Name ______________________ Date(YY/MM/DD) ______/_________/_______
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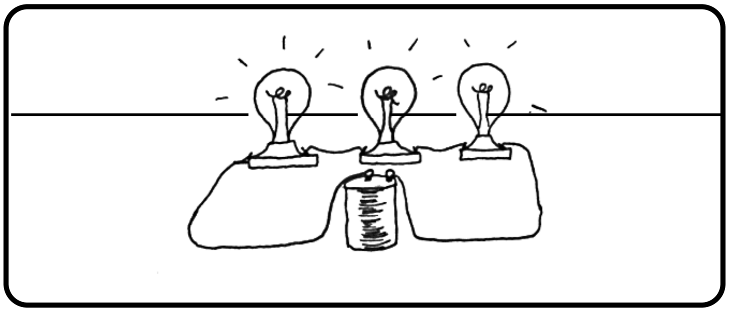
UNIT 22: BATTERIES, BULBS, AND CURRENT FLOW*



We have in us somewhere knowledge... of the taste of strawberries... When we bite into a berry, we are ready to taste a certain kind of taste; if we taste something very different, we are surprised. It is this – what we expect or what surprises us – that tells us best what we really know.

– John Holt

OBJECTIVES

1. To understand how a potential difference results in a current flow through a conductor.

2. To learn to design and wire simple circuits using batteries, wires, and switches.

3. To learn to use symbols to draw circuit diagrams.

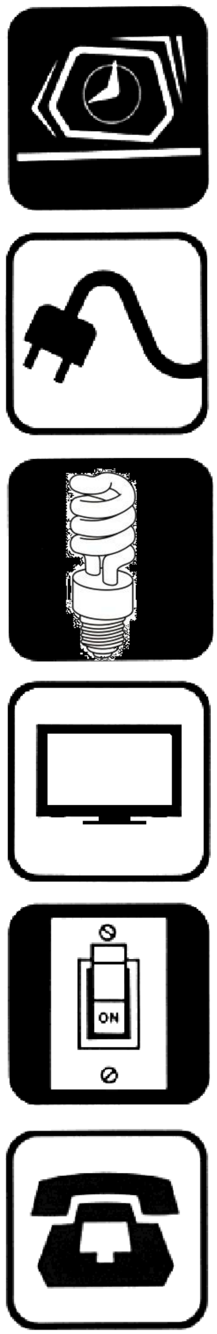
4. To understand the use of ammeters and voltmeters for measuring current and voltage respectively.

5. To understand the relationship between the current flows and potential differences in series and parallel circuits.

6. To understand the concept of resistance.

* Portions of this unit are based on research by Lillian C. McDermott & Peter S. Shaffer published in AJP 60, 994-1012 (1992).

OVERVIEW



In the following sessions, we are going to discover, extend, and apply theories about electric charge and potential difference to electric circuits. The study of circuits will prove to be one of the more practical parts of the whole physics course, since electric circuits form the backbone of much of twentieth century technology. Without circuits we wouldn't have electric lights, air conditioners, automobiles, cell phones, TV sets, dishwashers, computers, or DVD players.

In the last unit you used a battery to establish a potential difference (or voltage) across two electrodes. *Battery* is a term applied to any device that generates an electrical potential difference from other forms of energy. The type of batteries you are using in this course are known as chemical batteries because they convert internal chemical energy into electrical energy.

As a result of a potential difference, an electrical charge can be repelled from one terminal of the battery and attracted to the other. No charge can flow out of a battery unless there is a conducting material connected between its terminals. A flow of charge can cause a small light bulb to glow.

In this unit, you are going to explore how charge originating in a battery flows in wires and bulbs. You will be asked to develop and explain some models that predict how the charge will flow in series and parallel circuits. You will also be asked to devise ways to test your models using a computer-based laboratory device that can measure the rate of flow of electrical charge through it or the potential difference between two points in a circuit.

SESSION ONE: CURRENT FLOW AND POTENTIAL DIFFERENCE

What is Electric Current?

The rate of flow of electric charge is more commonly called *electric current*. If charge is flowing through a conductor then the official mathematical definition of the average current is given by

$$< i > \equiv \frac{\Delta Q}{\Delta t}$$

Instantaneous current is defined in the usual way with a limit:

$$i \equiv \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

The unit of current is called the ampere (A). One ampere represents the flow of one coulomb of charge through a conductor in a time interval of one second.

15 min

Designing Your Own Circuit
(If you have prepared before class, this will not take too long.)

Let's apply what you know about circuits to make some original devices. You can use extra switches, wires, bulbs, etc. if needed. Construct all three of the devices described below. Sketch the circuit for each of your devices. You can use the following equipment:

- three #14 bulbs with holders
- D-cell alkaline battery w/ holder
- six wires with alligator clip leads
- An assortment of switches:
(1 SPST, 1 DPDT, 1 SPDT)

1. *Christmas Tree Lights:* Suppose you want to light up your Christmas tree with three bulbs. What happens if a bulb fails? (Don't break the bulb! You can simulate failure by loosening a bulb in its socket.) Figure out a way to wire in all three bulbs so that the other two will still be lit if any one of the bulbs burns out.

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2. *Lighting a Tunnel:* The bulbs and switches must be arranged so that a person walking through a tunnel can turn on a lamp for a part of the tunnel and then turn on a second lamp in such a way that the first one turns off automatically.

3. *Caller Indicator for the Deaf:* A deaf person should be able to see, by looking at one or two bulbs, whether a visitor is at the front or back door of a house. You should do this with only 1 battery, 2 bulbs and 2 switches.

