THE LIGHT BULB EXPERIMENT:
Exploring Simple Electric Circuits

Preparatory Questions for Review:
(also read this guide sheet, which contains some of the answers!)

1. State Ohm's Law, defining every term in the equation.

2. If a bulb connected directly to a 6 V battery glows brightly when 1 A of current passes through it, what is the resistance of the bulb at that point? What is the power delivered to the bulb by the battery in this case.

3. Two equal resistors are connected a) in series and b) in parallel. Write down the resistance of the combination in the two cases.

4. Read "Some electrical terms - a review" (next page). What is the electrical analogue of pressure difference in the hydraulic model?

Objectives:

- to develop facility in wiring simple circuits
- to understand the concepts of electrical potential difference (voltage) and of electrical current
- to understand how voltage and current are divided up when circuit components are combined
- to draw schematic diagrams
- to use schematic diagrams as an aid to understanding what a circuit is doing
- to use schematic diagrams as an aid to wiring

References:

- The introductory electric circuits chapter of your first year textbook
- Lillian McDermott, *Physics by Inquiry, Vol 2*; John Wiley, Toronto, 1996.

Introduction:

This series of experiments enables you to test your understanding of the properties of electric current flow. You will have available to you some small light bulbs, a battery (source of constant voltage), a current supply (source of constant current), a power supply of variable voltage, meters to measure voltage and current, and lots of wires to connect all of these together. Since much of this lab is qualitative, be sure to write clear and concise notes on your procedure, and highlight those measurements you do make.

Notes: This experiment is mainly a qualitative one. Careful error analysis is not appropriate for the most part, but you should give quick estimates of uncertainties.

Some electrical terms - a review.

In this section, in order that you better visualize what the electrical phenomena are, we will draw upon an hydraulic analogy - in other words, we will take a simple electric circuit, shown in Figure 1, of a battery connected by wires to an electric motor, and compare it to an hydraulic circuit, show in Figure 2 - of an upper water reservoir in which the water in it has previously been taken from a lower tank to an elevated tank - connected by pipes to a paddle wheel motor. (We hope to have a working model of this hydraulic analogue available to clarify this explanation).

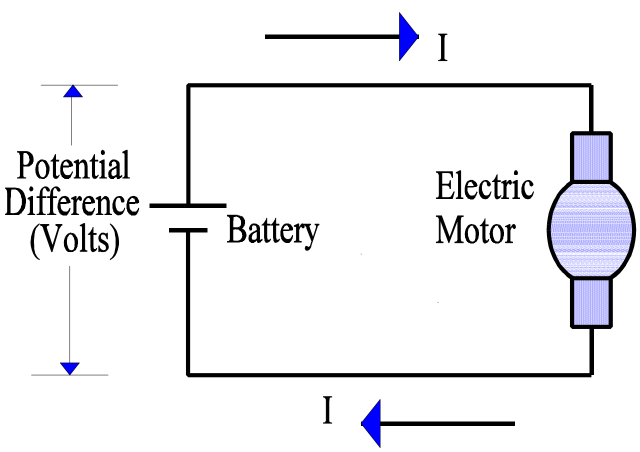


Figure 1

I = current in Coulombs/s (Amperes)

(Note: the battery gets recharged prior to use by moving electrical charge from one battery terminal to the other.)

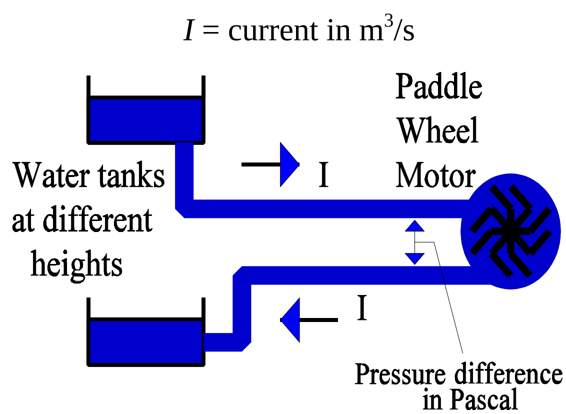


Figure 2

(Note: the hydraulic energy source gets recharged prior to use when the water in the lower tank gets placed in the upper tank.)

