When electrons flow through a resistor we expect a lot of collisions transferring energy from electrons to the atoms. Those atoms cannot travel as the electrons do, but they can jiggle a bit. The collisions increase that jiggling motion, which is known as "heat". In that way the electrons lose potential energy on their way through a resistive material. When they come out, each one has a smaller amount of potential energy than it had when it entered because it is a little farther from its neighbors. Consequently the "electron pressure". (potential) is lower at the point where they leave the resistor than at the point where they enter. We could describe electron pressures in pounds per square inch or any other ordinary pressure unit, but it is more convenient to measure differences in the *POTENTIAL ENERGIES* of electrons. For any small bunch of compressed electrons, the quotient of the *POTENTIAL ENERGY* that it can release through decompression divided by the *CHARGE* of the bunch is called the **"potential"** at that location. The "**voltage**" between two points is defined as the *DIFFERENCE* between the potentials at those two points. Please copy those *improved definitions* onto a review sheet and *remember to use them in 7d below*.

1. Voltmeters were invented before the discovery of electrons. At that time an arbitrary unit of electric charge called the "coulomb" was commonly used. On pages 81 and 82 you learned that a coulomb is the amount of _______ necessary to electroplate _______milligrams of silver out of solution. In other words, a coulomb is the amount of _______ carried by _________ electrons.
   Please use scientific notation if appropriate. -These definitions have been recorded on RS ___.

2. If energy is measured in *joules* and charge is measured in *coulombs*, then "energy per charge" must be measured in __________s per _________. Therefore **one "volt" must be defined as one ______ per** _________. Where has this definition been recorded for future use? ____

3. To calculate how much energy is given to each electron by a one-volt battery you must ________ one _____ per coulomb by the charge of one ______ , which is measured in _______s. Using #9 on RS IX, we see that a one-volt battery would deliver ________ _______s of _______ to each electron.

4. Your use of language is a picture window through which other people can see into your mind. Ignorance is displayed not only by *what* you say, but also by ***how you say it.*** For example, suppose somebody claims to have scored points by "throwing the ball across the basket", and describes an airplane flight "through a mountain". How can we tell that there is something strange about this person? His ignorance of ______________s gives him away. (nouns, adjectives, prepositions, adverbs)

5. The prepositions in the "connection rules" below are in capital letters because they are important. If you misuse them it shows that you don't understand what you are talking about. That kind of ignorance can damage lab equipment and it can cause people to suspect that you are a strange person, as in #4.
   a. Since an ammeter is used to measure the current *THROUGH* a circuit component, it must be connected in _______ with that component. (series or parallel?)
   b. When a voltmeter is used to measure potential difference *BETWEEN* the terminals of a device, it must be connected in __________ with the device. (series or parallel?)
   c. On page 83 we shortened the last phrase above by using another of the prepositions mentioned in #4. We said that the voltmeter was connected "_________" the other component. That kind of slang is acceptable because it is *not* misleading and it *does* shorten the sentence.
   d. The connection rules stated in 5a and 5b are recorded in #_____ on RS IX.

6. **Sign Rules**: Most voltmeters and ammeters cannot give negative readings. That's why you wrote in #7 on RS IX that we always connect meters so that electrons will be pushed *INTO* the end with the _____ sign and pulled *FROM* the end with the ___ sign. Please draw a diagram with both kinds of meter to illustrate that rule. *Do NOT draw a "bozo" circuit.*
   a. Is the same rule used for all passive components? ____ (If not, describe the exceptions.)
   b. Does the same rule apply to "active" components such as generators and batteries? ___
   c. Do the arrows in your diagram agree with 6b? ___ (See #7 on RS IX.)

7. **Review of SI Units:** (Use your Chapter Review sheet.)
   a. A "joule" is a unit of ________. A "coulomb" is a unit of _____. Does this contradict #1 or #3?___
   b. An "ampere" is a standard unit of ______. One ampere is one _________ per _____.
   c. A "watt" is a standard unit of ______. One watt is one _____ per ____.
   d. A "volt" is a unit of __________ __________. One volt = one ______ per _______, as in #__ above.
   e. You will need all of this information on page 88. Has it all been recorded on RS IX? ____

1. If two coulombs of charge arrive each second and each coulomb carries three ______s of energy, then the energy delivered in one second must be ____ _____s. (Give a number with units)
   a. On pages 64, 65, & 87 what *name* did we give to the "amount of energy delivered per second"? ___
   b. What *name* did we give to the "number of coulombs arriving per second"? __________
   c. What *name* did we give to the "number of joules delivered by each coulomb"? _______
   d. Conclusion: The RATE at which electrical energy is delivered to a device (in _____s per ____) can be calculated by ________ing the current through the device by the _______ across the device.
   e. A **watt** is a unit of ____________. (Copy the word from RS VI. You'll need it on page 98!)
   f. Please circle all of the *names* mentioned in 1d, 1e & 3. -Do they match the names in 1a-c? ___ -Do the units also agree? ___ Have you been careful not to confuse names with units? __
   g. Using 1f, equation 1d says _______ = ________________ (Recorded in #15 on RS ___)