✍ Activity 22-1: Description of the Invention(s)

(a) Include a description and a circuit diagram for your Christmas tree lights.

(b) Include a description and a circuit diagram for your tunnel lighter.

(c) Include a description and a circuit diagram for your deaf caller.

Circuit Diagrams

Now that you have been wiring circuits and drawing diagrams of them you may be getting tired of drawing pictures of the batteries, bulbs, and switches in your circuits. There are a series of symbols that have been created to represent circuits. These symbols will enable you to draw the nice neat square looking circuits that you see in physics textbooks. A few of the electric circuit symbols are shown below.

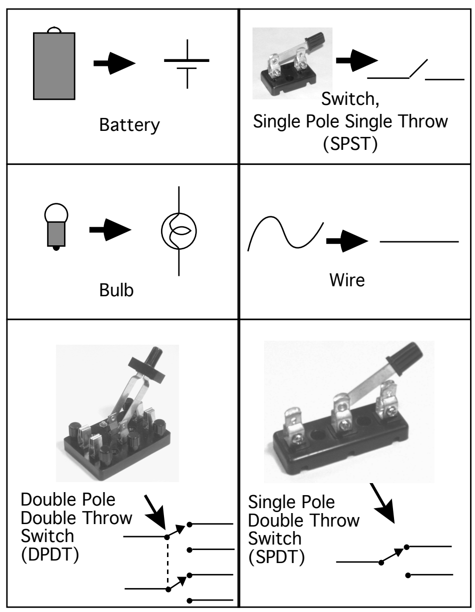


Figure 22-3: Circuit Symbols

Using these symbols, the standard circuit with a switch, bulb, wires, and battery can be represented as in the diagram below.

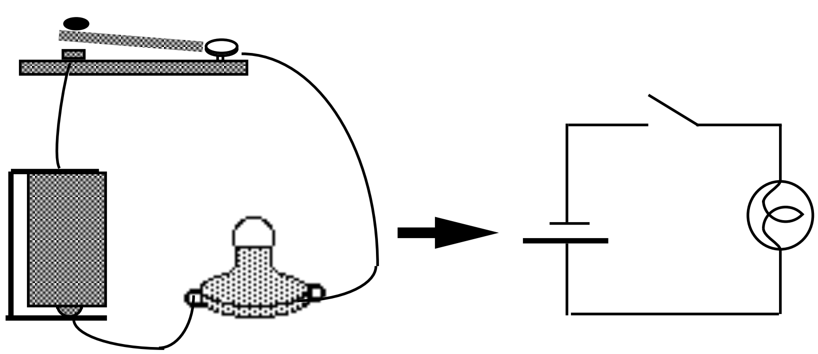


Figure 22-4: A circuit sketch and corresponding diagram

✍ Activity 22-2: Drawing Circuit Diagrams

(a) On the battery symbol, which line represents the positive terminal? The long one or the short one? **Note**: You should try to remember this convention for the battery polarity because some circuit elements, such as *diodes*, behave differently if the battery is turned around so it has opposite polarity.

(b) Sketch nice neat "textbook" style circuit diagrams for the circuits you designed in Activity 22-1. (If you already used the correct symbols there, good on ya!)

30 min

Developing a Model for Current Flow in a Circuit

Several models for current flow in the circuit might be proposed. Four are diagrammed below.

After you have discussed the various ideas you will be asked to figure out how to use one or more ammeters in your circuit to measure current and test your model.

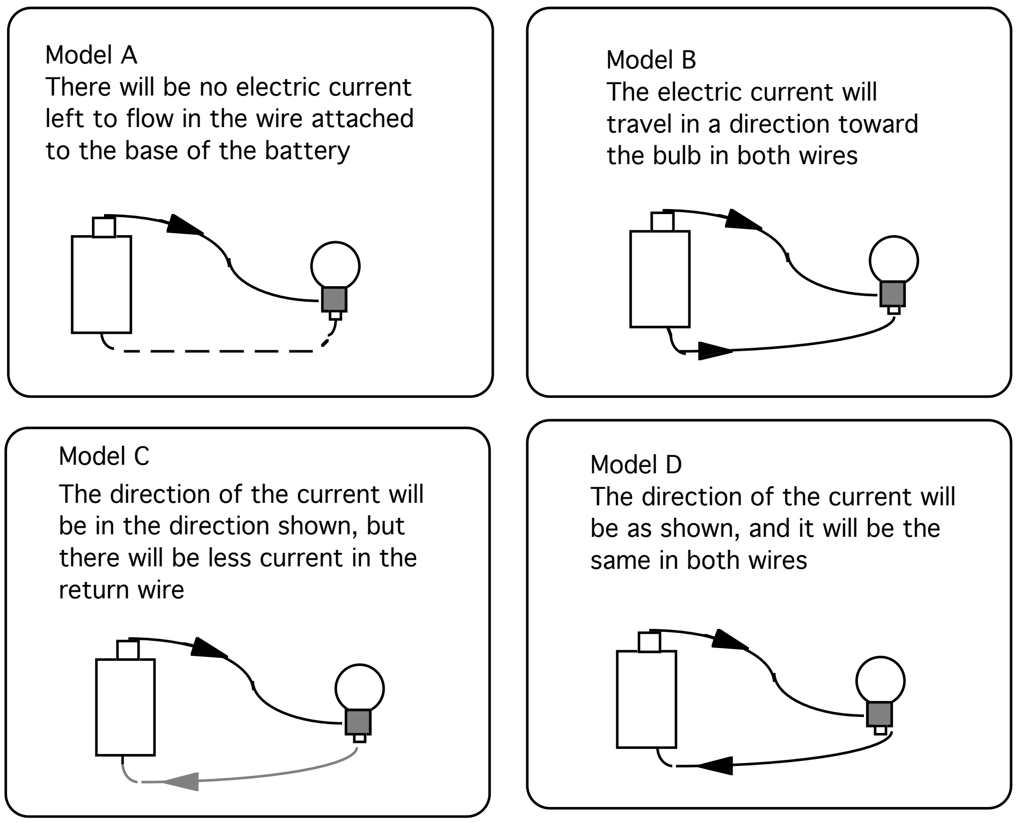
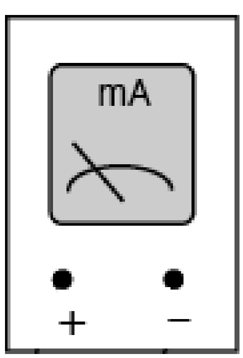


