143 mA

c) This condition is precisely the reverse of condition *A*:

V1 = VB - V(D2) = 10V - 0.7 V = 9.3 V
I1 = 0 mA since D1 is reverse biased
I2 = I3 = V1 / RL = 9.3 V / 100 Ohms = 93 mA