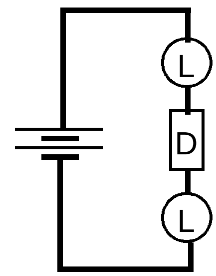
1. Find two small light bulbs which have equal brightness when connected in series, as on page 79. Then connect a "diode" between them so that all three devices are in series, as in the diagram at the right.



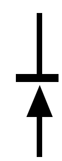
* a. Describe what happens when the circuit is completed.
* b. Describe what happens when you reverse the direction of electron flow by exchanging the plugs in the power supply. (Put the red plug into the black hole, and put the black plug into the red hole.)
* c. Describe what happens when the diode itself is reversed. (Disconnect it, turn it end-over-end 180 degrees, and then reconnect it.)

2. True or false:
   a. "Electrons can pass through one end of a diode, but not the other end." _____
   b. "One bulb in the series will glow, but the other will not." ____
   c. "If both bulbs in the series are lit, then reversing the diode or the power supply causes both bulbs to stop glowing." ______
   d. "The diode consumes electrons, so that the electron flow *from* the diode is less than the flow *into* the diode." _____
   e. "Electrons can travel through a diode in only one direction." _____

3. Which statement(s) in #2 are *predictions?* ____
   Which one(s) are *observations?* _____
   Which one(s) are *conclusions?* _____

4. One end of a diode is marked in some way to make it visibly different from the other end.
* Explain how to interpret that marking and illustrate your explanation.

5. The circuit symbol representing a diode is an arrow with a "blocker" in front of it, saying "*electrons may not flow in this direction*." (See illustration at the right.) Draw a new diagram showing two bulbs connected in series to a power supply. Then draw a diode connected as a jumper across one of the bulbs.



* a. Predict what will happen when the diode is added to the circuit, and predict what will happen when the direction of the current is reversed. Explain your predictions, using the word "because".
* b. Get your plans approved, test your predictions, and then *describe your observations.*
* c. Write a *conclusion* about which device resists electron flow the most (or least) in each case.

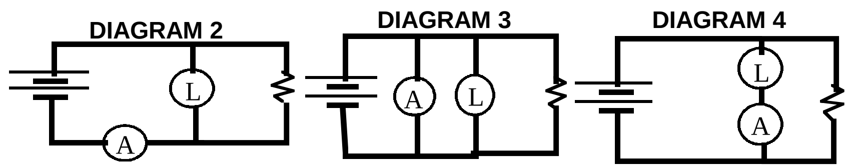
6. We have already seen that a light bulb can be used to detect electron flow. (A bulb lights up only when there is a significant amount of current through it.) Invent a device for determining the *direction* of electron flow. Arrange two diodes and two light bulbs so that one lights up when electrons flow one way through the device, and the other lights up when electrons flow the other way. Remember to get your plan approved before testing it.

7. Imagine a small town called "Bottleneck" which is located on a major highway. Every morning commuters must enter the east end of this town and exit from the west end. Every evening they pass through town again, the other way. The proud mayor has requested one-way signs on all of the streets in town so that all of the commuter traffic always goes northward past his office. Draw the simplest possible road map for such a town. Make it as simple as possible, using straight lines with right-angle bends to represent the roads, and using diode symbols to represent the one-way signs. If your plan is approved you may test it. Use a light bulb or the device in #6 to represent the one-way street by the mayor's office.

1. Imagine an elf who is so small he can see electrons. He lives in a windowless box with one entrance and one exit, and his job is to measure electric currents in __________s per ________, as in 5c on page 78. The elf counts only the electrons that he sees going through his home. Since he refuses to leave the box we must arrange for the electrons to enter at one end and leave the box at the other.
   a. The elf will need a calculator and a ___________, because he must divide the number of electrons he counts by the corresponding ________ _________.
   b. Some people say the electrons go *"through"* the box. Others prefer to say that electrons go *"of"* the box. Which preposition makes sense to you? ___________ *(See 2a on p. 78.)*

2. In the space at the right, please draw a circuit diagram with a light bulb and a resistor connected in parallel to a battery. Insert the elf box in the correct position to measure the current at the point where electrons enter the resistor. (You saved a copy of #1 on page 79 to help with this exercise.) *Make it impossible for electrons to enter the resistor without first being counted.*

3. Any current-measuring device like the imaginary one described above can be called an "ammeter". In a diagram it would be represented by a box or circle containing the letter "A".
   a. In which circuit below does the ammeter measure the rate of charge flow *from* the battery? ___
   b. In which one does the ammeter measure the rate at which charge flows *into* the bulb? ___
   c. In *one* of these four circuits the ammeter invites an unlimited flow of electrons from one battery terminal to the other. We call that a "NO-NO" or **bozo** circuit.