Figure 22-5: Four alternative models for current flow

Measuring Current with an Ammeter



The ammeter is a device that measures current and displays it. It will allow you to explore the current flowing at different locations in an electric circuit.

Current is typically measured in amperes (A) or milliamperes (mA). (1 ampere = 1000 milliamperes.) Usually we just refer to current as "amps" or "milliamps".

To measure the current flowing through a part of the circuit, you must "insert" the ammeter at the point of interest. Disconnect the circuit, put in the ammeter, and reconnect with

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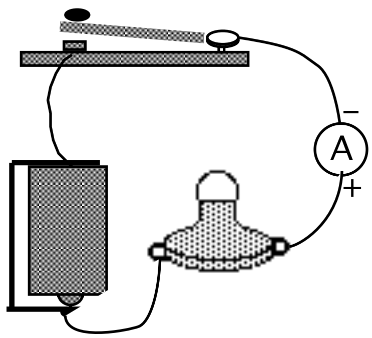
it in place. For example, to measure the current in the right-hand wire of the circuit in Figure 22-4 the ammeter could be connected as shown below (We will be using a circle with a capital A on it to represent an ammeter.):



The ammeter measures both the *magnitude* and *direction* of current flow. A current flowing in through the positive (+) terminal and out through the negative (–) terminal will be displayed as a positive current.

Discovering Models for Current Flow that Work

Discuss the various current flow models with your partners, and design measurements that will allow you to choose the model or models that best describe the actual current flowing through the circuit. (For example, to see if the current has a different magnitude or direction at different points in a circuit (e.g. model B or model C) you should connect two ammeters in various locations around the circuit.

To investigate current flow models you will need:

- 1 ammeter, 0.25 A
- 1 digital multimeter
- 2 #14 bulbs with holder
- 1 D-cell battery and holder
- 1 SPST switch
- 6 alligator clip wires

Describe your test (or tests) in the space below as well as your choice of the best model as a result of these tests.

✍ Activity 22-3: Picking a Model for Current Flow

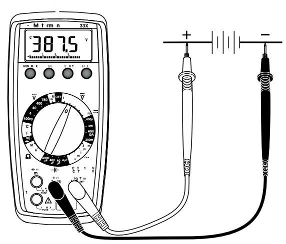
(a) Describe your tests. Include drawings of the circuits you used, showing where the ammeters were connected.

(b) Which model or models seem to work? Is the current different at different locations in the circuit? Explain how you reached your conclusion based on your observations.

30 min

Measuring Potential Difference with a Voltmeter

Since a battery is a device that has a potential difference across its terminals, it is capable of giving energy to charges, which can then flow as a current through a circuit. Exploring the relationship between the potential differences in a circuit and the currents that flow in that circuit is a fundamental part of developing an understanding of how electrical circuits behave.



A Digital Multimeter (DMM) used as a voltmeter and connected to a battery.

Because potential differences are measured in volts, a potential difference is often informally referred to as a *voltage*.

Let's measure voltage in a familiar circuit. Besides the ammeters you have been using so far to measure current, there are voltmeters to measure voltage. Figure 22-6 shows the symbols we will use to indicate a voltmeter and an ammeter.

Figure 22-6: Symbols for a voltmeter (left) and an ammeter (right). The + sign on the voltmeter should be at the higher potential if the voltmeter reads positive. If the current in the ammeter flows from + to – then the ammeter reads positive.

Figure 22-7 shows a simple circuit with a battery, a bulb, and two voltmeters connected to measure the voltage *across* the battery and the voltage *across* the bulb. The circuit is drawn again symbolically on the right. Note that the word *across* is very descriptive of how the voltmeters are connected to measure voltage.

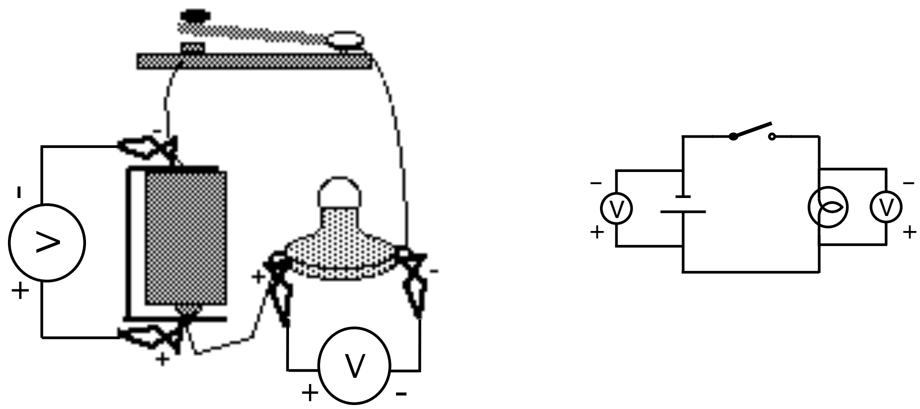


Figure 22-7: Two voltmeters connected to measure the voltage across the battery and the bulb.

