4C - Electricity

1	The Flow of Electricity	Circuits, conductors, insulators, electric current, ammeters	Wires, bulbs, batteries, ammeters, switches	Read: *Electric Circuits*, pg. 316-317 *Electric Current*, pg. 319-320 Problems: pg. 318 #1 pg.320 #1 Simulation: Electric Circuits Lab
2	Electric Circuits and Voltage	Circuit diagrams, batteries, electric potential difference, voltage, voltmeters, voltage rise, voltage drop, sources, loads	computers	Read: *Electric Potential Difference*, pg. 324-325 Read: *Circuit Symbols*, pg. 576 Problems: pg. 326 #1, pg. 327 #1 Video: Current and Voltage
3	Bulbs in Series	Series circuits, current model, resistance, resistance in series, voltage rule		Simulation: Battery-Resistor Circuit Video: Dr. Megavolt
4	Bulbs in Parallel	Parallel circuits, resistance in parallel, current rule		Handbook: *Bulbs in Parallel Homework* Video: Series and Parallel
5	A Complex Circuit	Current rule, voltage rule		Handbook: *A Complex Circuit Homework*
6	Resistance and Ohm's Law	Ohm's law, definition of resistance, equivalent resistance in series and parallel		Read: *Electric Resistance*, pg. 328-331 Problems: pg. 330 #1, pg.331 #5,7,8 Lesson: Ohm's Law Lesson: Resistors in Series Lesson: Resistors in Parallel Simulation: Ohm's Law
7	Circuit Decomposition	Circuit decomposition		Handbook: *Electrical Connections* Lesson: Circuit Decomposition
8	Kirchoff's Laws	Voltage law, current law		Read: *Kirchoff's Laws*, pg. 335-341 Problems: pg. 337 #1-3, pg. 339 #4-6, pg. 340 #7
9	Circuit Analysis	Circuit analysis		Read: Analyzing Series-Parallel Circuits, pg. 341-343 Problems: pg.342 #9, pg.343 #1-8
10	Review			Review: Electric Circuits Electricity Review: pg. 363 #1-8, 11-17, pg.364 #5-13
11	Test			

SPH4C: The Flow of Electricity

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
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How do electric circuits work? What happens when we flick on the light switch at home? In this investigation, we begin to explore how electrical circuits work.

A: How Many Ways Can You Light a Bulb?

You will need a battery, a light bulb and a single wire.

1. In the chart below, connect the three items together in a variety of ways. Draw a sketch (not a circuit diagram!) of two arrangements that cause the bulb to light on the left and two arrangements that don't on the right.

Bulb lights	Bulb doesn't light

2. According to your examples, what conditions are necessary for the bulb to light? How are those conditions **not** satisfied in the arrangements that don't light up?

A *closed* circuit is one in which electricity can flow. An *open* circuit does not allow current to flow.

3. Describe how a circuit must be built in order to create a closed electric circuit. Label the circuits above as open or closed.

B: Investigating Current Flow

1. **Briefly** connect the bare wire from one end of the battery to the other. (Don't leave it attached too long or you will ruin the battery!) Describe how the wire and the battery feel.

2. Feel the wire in a few different places. What do you think is happening at one place compared to the others?

The flow of electricity is called the *electron current*, or just simply, the *current*. We picture this as the movement of negative charges (the electrons) through the parts of an electric circuit.

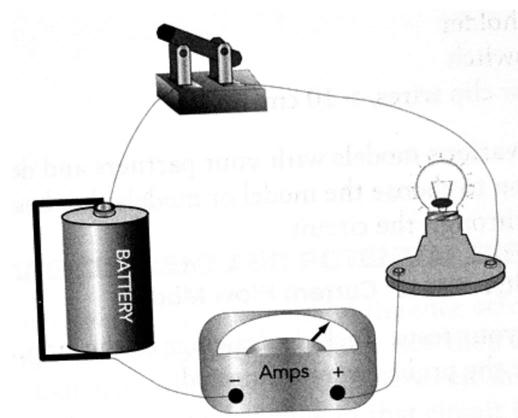
Adapted from *Workshop Physics Activity Guide: 4 – Electricity and Magnetism,* Laws, John Wiley & Sons, 2004

3. Based on your observations of the circuit in question B #2, in which parts do you think current flows?

C: Measuring Current Flow

An *ammeter* is a tool that measures the size and direction of the current that flows through it. Electric current is measured in units of *amperes* or amps (A). Remember that current is the flow of electric charge. The unit for electric charge is the *coulomb* (C) which represents a very large number of individual electrons (just like a *dozen* represents a large number of eggs!) One amp of current is defined as one coulomb of charge flowing past a point every second. This can be shown with the equation: $I = Q/\Delta t$, where I is the current, Q is the number of electrons measured in coulombs and Δt is the interval of time during which the charge flows.