Please label the no-no circuit with big capital letters and copy it onto RS IX for future reference.

4. **SECRET CONNECTION RULE:** According to #1, #2, and #3, you can measure the rate at which electrons enter a device by connecting an ammeter in ________ (series or parallel) with that device. -Do 3a & 3b agree with that rule? ___ Only a *BOZO* would connect an ammeter in ________ with another device. Have you identified the "bozo" circuit above?___ Have you copied the answers into the blanks without misspelling them?___ *A copy of the connection rule is saved in #___ on RS___.*

5. **SIGN RULE:** If electrons flow through an ammeter in the wrong direction they will cause the needle to move the wrong way. To help you avoid that mistake, ammeter terminals are labelled with positive and negative signs. (The positive one is red, the negative one is black.) Always connect electrical meters so that electrons will flow **IN** through the "-" terminal and **OUT** through the "+" terminal.
   a. To show that you understand this rule, please put appropriate signs onto the ammeter terminals in *each* of the four diagrams above. If necessary, you may make the diagrams bigger.
   b. Draw arrows on *all* of the wires *in all 4 diagrams* (as on p. 79) showing directions of electron flow.
   c. A copy of the *sign rule* has been recorded in #___ on RS___.

6. According to #1 on this page, electric currents should be measured in _______s per ______. But ammeters were invented long before electrons were discovered, so a more convenient unit of electric current was established, named after Andre Marie Ampere (french, 1775-1836) who investigated the magnetic effects of electric currents. His unit was originally defined as the amount of current that would electroplate silver out of a silver nitrate solution at a rate of 1.1180 x 10^{-3} grams per second. *That fact will be needed on page 87.* (The reason for that number is a long and obscure story.)

   It turns out that **one ampere = 6.2425 x 10^{18} electrons per second.** *(recorded on RS ____)*
   When used as a unit, the word "ampere" is often shortened to "amp" or abbreviated as "A".

7. Two different *units of electric current* are mentioned in 6a. -Which one is a very *small* unit?______ Which one is much greater? _______ Does 6a agree? ___ -Which one is almost never used? ________ What *preposition* is best for describing an electric current? _______ -Does 1b agree? ___

8. Invent a way to connect diodes to an ammeter so that the meter measures only the absolute value of the current through it, regardless of the direction of that flow. Put correct signs on the ammeter terminals.

For questions 1-6 below you must complete five steps: *First*, draw diagrams showing how you plan to use an ammeter to find the answer. Put signs on the ammeter terminals *and* on the battery terminals. *Second*, show the diagrams to your teacher for approval. *Third*, hook up the circuits and record the currents. *Fourth*, answer the question with a short, clear statement that is *ALWAYS TRUE*. Show it to your teacher immediately. Each statement must make sense all by itself, must avoid confusing cause with effect, and must be accompanied by *evidence*, i.e. diagrams and data. *Fifth*, record your discoveries on RS IX.

* 1. Does a light bulb consume electrons or convert them into anything else? Find the answer by measuring and comparing the light bulb's ***input and output currents***. Both measurements should be made with the same ammeter because it's hard to make two ammeters exactly alike.

* 2. Modify the simple battery-and-light-bulb circuit in #1 by inserting a resistor *in series* with the bulb. Use words like "increases", "decreases", or “causes” to describe how the current is affected by this modification. Again, your statement must be *always true. (See 2a on page 78 or #2 on page 82R.)*

* 3. The resistor in #2 can be placed either upstream or downstream from the light bulb. If we *exchange the positions* of those components in the series, is the current affected by that modification?

* 4. Does *any* component in circuit 2 create or consume electrons? *Give evidence, as in #1. (See p. 82R.)*

* 5. See what happens if circuit #1 is modified by connecting a resistor in *parallel with the bulb.* Describe how the battery current is affected by this change. ALSO describe how the *bulb* current is affected.

* 6. A "branch point" is a place like a fork in a road, where electric currents either split up or merge. There are *two* branch points in the parallel circuit described in #5. Investigate *ONE* of those branch points to find out if it creates or consumes electrons. (*Three* measurements are necessary. Notice that question 6 is similar to questions 1 and 4, so similar language should be used in all three answers.)