Notice that both the battery and the water tanks have stored energy, and after some use they both run down and no more energy is available from these sources.

Charge: this is the electrical "size" of the electrical entities that are acting, as evidenced by the force between two of these charges. Units are Coulombs (=6.2×10^{18} electron charges). In our hydraulic analogue its equivalent is volume of water = m^3.

Current: this is the rate of flow of electrical charge through a device or wire (i.e. flowing past a point in the wire). Units are Coulombs/second = Amperes. The hydraulic analogue is volume rate of flow of water = m^3/second.

Potential difference or **voltage:** this has to do with the "push" on charges that the electrical force has between two points in a circuit. More clearly, it is the difference in potential energy that a 1 Coulomb charge experiences in being transferred between the two points in the circuit that are being compared. Units are Joules/Coulomb = Volts. The hydraulic analogue is pressure difference = Pascal = Newtons/m^2.

Note that in both cases current flows *through* a wire or pipe whereas voltage (or pressure difference) has to do with a difference *between* two points in wires or pipes.

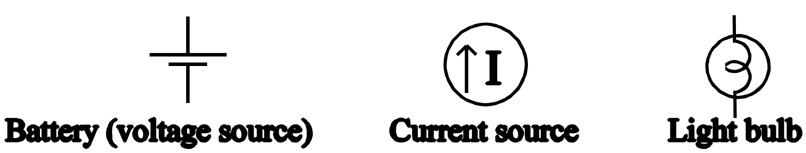
It is left to you to conclude that in both the electrical and hydraulic cases, current flow between points in the circuit at different potentials implies transfer of power into/out of that region and that the power transferred is just the current times the potential difference. (Thus, both electric circuits and hydraulic circuits are convenient media for transporting power.)

A note about the equipment:

The bulbs and power sources are reasonably inexpensive and not easily destroyed by wrong connections. Also, the voltages used are so low that there is no danger of electric shock. This allows you to try out any combination you wish without concern. The battery does have a "breaker" on it so that if too much current does get demanded from it, the breaker will open. If that happens, merely disconnect the wire you had connected, wait a minute, and then push the breaker's reset button. So we invite you to play with this equipment and to not worry about damaging it. **[EXCEPTION -** ***PLEASE NOTE****: When using the ammeter NEVER connect it directly across the battery, and, when you first introduce it into the circuit* ***ensure that it is set on the*** **20A** ***selection****. Read the* ***CAUTIONS*** *in the section on the ammeters at the end).*

The brightness of a bulb is proportional to the power delivered to it - i.e. the product of the resistance and the square of the current passing through it. The bulbs vary somewhat in construction and room-temperature resistance, and their resistance increases as they shine more brightly. The bulbs shine at full brightness when the voltage across them is about 6 Volts so that they pass a current of about 1 Ampere. The battery supplies an approximately constant voltage of 6 Volts.

We use the following symbols in our schematic diagrams:



What to do: *Note: As a general guide, we expect that most students will be able to complete parts 1 through 5 or possibly 6 during the first session devoted to this experiment, and the remaining sections during the second session.*

1. The Circuit: Use one bulb and one battery and a maximum of two wires. Note that both the battery and the bulb have two connections each. Explore all the ways you can join (with one and with two wires) the various connections to the battery and the bulb. Which ways make the bulb light? Which ways blow the breaker on the battery? Which ways do nothing? Does the order of which end of the battery is connected, or of which end of the bulb is connected, make any difference to your observations?