To measure the current travelling through one part of a circuit, simply “insert” the ammeter into that location in the circuit. Set up the circuit as shown in the diagram to the right.

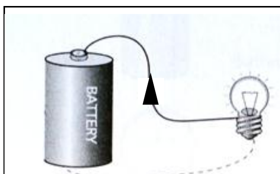
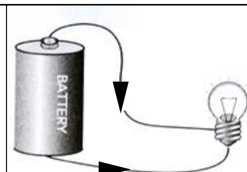
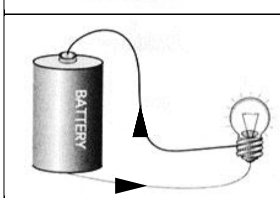
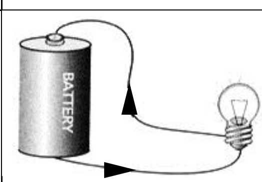


1. What is the value of the current in amperes? Is it positive or negative?

2. Reverse the leads going into and out of the ammeter. Explain what happened to the meter reading.

D: A Model for Current Flow

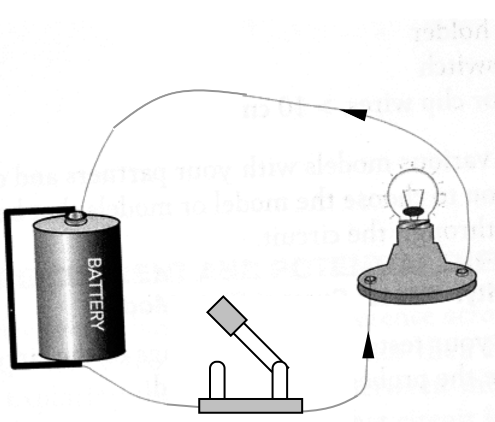
1. Examine the four diagrams below and the explanations provided with each. Explain which you think provides the best model for the flow of the electric current.

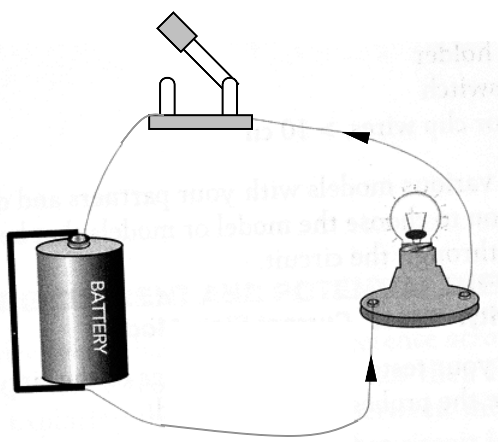
	Model A: There will be no electric current left to flow in the bottom wire. The current is used up in the bulb.		Model B: The electric current will travel in a direction toward the bulb in both wires.
	Model C: The direction of the current will be in the direction shown, but there will be less current in the return wire.		Model D: The direction of the current will be as shown, and it will be the same in both wires.

2. Your goal is to make some measurements which will clearly indicate which model is correct. Decide what circuit you should build to test the models. Draw a picture of the circuit and show where you will place the ammeter in order to make the necessary readings. Record your measurements (including the sign) along side your diagram.

3. Explain how your measurements eliminate three of the models **and** confirm the fourth. Call your teacher over to explain your results.

4. **Apply.** Does the location of the **open** switch in the circuit change whether or not the bulb lights up? Use your new theory of current flow to help explain.