7. Electrons & protons have a property called "charge" which neutrons do not have. This property enables electrons to be attracted by protons and repelled by other electrons. Protons _______ other protons because they have ________ charges. (similar, opposite) The electrostatic attraction between protons and _______s holds atoms together. The gravitational attraction between your body and the earth can be measured with a _____ ______. The SI unit for attraction or repulsion on RS III is the __.

8. The kind of charge that protons have is called "positive" charge. The kind that electrons have is "negative". Which has more negative charge: a set of five electrons, or a set of ten electrons? ____
   a. To deliver a lot of charge we must deliver for a ____ time interval. (long, short)
   b. If a current of 2 electrons per sec. continues for 3 seconds, how many electrons are delivered? ____
   c. *How* did you use the given current and time interval in 8b to calculate the number of electrons delivered? _____________ *(Name the operation that you used.)* -Does 8a agree? ____

9. Suppose you have measured the electric current entering a certain device, in ***amperes***. Suppose that current remains constant during a certain time interval, which is measured in ***seconds.***
   a. To calculate the amount of charge that enters the device during that time interval we must ________ the current (in _______s) by the time interval (in ________s). -Does 9a agree with #8?____
   b. In what *units* will that charge be expressed? ________________ (Use the ***italicized*** words above.)
   d. Does 9b contradict 9a? ____ (If so, please explain why you have not corrected that mistake.)

10. The SI unit of charge is called a "coulomb". (Its standard abbreviation is “C”.) One coulomb is the amount of electric charge delivered by a one-ampere current during a period of one second.
   a. A one-amp current running for *two* seconds will deliver ___ coulombs of charge.
   b. Does 10a contradict #8 or 9? ___ (If so, explain why you chose not to correct that blunder.)
   c. How much charge is delivered by a 2-amp current running for 3 sec.? ___ ___ -Does 9a agree? ___
   d. A wage of ten cents per hour = one "dime" per hour, so one "dime" must be ____ cents.
   e. Similarly, 6.24×10^{18} electrons per sec = one "coulomb" per sec, so one "coulomb" must be the amount of negative charge carried by __________ _______s.
   f. The charge of one electron must then be ____________ _____. *Please save 10e & 10f on RS IX.*

* 11. Use the information given above to express the charges of a proton and an alpha particle (helium nucleus) in SI units. Use scientific notation. Explain your logic. (See p. 78R and #8 & 10f above.)

* 12. While working in Millikan's lab as a graduate student, Harvey Fletcher showed Millikan how they might measure the charge of an electron. How and when did they do it, and what was their result?

1. We found that our light bulb's input current was ____ ___ and its output current was ___ ___.
   a. Please use the space below to show (with diagrams) how those two measurements were made.
   b. We concluded that a light bulb _______ create or consume electrons. (does, does not)

2. Inserting a resistor in *series* with the bulb caused the current to ___crease from ___ to ___ ___. Show how that new measurement was made: *Record the result beside the diagram.*

3. When we exchanged the positions of the resistor and light bulb in the circuit above we found that the new current was ______ _____ the old current. (less than, equal to, greater than) Show how that new measurement was made. *Record the result beside the new diagram.*

4. When we compared the resistor's input and output currents we found that it ________ create or consume electric charge. (does, does not)
   a. Show how that new measurement was made. *Record the meter reading beside the ammeter in your diagram.*
   b. We had already done the same thing for the bulb and for the ________ back in #1, so we concluded that electric charge seems to be _______ed. (created, consumed, conserved)

5. We then modified the simple bulb-and-battery circuit in #1 by connecting a resistor in _______ with the ______. That modification caused the ________ current to ___crease from ____ ___ to ____ ___, and it caused the ________ current to ______________________________. Show how those new measurements were made. Write the meter readings beside the ammeters in each diagram, and name the current that each ammeter measures. (resistor current, battery current, bulb current) *Use those names when you fill in the blanks above.*

6. To find out if a branch point creates or consumes electrons, we only had to measure the current through the __________ in circuit #5, because the currents through the other two devices had already been measured. *Show how you did it and show what the result was.* We found that the total current *into* a branch point is _______ _____ the total current *from* that same branch point. (less than, greater than, equal to) Therefore a branch point ______ consume electrons. (does, does not)

7. The experiments above show that electric charge seems to be __________ed in all devices that we have studied. (created, consumed, conserved) *Hint: See 7-9 on page 82.* We recorded that discovery in #__ on RS___. -Does #4 agree with that conclusion? ____ *If not, please explain.*