To do the next few activities, you will need:

- a D-cell alkaline battery and holder
- 2 #14 light bulbs
- a SPST switch
- a digital voltmeter
- an ammeter, 0.25 A

✍ Activity 22-4: Voltage Measurements in a Simple Circuit

(a) First connect both the + and the - clips of the voltmeter to the same point in the circuit. Observe the reading. What do you conclude about the voltage when the leads are connected to each other (i.e. not across anything else)?

(b) In the circuit in Figure 22-7, predict the voltage across the battery compared to the voltage across the bulb. Explain your predictions.

(c) Now test your prediction. Connect the circuit in Figure 22-7. Use the voltmeter to measure the voltage *across* the battery and then use it to measure the voltage *across* the bulb.

Voltage across the Battery	Voltage across the bulb

What do you conclude about the voltage across the battery and the voltage across the bulb?

Now let's measure voltage and current in your circuit at the same time. To do this, connect a voltmeter and an ammeter so that you are measuring the voltage *across* the battery and the current *entering* the bulb at the same time. (See Figure 22-8.)

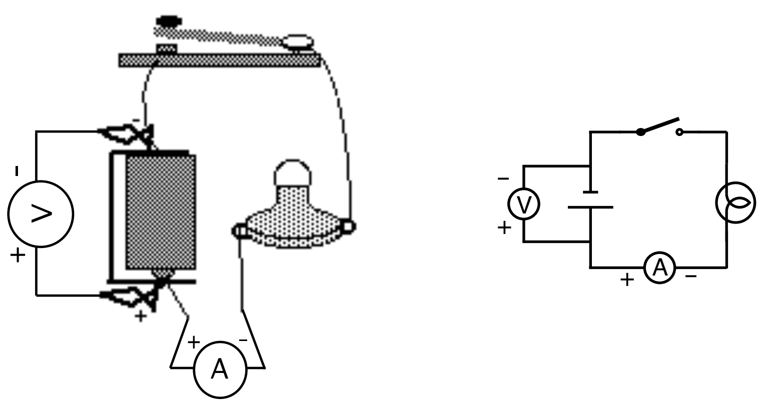


Figure 22-8: Meters connected to measure the voltage across the battery and the current through it. (The positive terminal of the battery is at the bottom.)

✍ Activity 22-5: Current and Voltage Measurements

(a) Measure the voltage across the battery when the switch is closed and the light is lit. Enter the value in the table below in Activity 22-6d

(b) Measure the current through the circuit when the switch is closed and the light is lit. Enter the value in the table below in Activity 22-6d

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Now suppose you connect a second bulb, as shown in Figure 22-9.

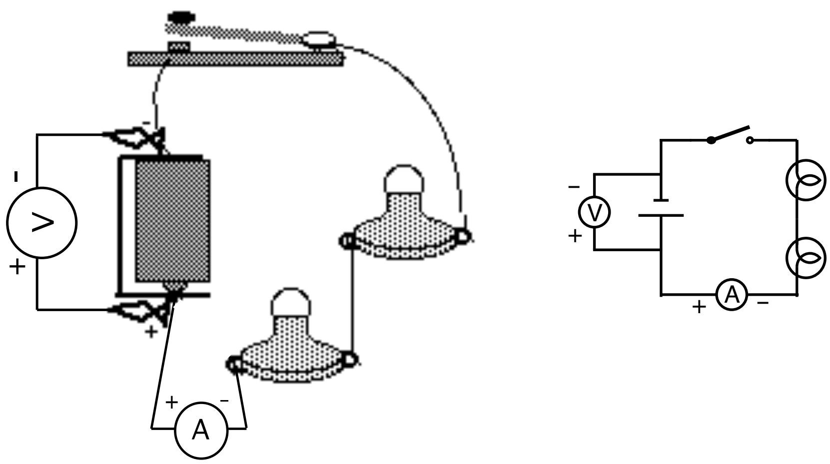

Figure 22-9: Two bulbs connected in series with a voltmeter and an ammeter.

✍ Activity 22-6: Current and Voltage Measurements with Two Bulbs

The predictions below should be completed before class.

(a) How do you think the voltage across the battery will compare to that with only one bulb? (More, less or the same within measurement error?)

(b) What do you think will happen to the brightness of the first bulb when you add a second bulb? Explain.

(c) What will happen to the current drawn from the battery? Explain.

(d) Connect a second bulb as shown, and test your predictions. Measure the voltage across both the bulbs and the current entering both bulbs with the switch closed and record in the table.

Measurements 22-5 and 22-6	1 bulb	2 bulbs
voltage		
current		

(e) Did the addition of the second bulb seem to affect the battery voltage very much?

(f) Did the first bulb dim when you added the second one to the circuit? What happens to the current drawn from the battery?

(g) Explain what you think the battery is doing and why the differences in voltage and current (if any) occur when a second bulb is added.

(h) Is the battery more like a "constant current source" or a "constant voltage source"?

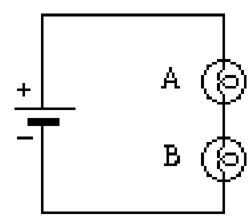

Figure 22-10: A series circuit with one battery and two bulbs. (Note that the battery polarity is reversed from the previous figures. This is the conventional orientation for schematic diagrams.)