SPH4C: Electric Circuits and Voltage

Recorder: ______________________
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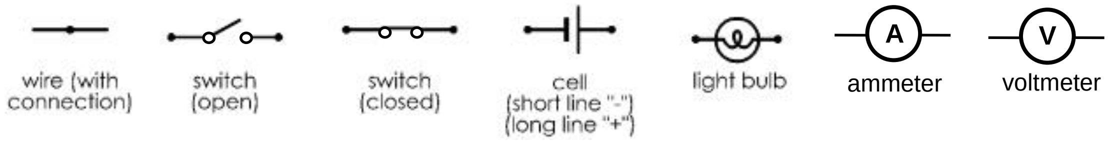
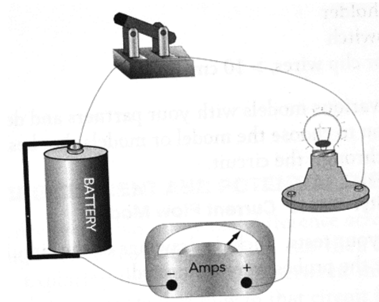
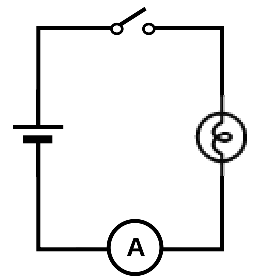
A: Drawing Electric Circuit Diagrams

A circuit diagram is a simplified drawing of an electric circuit. Instead of drawing pictures of the parts in a circuit, we use simple symbols like the ones shown below. Any wires are drawn using straight lines and right angle corners. It is important to remember that a circuit diagram *shows the electrical connections of a circuit, not its physical layout*.

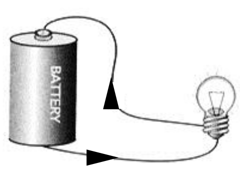


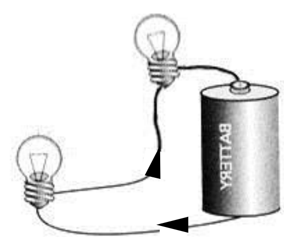
The circuit you built in part C of the previous investigation has a circuit diagram that is shown below.





1. Draw the circuit diagram (do it neatly with a ruler!) for the circuits shown below.

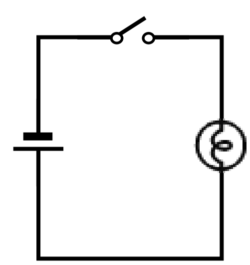




B: Voltage Rise and Drop

A battery is a device that increases the potential energy of electric charges which can then flow through a circuit. A charge moving through a battery will go from a low potential energy to a high potential energy. The *electric potential difference* (ΔV) is the gain in energy by each unit of electric charge. The unit for potential difference is *volts* (V) and potential difference is often referred to as *voltage*. A *voltmeter* measures the electric potential difference between two parts of a circuit.

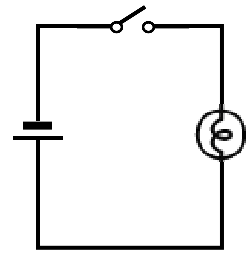
1. Construct a circuit with one bulb and a switch. Close the switch while you make your measurements, *but don't leave it closed or you will ruin the battery!* Connect both the positive and negative leads of the voltmeter to the *same point* in the circuit. Draw the voltmeter symbol and wire leads attached to the circuit to show each reading. Record the voltage reading (don't worry about the positive or negative signs yet). Try this again at a different point in the circuit.



2. What do you conclude about the difference in voltage when the leads are connected to the same point (i.e. to each other)? What does this imply about the difference in potential energy at the ends of the leads?

3. Measure the voltage *across* the battery. Draw the voltmeter in the diagram and show where the leads connect. Record your measurement on the diagram.

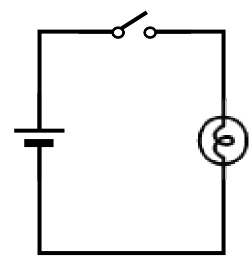
4. Measure the voltage *across* the bulb. Draw the voltmeter in the diagram and show where the leads connect. Record your measurement on the diagram.



A source of energy like a battery causes the electric potential energy of the charges to increase. We call such an increase in voltage a *voltage rise*. An element of a circuit like the light bulb is called a *load* and loads cause the electric potential energy of the charges to decrease. Such a decrease is called a *voltage drop*. A potential difference of 1 volt is defined as a change in potential energy of 1 joule for each coulomb of charge, or 1 V = 1 J/C. This is represented by the equation: $\Delta V = \Delta E/Q$.