Generalize what you find in terms of the concept of a *closed electric circuit* or *complete circuit*. Describe what is happening from the point of view of the hydraulic analogue. Write down, in your lab notebook, your successful circuit diagrams, your observations and generalizations. If you don't know how to draw a schematic diagram of your circuit, ask your demonstrator. Can you now define the terms *open circuit* and *short circuit*?

Some examples of configurations you might try are shown in Figure 3.

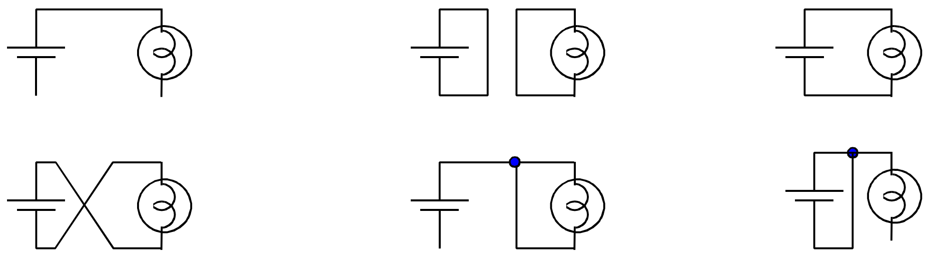


Figure 3

2. Lamps in Series: The connection for two bulbs in series, connected to the battery, is shown in Figure 4. By series we mean that the two lamps are strung in a line, with one wire coming out of one lamp and going into one side of the next lamp.

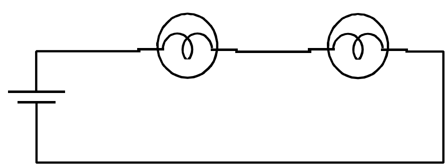


Figure 4

Connect the circuit of Figure 4. From your observation of the brightness of the lamps, what can you conclude about the current through each lamp compared to the case of the successful single bulb and battery circuit of Figure 3? What can you say about the current through one lamp compared to that through the other in this configuration? We have heard students say that, with two lamps in series, the second lamp should get less current as the charge carriers (electrons) should get "tired" after going through the first. Do you agree? Comment on this statement, particularly in the light of the hydraulic analogue. With the circuit of Figure 4, try taking an extra wire and connecting it across the two terminals of one lamp. What happens to that lamp? What happens to the other lamp?

[Note: before using the meter as an ammeter, see the instructions for its use in Appendix 1; *use only the 20A range in this experiment*]

Now, with the circuit of Figure 4, measure the current into and out of each lamp, using your meters as ammeters. Comment on the three values you can measure - between the "+" battery terminal (red) and a bulb, between the two bulbs, and between the a bulb and the "-" battery terminal (black). Do the numbers you observe agree with your conclusions?

Now, with the circuit of Figure 4, measure the voltage across each of the lamps separately, using a meter as a voltmeter. Also measure the voltage across the battery. What can you say about the way the voltage distributes itself across these identical lamps in series?

Repeat the "lamps in series" observations above with three lamps in series instead of two, and write down your observations.

<u>3. Lamps in Parallel:</u> The connection for two bulbs in parallel, connected to the battery, is shown in Figure 5. By parallel we mean that the lamps are connected side-by-side, with corresponding sides of both lamps connected together.

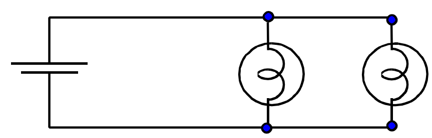


Figure 5

Connect the circuit of Figure 5. From your observation of the brightness of the lamps, what can you conclude about the current through each lamp compared to the case of the single bulb and battery circuit?

Now, with the circuit of Figure 5, measure the current into and out of each lamp, and the current out of the battery. How do these currents appear to be related? Do the numbers you observe agree with your conclusions?

With the circuit of Figure 5, measure the voltage across each of the lamps separately. Also measure the voltage across the battery. What can you say about the way the voltage distributes itself across these lamps in parallel?