✍ Activity 22-7: More Current and Voltage Measurements with Two Bulbs

(a) Explore the current flowing at various points in the series circuit of 22-10. Use an ammeter and insert the ammeter at various places, removing the wires as necessary. to find

The current entering Bulb A
The current flowing from Bulb A to Bulb B
The current leaving Bulb B

Enter the data in the following table:

Current flowing into Bulb A	Current flowing from Bulb A to B	Current flowing out of Bulb B

(b) Formulate a rule about the current flowing through the different parts of a series circuit.

(c) Now measure the voltages across both bulbs and compare to the voltage of the battery.

Element	Voltage
Bulb A	
Bulb B	
Battery	

(d) Formulate a rule about voltages across the elements of a series circuit.

SESSION TWO: SERIES AND PARALLEL CIRCUITS

In the last session you saw that, when an electric current flows through a light bulb, the bulb lights. You also saw that to get a current to flow through a bulb you must connect the bulb in a complete circuit with a battery. A current will only flow when it has a complete path from the positive terminal of the battery, through the connecting wire to the bulb, through the bulb, through the connecting wire to the negative terminal of the battery, and through the battery.

By measuring the current at different points in the simple circuit consisting of a bulb, a battery and connecting wires, you discovered a model for current flow, namely that the electric current was the same in all parts of the circuit. By measuring the current and voltage in this circuit and adding a second bulb, you also discovered that a battery supplies essentially the same voltage whether it is connected to one light bulb or two.

In this session you will examine more complicated circuits than a single bulb connected to a single battery. You will compare the currents through different parts of these circuits by comparing the brightness of the bulbs, and also by measuring the currents with ammeters.

Devising Your Own Rules to Explain Current Flow

In the next series of exercises you will be asked to make a number of predictions and then to confirm your predictions with actual observations. Whenever your observations and predictions disagree you should try to develop new concepts about how circuits with batteries and bulbs actually work. In order to make the required observations you will need:

- A fresh D-cell alkaline battery in a holder
- 6 wires with alligator clip leads
- 4 #14 bulbs in sockets
- a SPST switch
- one ammeter, 0.25A

Consider the two circuits shown in Figure 22-13. Assume that all batteries are identical and that all bulbs are identical. What do you predict the relative brightness of the various bulbs will be? (Remember that you saw in the last session that the battery supplies essentially the same voltage whether there is one light bulb or two.)

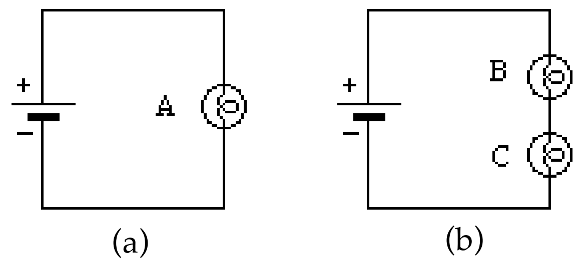

Figure 22-13: Two different circuits with identical components–**(a)** a battery with a single bulb; **(b)** a battery with two bulbs

25 min

Current and Voltage In Parallel Circuits

There are two basic ways to connect resistors (such as bulbs) in a circuit – *series* and *parallel.* So far you have been dealing with bulbs wired in series. To make predictions involving more complicated circuits we need to have a more precise definition of series and parallel. These are summarized in the box below.

Series Connection:
Two resistors are in series if they are connected so the *same* current that passes through one bulb passes through the other.

Parallel Connection:
Two resistors are in parallel if their terminals are connected together so that *at each junction* one terminal of the one bulb is *directly* connected to the terminal of the other.

Figure 22-14 Series and Parallel Connections

Let's compare the behaviour of a circuit with two bulbs wired in parallel to the circuit with a single bulb. (See Figure 22-15.)

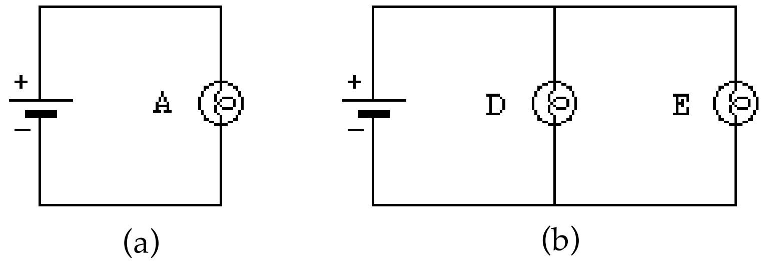

Figure 22-15: Two different circuits with identical components–**(a)** a single bulb circuit and **(b)** a parallel circuit.

Note that if bulbs A, D and E are identical, then the circuit in Figure 22-16 (below) is equivalent to circuit 22-15(a) when the switch is open (as shown) and equivalent to circuit 22-15(b) when the switch is closed.

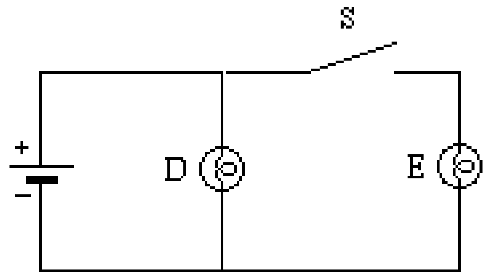

Figure 22-16: When the switch is open, only bulb D is connected to the battery. When the switch is closed, bulbs D and E are connected to the battery *in parallel*.

Now, let's make some predictions about the currents in the branches of a parallel circuit.