5. Suppose you measured a voltage rise of 3V when the voltmeter was connected across the battery. Let's understand what this reading tells us about the charges. Describe how the energy of each unit of charge (one coulomb) changes when travelling through the battery. (For example, Q = 1 C, ΔV = 3 V)

6. Is there a voltage rise or drop across a single wire? What does this tell us about the gain or loss of energy as charges travel through the wire? Show where you connected the voltmeter leads on the diagram.



We will record **all** our voltage values as positive quantities for both rises and drops. This is our voltage sign convention. From our understanding of the voltage measurement, we know whether it is a rise or drop (if it's a source or a load) so we can always decide if energy was gained or lost. Our future work will be simpler using only positive voltages. We will ignore any negative signs appearing on the voltmeter.

7. Label each element of the circuit in Q#6 as a voltage "rise" or "drop" along with the voltage value.

8. Imagine a charge making a complete trip through your circuit. What happens to the energy of that charge during the complete trip?

9. Devise a rule that describes the total change in voltage in a complete circuit – use the terms rise and drop. Don't use any math.

Preliminary Rule for Voltage:

10. Use your new rule to predict the voltage drop across the bulb in the previous circuit if we double the voltage rise of the cell. Test your prediction.

SPH4C: Bulbs in Series

Recorder: ______________________
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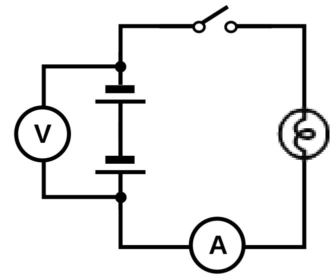
0 1 2 3 4 5

What happens to the current and voltage in a circuit with more than one bulb? Let's find out! **Don't build the circuit yet!**

A: Batteries in Series and a Single Bulb

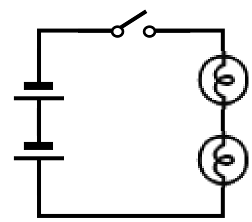
1. Two 1.5 V cells are connected in series. What do you predict the total voltage across the two batteries will be?



2. Build this circuit. Measure the current and voltage as shown. Record the result beside the meters in the diagram.
3. What do you think happens to the energy of a charge as is travels through the two cells?

B: The Two Bulb Circuit - Predictions

Don't build this next circuit yet! Let's make a few **quick** predictions about the two-bulb circuit shown to the right. Don't spend too long on your predictions.

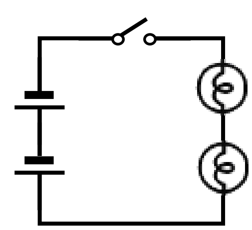


1. How do you think the total voltage across the two cells will compare to your previous circuit with only one bulb? Explain.
2. What do you think will happen to the brightness of the first bulb when you add a second bulb to the circuit? Will it get brighter? Dimmer? Remain the same? Explain.
3. What will happen to the current drawn from the battery when a second bulb is added? Will it remain the same, decrease or increase? Explain.

C: The Two Bulb Series Circuit

Set up a two-bulb circuit with identical bulbs connected one after the other as shown. Bulbs connected in this way are said to be connected in *series*.

1. Measure the voltage across the cells when the switch is closed. Add a voltmeter to your circuit diagram showing how you connected it to make this measurement. Record your results beside the meter.



2. Did the voltage across the battery change significantly? Did the addition of the second bulb change the potential difference across the cells?
3. Did the first bulb dim when you added the second bulb to the circuit? What happens to the current drawn from the battery? Add an ammeter to your circuit diagram showing how you connected it to make this measurement.

4. Is the cell a source of constant current? Does the amount of current flowing through the cells depend on the other elements connected in the circuit? Why or why not?

An ideal battery is a source of a constant voltage, no matter what circuit is connected to it. Real batteries are to a good approximation a source of constant voltage.

We may think of a bulb as presenting an obstacle, or *resistance*, to the current in the circuit.

5. Would adding more bulbs in series cause the total obstacle to the flow, or *total resistance*, to increase, decrease, or stay the same as before?