2. Two people heat identical cups of water with identical heaters connected to identical power supplies: The first one uses the heater for 1.0 second, starting at 5 PM. The second person uses the heater for 10 seconds, starting at 2PM. Which one delivers more energy? ____

* 3. How can you use a voltage, a current, and a time interval to calculate the amount of electrical *ENERGY* delivered during that interval? Answer with an equation. Define your symbols clearly and give their SI units *without* contradicting #1 or #2. This formula is being saved in #___ on RS __.

4. As you know, heat energy moves from one object to an adjacent one if and only if the ______________ of the first object is higher than the _____________ of the second object. Such a transfer causes the first object to become cooler and the second object to become _______er.

5. One "calorie" is the amount of energy needed to raise the temperature of one _____ of ______ by one _________ degree. *Do not abbreviate four-letter units. Avoid using words you can't spell.*
   a. How much energy is needed to raise the temperature of 2 grams of water by 3 degrees? ____ ___
   b. How can you use the mass of a water sample and its change in temperature to calculate the amount of heat energy it has lost or gained? ___________ (verb) -Does 5b contradict 5a?__
   c. In 5b the mass must be in _____s, the temperature change must be in ________ degrees and the energy will be in _____. Equation 5b has been recorded in # __ on RS ______.

6. To compare the sizes of the two energy units mentioned above, we can measure a certain batch of energy twice (once with each unit) and then _________ the results. *(add, subtract, multiply, divide)*
   a. Electrical energy will be delivered to a wire resistor immersed in a measured amount of water in an insulated cup. As explained at the top of page 87, the resistor will convert the electrical energy into ______, causing the water's _____________ to rise. -Does this contradict #4? ____
   b. The *heat* energy received by the water can be calculated (in _______s) with formula __ on this page.
   c. The amount of *electrical* energy (in ______s) can be calculated with the formula in #__ above.
   d. How must the amount of energy in 6b compare with the amount in 6c? ____

* 7. Using #6 above and #9 below, state the *purpose* of the experiment clearly. Then draw a diagram of the circuit that you will use. Use one voltmeter to see what happens to the power supply voltage when you complete the circuit. Use a *second* voltmeter to measure the resistor voltage.)

* 8. After your plans have been approved you may hook up the circuit. Measure the mass of the water, its initial and final temperatures, the current, the resistor voltage, the power supply voltage, and the time interval. Record all readings neatly and clearly, with names, units and uncertainty estimates.
   a. Record the power supply voltage *before and after* turning the current on. Record the resistor voltage and current *while* the water is heating. *Do not abbreviate four-letter words.*
   b. Continue stirring the water and watching thermometer after switching off the current. You may notice that the thermometer takes some time to respond to temperature changes.
   c. After you have determined the water's final temperature, calculate its change in temperature. *Show* clearly how its absolute *AND* relative (percentage) uncertainties are calculated. (Use #26 on RS II.)
   d. Could you have made that percent uncertainty smaller by using a different change in temperature or by using a different thermometer? *Explain this answer*. Repeat the experiment if necessary.

* 9. Using the plan in #6, show how you calculate the number of joules in one calorie. Also show how the uncertainty of that result is calculated. Identify the two main sources of percentage uncertainty in your experiment and explain how you know that the other sources of uncertainty are less important.

1. "Electric Current" is defined as the "rate at which electric ________ flows".
2. It is customary to use the letter "Q" to represent electric charge and the letter "I" to represent electric current, so that definition can be written in algebra language as I = (Δ)/(Δ).
3. According to that definition, you can calculate the amount of charge that passes through a device during a given time interval by __________ing the average _________ by the time interval.
4. The SI unit of charge is called a "__________". When charge flows through a resistor it delivers ____________ energy. The amount of energy delivered by each unit of charge is measured in _________s per __________ and is called "________age".
5. If 2 units of charge passed through a device and each one deposited 3 units of energy, then ____ units of energy have been deposited altogether.
6. If each unit of charge delivers 3 joules of energy, and the charge is flowing at the rate of 2 coulombs per second, then energy is being delivered at the rate of ____ _______s per second.
7. The name of the "energy delivery rate" in #6 is "_________". If "P" represents that rate and "V" represents voltage and "I" represents the current, then the equation used in #6 must say P = ______.