Repeat the "lamps in parallel" observations above with three lamps in parallel instead of two.

<u>4. Sources of Voltage and Sources of Current:</u> You performed all the above experiments using a battery, which is approximately a constant voltage source. This means that your battery will keep an approximately constant voltage across it no matter how much current is drawn from it. (It is because of this that we had to use a "breaker" to protect you and the wires and the battery from delivering so much current under short-circuit conditions that the wires would heat and melt.) Looking over your observations above, do you agree with our statement that the battery is a constant voltage source? The hydraulic analogue to the battery is a constant pressure source - as would be obtained from the two water reservoirs being kept at a constant height difference. (The electric power we receive from Hydro is constant voltage - rated at 117 Volts ± 10%.)

We now introduce you to a constant current source. This is a box that delivers a constant current to the wires that come out if it, no matter what voltage appears across those wires. What is the hydraulic analogue to this? As with the battery, we have had to introduce some protection in this device so that you don't get hurt by a high voltage electric shock. This protection is built-in and doesn't let the voltage go higher than about 30 Volts.

Replace the battery in parts 2 and 3 above by the constant current source and repeat the experiments. Note the differences in behaviour of the circuits powered by the constant current supply and those powered by the battery. In particular, which of parallel or series circuits produces full brightness of the bulbs for which type of electrical power source? Can you explain these differences?

<u>5. Various Series-Parallel Circuits:</u>

(a) Parallel Behaviour: Using the battery as the source, consider the two parallel branches in the circuit shown in Figure 6.

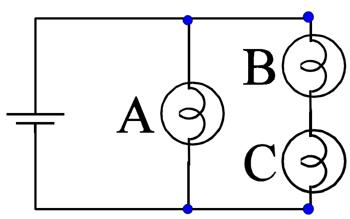


Figure 6

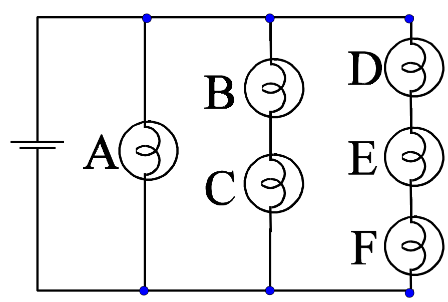


Figure 7

For Figure 6, what do you predict will happen to the brightness of each of the three light bulbs when one of the wires connecting to lamp B is disconnected and then later reconnected? What do you predict will happen if a wire is added, connected across the terminals of lamp B? Try it out and see if your predictions are correct. Does the intensity of lamp A change with any of these changes?

Now add a third parallel branch, as in Figure 7. What happens to the brightness of the lamps of Figure 6 when the additional branch is added?

Generalize on the independence of parallel branches of a circuit connected to a constant voltage source.

(b) Series Behaviour: Using the current supply as the source, consider the series circuit that is shown in Figure 8.

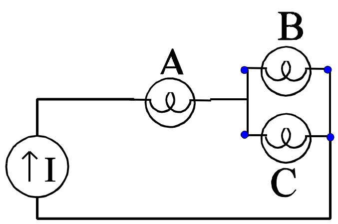


Figure 8

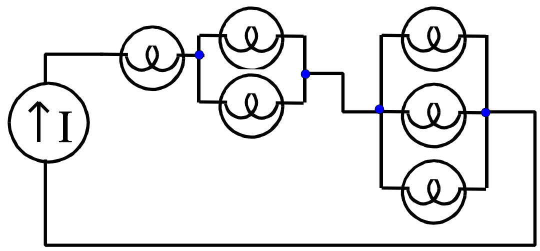


Figure 9

What do you predict will happen to the light bulbs when a wire connecting to lamp B is disconnected and then reconnected? What do you predict will happen if a wire is added, connected across the terminals of B? Try it our and see if your predictions are correct. Does the intensity of lamp A change with any of these changes?