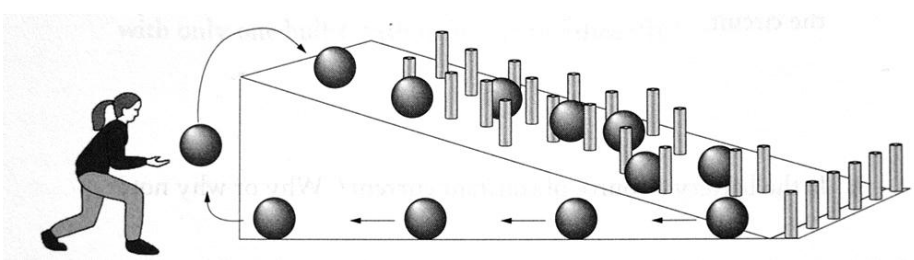
6. Devise a rule for the total resistance of elements connected in series. Don't use any math.

Preliminary Rule for Total Resistance of Elements in Series:

7. Describe how the current through the battery would change (increase, decrease or remain the same) if the number of bulbs connected in series were increased or decreased. Use the term total resistance in your explanation.

D: Expanding Our Model for Current Flow

What is happening inside a circuit to produce the results we have found from part C of our investigation? What can we picture charges doing when they flow? Consider the illustration below and answer the following questions. Note that due to the pegs on the incline, the balls end up rolling down at **a fairly constant average speed** (from all the stopping and starting due to the collisions).



1. What would happen to the ball current (the rate of ball flow) if twice as many pegs were placed in the path of the balls on the incline?

2. What would happen to the ball current if the ramp was raised to twice the height (a steeper angle), so they have twice the gravitational energy when they start to fall?

3. Label on the diagram which elements of the model correspond to elements of a circuit consisting of battery and bulbs. Use the labels from the following lists.
   Model: average speed of balls, number of pegs encountered, person raising balls, height of the ramp
   Electrical: number of bulbs, battery action, current, voltage of battery

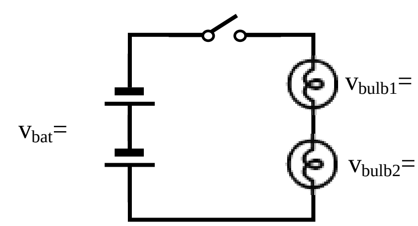
4. What ultimately happens to the gravitational potential energy given to the balls by the person? What do you think might happen to the electrical potential energy of an electron as it passes through a bulb?

5. Use this model to explain why electric current isn't used up when it flows through a bulb.

6. What would happen to the "ball" current if the velocity down the incline doubles? What can you do to the ramp to increase this velocity?

E: Potential Difference

Let's return to the circuit we were using earlier. With one change: double the resistance of one of the bulbs (right click).



1. Measure the potential difference across each element in the circuit. Record this beside each circuit element. Treat the two cells as one.

2. Consider the voltage rule you devised from question B#9 of the previous investigation. Does it still work in this situation? Or do you need to modify it? Explain.

3. Revise or rewrite your voltage rule. Don't use any math.

Preliminary Rule for Voltage in a Loop:

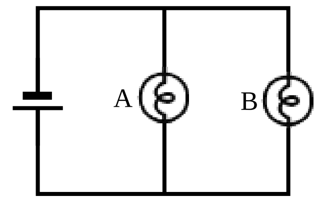
3. Use this rule to explain what is happening to the energy of a single charge as it travels through the circuit above.

SPH4C: Bulbs in Parallel

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

A: The Two Bulb Parallel Circuit - Predictions

Don't build the circuit yet! There is a second way to connect two bulbs in a circuit. Instead of connecting one after the other (in series), they are connected side-by-side, or in *parallel*, as shown in the diagram to the right.

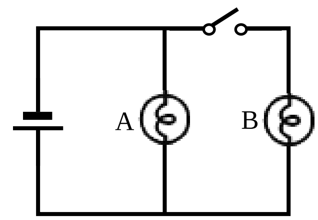


1. Is it possible for a charge to travel from the source, to bulb A and back to the source without passing through bulb B? Colour this path on the diagram.

2. Is it possible for a charge to travel from the source, to bulb B and back to the source without passing through bulb A? Draw this path on the diagram with a different colour.