✍ Activity 22-9: Predicting Currents in a Parallel Circuit

(a) Predict the relative brightness of bulb A in Figure 22-15a with the brightness of bulbs D and E in Figure 22-15b. Which of the three bulbs will be the brightest? The dimmest? Explain the reasons for your predictions.

(b) How do you think that closing the switch in Figure 22-16 will affect the current through bulb D? Explain.

You can test your predictions in (a) and (b) by wiring up the circuit shown in Figure 22-16 and looking at what happens to the brightness of the bulbs as the switch is closed.

Note: Before you start the next activity make sure that (1) bulbs D and E have the same brightness when placed in series with the battery and (2) use a **very fresh** alkaline D-cell battery so it behaves like an "ideal" battery.

✍ Activity 22-10: Actual Currents in a Parallel Circuit

(a) Wire up the circuit in Figure 22-16 and, by opening and closing the switch, describe what you observe to be the actual relative brightness of bulbs A, D and E. (Very small changes may be due to your non-ideal battery.)

(b) Were the relative currents through bulbs A, D and E what you predicted? If not, can you now see why your prediction was incorrect?

(c) Did closing the switch and connecting bulb E in parallel with bulb D significantly affect the current through bulb D? How do you know?

What about the current from the battery? Is it always the same no matter what is connected to it, or does it change depending on the circuit? Is the current through the battery the same whether the switch in Figure 22-16 is open or closed? Make predictions based on your observations of the brightness of the bulbs, and test it using meters.

✍ Activity 22-11: Predicting Changes in Battery Current and Voltage

(a) Based on your observations of the brightness of bulbs D and E in Activity 22-10, how do you think that closing the switch in Figure 22-16 will affect the current from the battery? Explain.

(b) Based on your observations in Activity 22-10, how do you think that closing the switch in Figure 22-16 will affect the current through bulb D? Explain.

(c) Based on your observations in Activity 22-10, how do you think that closing the switch in Figure 22-16 will affect the voltage across the battery? Explain.

You can test your predictions by placing the voltmeter across the battery and inserting the ammeters in the circuit as shown in the following diagram.

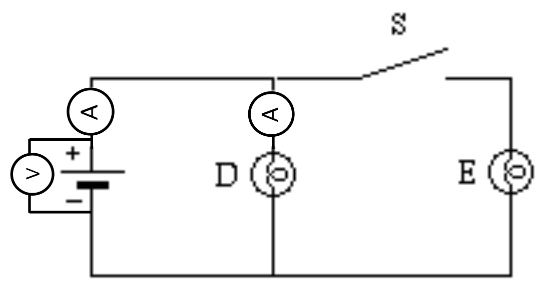

Figure 22-17: Meters connected to measure the current through the battery and the current through bulb D and the voltage of the battery when the switch is opened and closed.

✍ Activity 22-12: Observing Battery Voltage and Current

(a) Collect data while closing and opening the switch as before. Measure the currents through the battery and through bulb D. How does closing the switch in the circuit affect the voltage across the battery?

	Current from Battery	Current into Bulb D	Battery Voltage
Switch Open			
Switch Closed			

(b) Use your observations to formulate a rule to predict how the current through a battery will change as the number of bulbs connected *in parallel* increases. Can you explain why?

(c) Compare your rule in (b) to the rule you stated previously for bulbs in series connected to the battery. Does the addition of more bulbs in parallel increase, decrease, or not change the total *resistance* of the circuit?

(d) Explain your answer to (c) in terms of the number of paths available in the circuit for current flow.

(e) Does the amount of current through a battery appear to depend only on how many bulbs are in the circuit or does the arrangement of the bulbs matter also? (Don't forget your observations with bulbs in series!) Explain.

(f) Does the total resistance of a circuit appear to depend only on how many bulbs are in the circuit or does the arrangement of the bulbs matter also? Explain.

60 min

More Complex Series and Parallel Circuits

Applying your knowledge to a more complex circuit.
Consider the circuit consisting of a battery and two bulbs, A and B, in series shown in Figure 22-18(a). What will happen if you add a third bulb, C, in parallel with bulb B (as shown in Figure 22-18(b))? You should be able to answer this question about the relative brightness of A, B, and C based on previous observations. The tough question is: how does the brightness of A change?

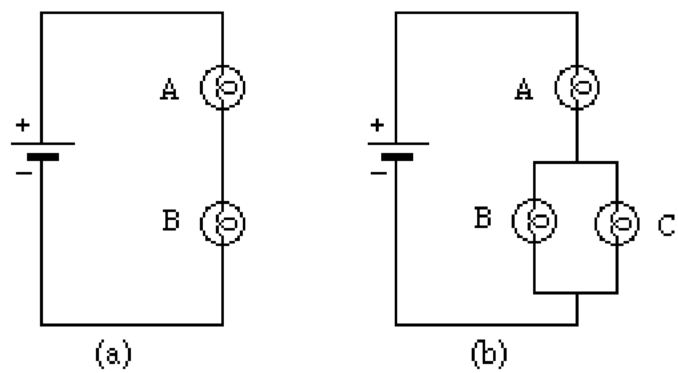

Figure 22-18: Two different circuits with identical components

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✍ Activity 22-13: Predictions About a More Complex Circuit

(a) In Figure 22-18 (b) is A in series with B alone, with C alone, or with a combination of B and C? (You may want to go back to the definitions of series and parallel connections given earlier in this session.)

(b) In Figure 22-18(b) are B and C in series or in parallel with each other? Explain.

(c) Is the resistance of the combination of B and C larger than, smaller than, or the same as B alone? Explain.