Now add a third cluster in series, as in Figure 9. What happens to the brightness of the lamps of Figure 8 when the additional cluster is added?

Generalize on the independence of series components in a circuit connected to a constant current source.

(c) Other Combinations: Try out the combinations of light bulbs shown in Figure 10. In each case you will find some lamps don't appear to light, some are bright, some are less bright. Try to predict what you will see before you turn them on and work out why you predictions work or do not work. Use the ammeter and voltmeter to help you figure out what is going on.

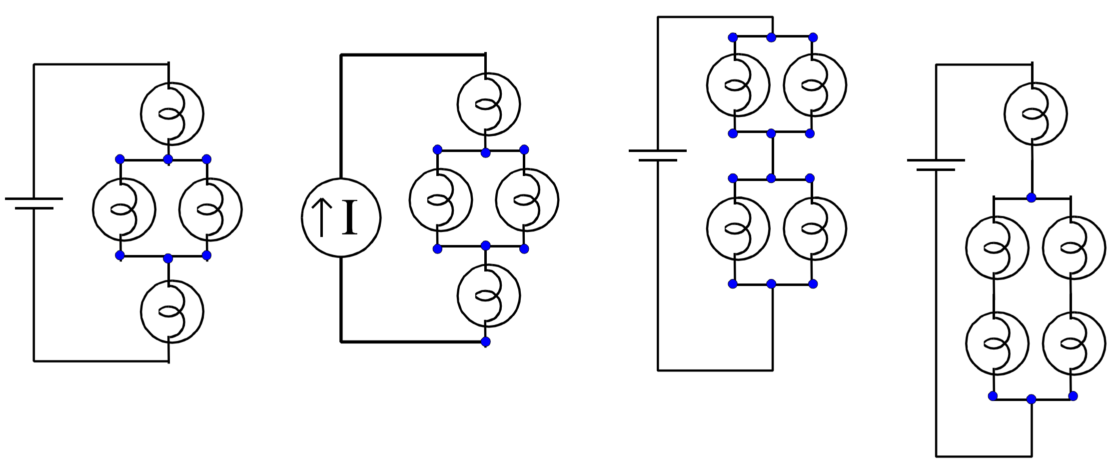


Figure 10

The observations that you have been making in these experiments, of currents flowing in circuits and of voltages distributed around circuits, are formalized in two laws, called Kirchhoff's Laws. Consult the introductory electric circuits chapter of your first year textbook for details.

6. Resistance - Ohm's Law for Constant Resistance.

When a current flows through a conductor, the carriers (electrons) do not move entirely freely and they lose energy due to collisions within the conductor. Thus the electrical potential at one side of the conductor is different from the other. Resistance (R) is defined as the ratio of the voltage across the conductor (V) to the current through it (I). (Resistance is measured in Ohms - Ω.) This definition is known as Ohm's Law, $R = V/I$. R is a constant which depends on the material of the conductor, its dimensions, and its temperature.

Connect up one of the two "unknown" resistors in series with the variable voltage power supply. Arrange the meters in your circuit to read the current through the resistor and the voltage across it. Vary the voltage and make a plot of the voltage vs. the current. From this graph, calculate the resistance of the resistor. Compare it to the value you obtain by direct measurement using the meter.

7. Internal Resistance of the Battery.

A battery *approximates* a constant voltage source. However, when current is drawn from the battery, its voltage does drop. For new or fully charged batteries, this drop is usually small. However, for a worn-out or discharged battery, drawing current from it can considerably reduce the voltage it supplies. A measure of the size of this drop is called the *internal resistance* of the battery. The internal resistance can be defined as minus the slope of the curve of voltage across the battery vs. the current drawn from it. (Check out whether this definition is dimensionally correct.)

Obtain data of battery voltage as you draw various values of current from it. Use various numbers and configurations of light bulbs to vary the current drawn. Plot the current vs. voltage curve for the data you obtained. Obtain a value of internal resistance for your battery and compare it to values obtained by other students. Include in your graph a value of the voltage when no current is drawn from the battery. (This value is often referred to as the *emf* or the *open circuit voltage* of the battery.)