These paths correspond to different complete *loops* in the circuit through which current can flow. A particular charge only ever travels through one loop in a circuit.

To help us make comparisons, we will modify the circuit by placing a switch in front of the second bulb. Make your predictions below quickly and move on.



3. When the switch is open (like in the diagram) bulb B will not light up. Explain why. When this happens, our circuit is just like the single bulb circuit from part A of this investigation.

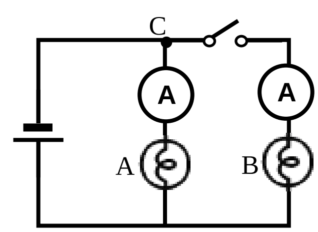
4. We will call the brightness of the bulb before the switch is closed A_1. After the switch is closed we will call them A_2 and B_2. Which of these three do you predict will be brightest? Dimmest? Will any be the same? Rank them and explain.

B: The Two Bulb Parallel Circuit - Measurements

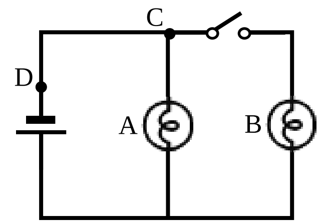
1. Build the circuit, open and close the switch and describe the relative brightness of the bulbs before and after. Only mention large differences in brightness. Don't leave the battery connected for extended periods of time. Disconnect it after you make your observations.

2. Did closing the switch and connecting bulb B in parallel with bulb A significantly affect the current through bulb A? How do you know?

3. Connect an ammeter into the circuit path for bulb A as shown in the diagram. Record the measurements for the current flowing through bulb A and B when the switch is open and closed.
   - Bulb A current with switch open: ________________
   - Bulb B current with switch open: ________________
   - Bulb A current with switch closed: _______________
   - Bulb B current with switch closed: _______________



C: The Battery



1. Predict: How does closing the switch affect the current flowing through the battery (that is, through point D – see below)? Explain your reasons.

2. Predict: How do you think closing the switch will affect the voltage across the battery? Explain.

3. Test your prediction by inserting an ammeter into the circuit at point D. Record your measurements below.
   Battery current with switch open: _____________ amps
   Battery current with switch closed: ____________ amps

4. Test your prediction by placing a voltmeter across the battery. Record your measurements below.
   Battery voltage with switch open: _____________ volts
   Battery voltage with switch closed: ____________ volts

5. Based on today's observations, define a preliminary rule for describing what happens to the current at a junction point (a branching point in a circuit). Don't use any math.

Preliminary Rule for Current at a Junction:

D: Elements in Parallel Circuits

1. Does the addition of more bulbs in parallel increase, decrease or not change the *total resistance* of the circuit connected to the battery? Use your current measurements to help decide.

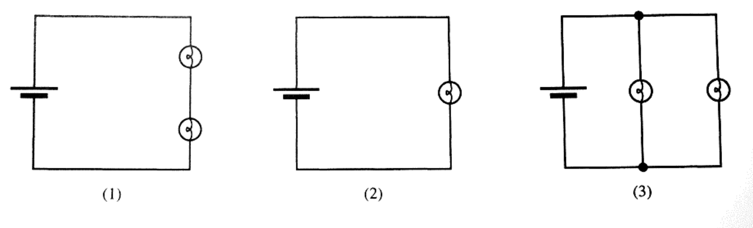
2. Devise a preliminary rule for the total resistance of elements connected in parallel. Don't use any math.

Preliminary Rule for the Total Resistance of Elements in Parallel:

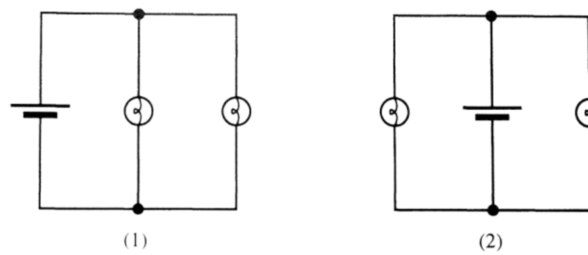
3. Does the total resistance of the circuit depend only on the number of bulbs in a circuit, or does the arrangement of the bulbs matter?