Final Results of the Joule Experiment

1. We heated some water by running electric current through a wire resistor.
   a. Before turning on the current, the power supply voltage was ______ ± ______ ______.
   b. When the heater was running, the voltage across it was ______ ± ______ ______. and the power supply voltage was ______ _____. According to #5 on RS IX, those two voltages differ because some effort was needed to propel electrons through the ____________.
   c. The ammeter was set on its 0-____A range. The heater current was ________ ± ______ _______.
   d. We cut off the heater current _____ ± ______ seconds after it was started.
2. Show how you use the data in #1 to calculate the amount of energy delivered to the water, in *range* form. *Remember to use scientific notation and to round off properly.*

3. The initial water temperature was _____ ± ____ ___. The final temperature was ____ ± ____ ____. The change in temperature was _____ ± ____ ____. The water volume was between ____ and ____ ___. To calculate the mass of the water I multiplied that volume by the water's ________, which is ___ gram per _____. The mass of the water was ____ ± ____ ____.

4. To calculate the heat energy delivered to the water (using 5b on page 88) you must _________ the mass of the water (in ____) by its ___________ __ temperature, in __________ degrees. Show how you use the data in #3 to calculate the heat energy received by the water, in range form. *Round off properly, and don't forget the units.*

5. Show how you use the data above to calculate the number of joules in one calorie:

   SLV = (_____ _____)÷ (______ ______) = ______ ______

   GLV = (_____ _____)÷ (______ ______) = ______ ______

6. Show how you calculate the number of calories in one joule. Again, please use *range* form.

1. Draw a resistor and an ammeter connected in series to a battery.

2. Let V_B represent the battery voltage, let V_R represent the resistor voltage, and let V_A represent the voltage across the ammeter:
   a. How must those three voltages be related? ____ = ____ + ____
   b. An "ideal" ammeter would require no effort to make electrons flow through it, so there would be no electron pressure difference between its terminals. In other words, the resistance of an ideal ammeter would be ________. (great, small, negative, zero, variable)
   c. Which two of the voltages mentioned above would be equal if the ammeter were ideal?

3. Real ammeters are not quite perfect. Some effort is needed to make electrons flow through a real ammeter. That explains why we found that the two voltages in 1c were not equal when we did the water-heating experiment on page 88. We found that the ________ voltage is slightly less than the __________ voltage, because some effort is needed to cause electrons to flow through the __________.

4. The battery voltage ___creased __________ly when we completed the resistor circuit in the water-heating experiment. We must conclude that the battery's voltage vs current graph has a _____tive slope.

5. What was the purpose of the heating experiment?

6. A student doing the same experiment in another class obtained the following data:
   Battery voltage = 22.5 ± 0.2 volts   Resistor voltage = 20.5 ± 0.2 volts
   Resistor current = 3.45 ± 0.05 amps
   Show how you use that set of data to answer each of the following questions in *range* form:
   a. If a voltmeter had been connected across the ammeter what reading would it have given?
      V_A = (____ ± ____ _____)(____ ± _____ _____) = between _____ and _____ _____
   b. At what rate did I deliver energy to the resistor?
      P_R = (____ ± ____ _____)(____ ± _____ _____) = between _____ and_____ ______
   c. How much charge flowed through the resistor in 10 ± 0.2 seconds?
      ΔQ = (____ ± ____ _____)(____ ± _____ _____) = between _____ and_____ ______
   d. How much energy was delivered to the resistor during that time interval?
      ΔE = (____ ± ____ _____)(____ ± _____ _____) = between _____ and_____ ______
   e. Did you round off properly in 6a-6d? ___ *If not give a good reason.*

7. Only one of the following is an example of converting units. Which one is it? (See page 6.)
   a. (162 cm^3)(1.00 gram per cm^3) = 162 grams
   b. (0.162 kg)(9.8 N/kg) = 1.59 N
   c. (20 joules per coulomb)(3.0 coulombs per second) = 60 joules per sec.
   d. (200 grams of H_20)(3.0 celsius degrees) = 600 calories
   e. (600 calories)(4.18 joules per calorie) = 2508 joules

Unit	Name of variable that it measures	Definition of that variable	measuring instrument	definition of unit	other units
gram			balance	mass of one ______ of water	kilograms
calorie		total KE of molecules or atoms in sample		energy needed to raise the temperature of one _____ of water by one _________ degree	
	force	push or pull	spring scale	force needed to accelerate one ______ of matter at one _____ per ___________	
coulomb				charge carried by 6.24×10^{18} electrons	
	energy	ability to do work		(1 newton)(1 meter)	ergs, _________s
	potential difference ("voltage")				millivolts, kilovolts
ampere		rate at which _______ flows		1 A = 1______ per _______	milliamp