8. Resistance - Ohm's Law for Varying Resistance.

The conductor in the light bulb is the filament which then gets heated and gives off light. This implies that if your light bulb is connected to the battery, the greater the voltage of the battery, the greater the current that passes through it. In the case of metallic conductors such as the tungsten filament in the light bulb, the resistance increases considerably as the metal is heated. (Note that this would also apply to the resistance of the wires you use in this experiment. However the resistance of the wires is very small so that there is virtually no voltage drop along the wires. Also, as the wires remain at room temperature, their (low) resistance stays constant). You should work out what the hydraulic equivalent of resistance is, and whether a greater pressure difference produces greater current flow.

Measure the voltage across and current through one of your light bulbs when it shows no light, when it is dim, when it somewhat bright, when it is very bright. (If you think carefully before starting this experiment, you can design your experiment in such a way that you do not need to re-connect the meters from one measurement to the next). Using the following *qualitative* table of colour of a tungsten body as a function of temperature, plot a graph of resistance as a function of temperature for your light bulb. You may vary the brightness (colour) of the bulb you are using by connecting it to the battery in series with various configurations of other light bulbs.

Colour Description	Temperature (^oC)
dark	<420
faint red	440
dull red	480
cherry red	600
orange	750
yellow	1100
low white	1300
bright white	1500
melting point	3410

<u>Appendix</u>

The use of voltmeters and ammeters

Ammeters: An ammeter, as it measures the total current flowing in a wire, has to be placed in series with that wire. In other words, the circuit connection to the wire must be cut and the ammeter placed in that cut. Note that an ammeter must have two terminals, one for the current in and the other for the current out. A one-wire ammeter is an illogical entity. Your multimeters have various range scales that you can select with the selector switch. For the ranges below 200mA maximum reading, use the two terminals marked "*COM*" and "*mA*". Through these connections, any current greater than 200mA will blow the fuse inside the meter, thus protecting the meter. For larger currents, use the 20A range selection and use the two terminals marked "*COM*" and "*20A*". These terminals are protected by a 20A fuse. **We recommend, for these light bulb experiments, that you always use the 20A range.** (If you do blow a meter fuse, take the meter to a technician in the lab.)

***CAUTION**: An ammeter is designed to pass all the current in the wire into which it is inserted without providing barriers to the flow of that current. Thus an ammeter should never be placed across the terminals of the battery, for such a connection would permit the maximum current available from the battery to flow through the ammeter. Please do not connect the ammeter ACROSS a voltage source, only connect it in series with the wire where you want to measure the current.*

Voltmeters: A voltmeter, as it measures the potential difference between two different wires, has to be placed in parallel with (across) those two wires. Unlike the ammeter, the circuit connection to the wires must be attached without breaking into the circuit. Note that a voltmeter must have two terminals as it is measuring a potential difference. A one-wire voltmeter is an illogical entity. Your multimeters have various range scales that you can select with the selector switch. All the voltage ranges use the two terminals marked "*COM*" and "*V-Ω*". In order that the introduction into the circuit does not change the voltages being measured, the voltmeter resistance is very large. As a result, there is not the danger of passing excessive current through the voltage terminals as there was for the current terminals.

The placement of a voltmeter and an ammeter in a simple circuit is illustrated in Figure 11. Here the voltage across the light bulb and the current into the light bulb are being measured.

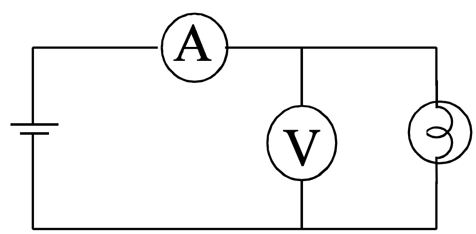


Figure 11