SPH4C: Bulbs in Parallel Homework

1. Rank the following circuits in order by current through the battery. Explain your reasoning.



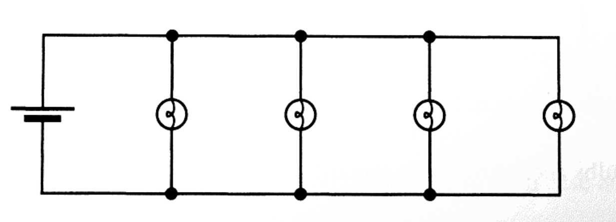
2. Consider the following dispute between two students. Which student is correct?



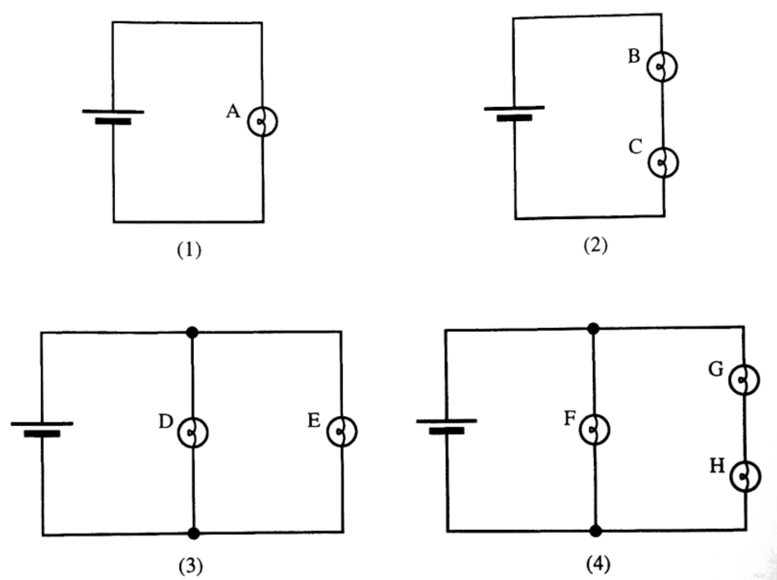
Student 1: "*Circuit 1 and circuit 2 are different circuits. In circuit 2 the bulbs are the same distance from the battery, but in circuit 1 one bulb is closer to the battery. So the brightness of the bulbs could be different in the two circuits*."

Student 2: "*Circuit diagrams don't show physical layout, only electrical connections. In each diagram, the electrical connections are the same. Each bulb has one terminal directly connected to one terminal of the battery and the other terminal of each bulb is directly connected to the other terminal of the battery. So the brightness of the bulbs will be the same in each circuit. Both diagrams represent the same circuit.*"

3. Consider the circuit diagram to the right. What would happen to the brightness of the other bulbs in the circuit if one of the bulbs were to burn out (so that no current could flow through it)? Explain your reasoning.



4. Identical bulbs are connected to identical batteries in the various circuits below. Rank all the bulbs (A-H) in order of brightness. If two bulbs have the same brightness, state that explicitly. Explain your reasoning.



SPH4C: A Complex Circuit

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
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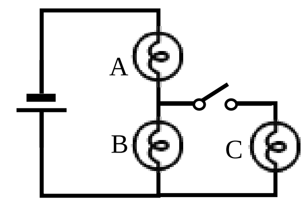
A: A Complex Circuit - Predictions

The circuit to the right shows a more complicated combination of three identical bulbs. Use a 3 V battery for this investigation (or two 1.5 V in series). Use your preliminary rules to help make your predictions below. Don't spend too much time – predict and move on.



1. When the switch is closed, are bulbs B and C in series or parallel with one another? Explain.

2. When the switch is closed, is bulb A in series with B alone, with C alone or with a parallel combination of B and C?

3. When the switch is closed, is the resistance of the combination of B and C larger than, smaller than, or the same as B alone? Explain.

4. When the switch is closed, will the total resistance of all the bulbs be greater than, less than or the same as when the switch is open? Explain.

5. Will the current through bulb A change when the switch is changed from open to closed? What will happen to its brightness?

6. When the switch is closed, predict the relative brightness of the three bulbs.

B: A Complex Circuit – Observations

Build the circuit according to the diagram above.