(d) Is the resistance of the combination of bulbs A, B and C in Figure 22-18(b) larger than, smaller than or the same as the combination of bulbs A and B in Figure 22-18(a)? Explain.

(e) Can you predict how the current through bulb A will change, if at all, when circuit 22-18 (a) is changed to 22-18 (b) (i.e. when bulb C is added in parallel to bulb B)? Explain the reasons for your answer.

(f) When bulb C is added to the circuit, what will happen to the brightness of bulb A? Explain.

(g) Finally, predict the relative rankings of brightness for all the bulbs, A, B, and C, after bulb C is added to the circuit. Explain the reasons for your answers.

Set up the circuit shown in Figure 22-19(a) below. You will need:

- 3 D-cell alkaline batteries
- 3 #14 light bulbs
- A SPST switch
- 2 ammeters, 0.25 A
- 1 digital voltmeter

Convince yourself that this circuit is identical to Figure 22-18(a) when the switch is open (as shown) and to 22-18(b) when the switch, S, is closed.

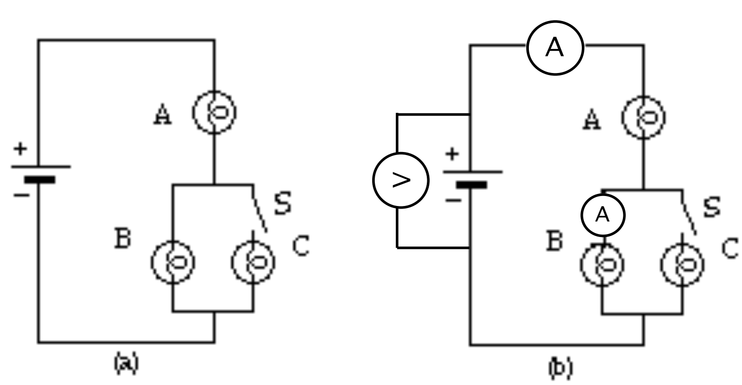

Figure 22-19: **(a)** Circuit equivalent to Figure 22-18(a) when the switch is open, and to Figure 22-18(b) when the switch is closed. **(b)** Same circuit with ammeters connected to measure the current through bulb A and the current through bulb B and a voltmeter to measure the battery voltage.

Now let's make some observations using this circuit.

✍ Activity 22-14: Observing a Complex Circuit

(a) Observe the brightness of bulbs A and B when the switch is open, and then the brightness of the three bulbs when the switch is closed (when bulb C is added). Compare the brightness of bulb A with and without C added, and rank the brightness of bulbs A, B, and C with the switch closed.

	Brightest		Dimmest
Switch Open			
Switch Closed			

If two bulbs have equal brightness, list them in the same box.

(b) If your observations and predictions of the brightness were not consistent, what changes do you need to make in your reasoning? Explain!

(c) Connect the two ammeters and the voltmeter as shown in Figure 22-19b. Measure what happens to the battery voltage and the voltage across bulb A. Also measure the current through bulb A and the current through bulb B when the switch is opened and closed. Record your measurements below:

Measurement	Switch Open	Switch Closed
Battery Voltage		
Bulb A Voltage		
*Bulb B Voltage**		
Bulb A Current		
Bulb B Current		

*This can be deduced from the other voltage measurements.

(d) What happens to the current from the battery and through bulb A when bulb C is added in parallel with bulb B? What do you conclude happens to the total resistance in the circuit? Explain.

Power

The brightness of a bulb depends on the product of the voltage across the bulb and the current through it. This product represents the power, or the electrical energy per unit time, used by the bulb:

Power: $P = VI$

If V is in volts and I in amperes then P is in watts.The electrical energy is converted to both heat and light so that the relationship of power to the brightness is not necessarily linear. Nevertheless, one should observe that the qualitative brightness increases with the power if the light bulbs are of the same manufacture. [1]

✍ Activity 22-15: Calculate the power of the light bulbs

(a) Use the voltage and current values in the table of 22-14 to calculate the power usage of the bulbs with both switch open and switch closed.

Power	Switch Open	Switch Closed
Bulb A		
Bulb B		
Bulb C		

(b) Does the power consumption of the bulbs correspond to the brightness ranking?

[1] Note that commercial light bulbs are rated by the power they dissipate when used at the standard voltage, e.g., 110 V in N. America or 220 V in Europe. If a light bulb is used at a voltage for which it was not intended then its power dissipation will not be the rated value. For example, if a 60 W bulb bought in Europe is used in N. America, its power usage is much less than 60 W.

Series and Parallel Networks

Let's look at a somewhat more complicated circuit to see how series and parallel parts of a complex circuit affect one another. The circuit is shown below.

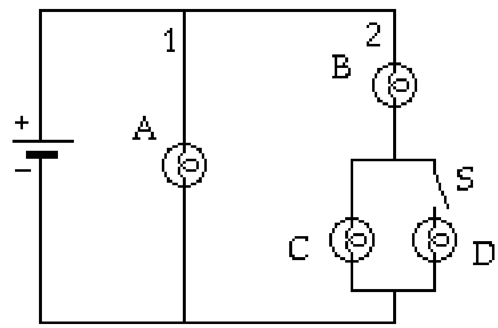

Figure 22-20: A complex circuit with series and parallel connections.

From your knowledge of current and voltage in parallel and series circuits you should be able to figure out what happens when the switch is closed.

✍ Activity 22-15: Series and Parallel Network

(a) Predict the effect on the current in branch 1 of each of the following alterations in branch 2: (i) unscrewing bulb B, and (ii) closing switch S.

(b) Predict the effect on the current in branch 2 of each of the following alterations in branch 1: (i) unscrewing bulb A, and (ii) adding another bulb in series with bulb A.

(c) Connect the circuit in Figure 22-20, and observe the effect of each of the alterations in (a) and (b) on the brightness of each bulb. Record your observations for each case.

(d) Compare your results with your predictions. How do you account for any differences between your predictions and observations?

(e) In this circuit, two parallel branches are connected across a battery. What do you conclude about the effect of changes in one parallel branch on the current in the other?

PLEASE READ THE FOLLOWING OUTSIDE OF CLASS:

We will not be doing the following activity, but please read this section on your own time.

An Analogy to Potential Difference and Current Flow

The fact that you found that a current is not "used up" in passing through a bulb seems counterintuitive to many people trying to understand how circuits work. Many physics teachers have invented analogies to help explain this idea for an electric circuit. One obvious approach is to construct a model of a gravitational system that is in some ways analogous to the electrical system we are studying.

It is believed that the electrons flowing through a conductor collide with the atoms in the material and scatter off of them. After colliding with an atom, each electron accelerates again until it collides with another atom. In this manner, the electron finally staggers through the material with an average drift velocity v_d.

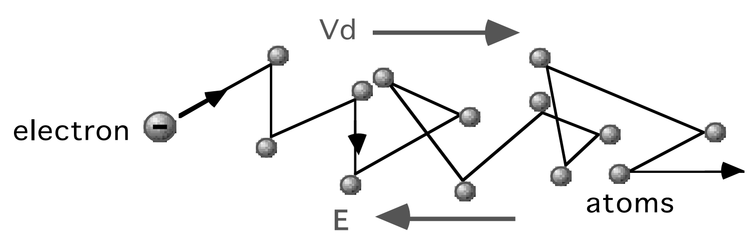

Figure 22-10: An electron in a uniform electric field staggering through a conductor as a result of collisions with atoms. Instead of accelerating it has an average drift velocity, v_d.

We can talk about the *resistance* to flow of electrons that materials offer. A thick wire has a low resistance. A light bulb with a thin filament has a much higher resistance. Special electric elements that resist current flow are called *resistors*. We will examine the behaviour of resistors in electric circuits in future sessions.

It is possible to use a two-dimensional mechanical analogue to model this picture of current flow through conductors. You should note that the real flow of electrons is a three-dimensional affair. The diagram for the two-dimensional analogue is reproduced in Figure 22-11.

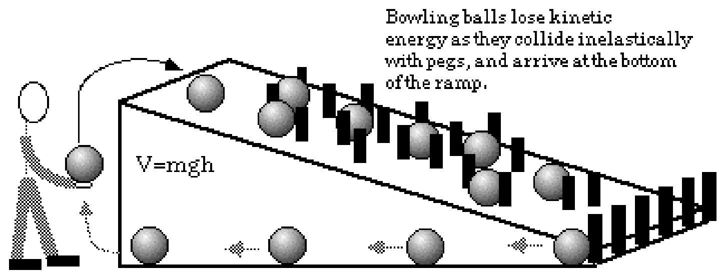

Figure 22-11: An analogue to electrical current flow.

Building a Working Model for Current Flow

In order to see how the model works, you should build it and play with it to see how it works.

To build the model you can take an adjustable wooden ramp and mount a piece of insulation board on it. Then push pins can be poked into the soft insulation board to simulate atoms. Graph paper can be placed on top of the insulation board to facilitate the spacing of the atoms. A marble can be used to represent an electron flowing through the circuit. Strips of poster board can be pinned into the sides of the insulation board to make side rails.

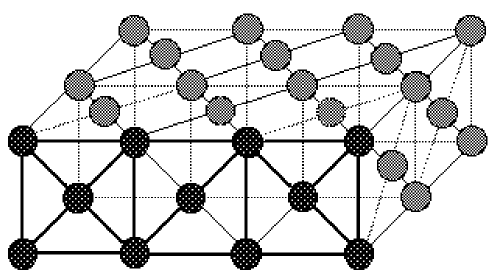

Figure 22-12: Arrangement of atoms in a face centred cubic crystal. The atoms in the foreground are represented by the dark circles.

By placing the board with face-centred pegs on the ramp and tilting it at an angle you can investigate the analogy between gravitational potential energy and the electrical potential energy stored in a battery. Suppose that the ramp is propped up so that one end is a height h above the other end and that a ball is rolled down the ramp with the pegs providing resistance to the flow of balls, and that a little person keeps lifting up a ball to the top to the ramp as soon as it reaches the bottom.

✍ Activity 22-7: Explaining the Features of the Model

(a) What would happen to the ball current (i.e. the rate of ball flow) if twice as many pegs were placed in the path of the ball?

(b) What would happen to the ball current if the ramp were raised to a height of 2*h*?

(c) Examine the list below and *draw lines between elements of the model and the corresponding elements of a circuit consisting of batteries and bulbs* (or other electrical resistors). In particular, what represents the electrical charge and current? What ultimately happens to the "energy" given to the bowling balls by the "battery"? What plays the role of the bulb? Where might mechanical energy loss occur in the circuit you just wired that consists of a battery, two wires, and a bulb?

Battery action	Rate of motion of bowling balls
Resistance of bulb	Person raising the balls
Current	Height of the ramp
Voltage of battery	Number of pegs

(d) How does this model help explain the fact that electric current doesn't decrease when it flows through the bulb?

(e)How does this ramp analogy support a model in which current doesn't accelerate when it flows through a circuit?

(f) In this model, what would happen to the "ball" current if the drift velocity doubles? What can you do to the ramp to increase the drift velocity?