1. Rank the brightness of the bulbs when the switch is both open and when it is closed.

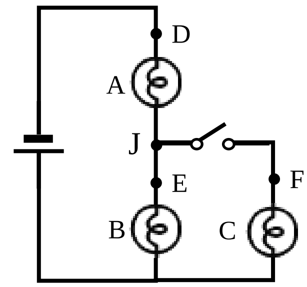
2. Describe any differences between your predictions and observations. There may be a few!

3. Based on your observations of the brightness, what happens to the current through bulb A when bulb C is added in parallel with bulb B?

4. What happened to the current through the battery? What do you conclude happens to the total resistance in the circuit? Does this agree with your two rules for total resistance? Explain.

C: A Complex Circuit - Measurements

1. Complete the chart showing measurements of the currents through the bulbs. Insert an ammeter at point D, E and F to make these measurements.

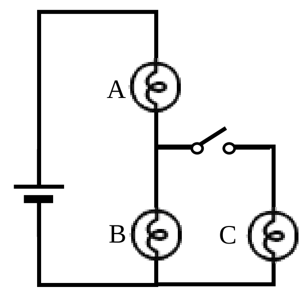


Measurement	Switch open	Switch closed
Bulb A current		
Bulb B current		
Bulb C current		
Battery Current		

2. Use your measurements to help explain the brightness rankings from question B#1.

3. Does your rule for current from question C#5 of the previous investigation still work to explain what happens at the junction point (J) when the switch is open? What about when it is closed?

4. Complete the chart showing measurements of the voltages across the battery and bulbs when the switch is both open and closed.



Measurement	Switch open	Switch closed
Total battery voltage		
Bulb A voltage		
Bulb B voltage		
Bulb C voltage		

5. Draw two complete paths or loops through which current can flow when the switch is closed. Use different colours. For simplicity, choose two paths that pass through the battery.

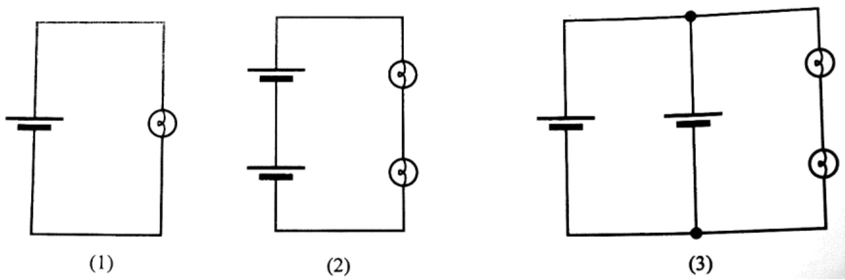
6. Does your voltage rule from question E#3 of the “Bulbs in Series” investigation still work for each loop when the switch is closed? Explain.

7. Imagine we could follow a single charge through the circuit. Describe how it gains and loses energy in each element of the circuit and describe how this agrees with your voltage rule.

SPH4C: A Complex Circuit Homework

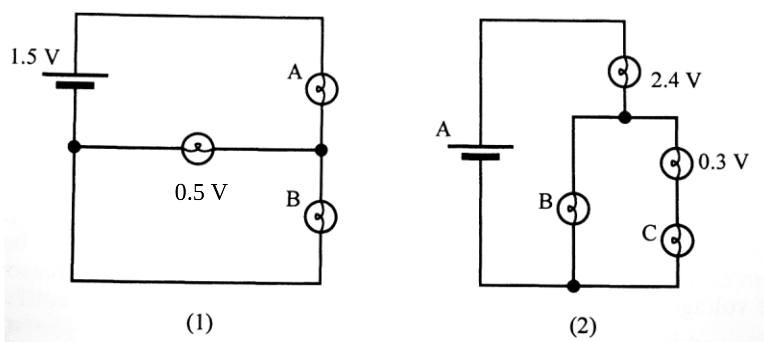
1. Consider circuit 2 and 3 below.
   (a) How does the voltage across the top bulb in each circuit compare to the voltage across the bottom bulb in each circuit?

   (b) How does the current through the top bulb in each circuit compare to the current through the bottom bulb in each circuit?



   (c) Compare the current through the bulbs for the three circuits shown. In which circuit if the current through the bulbs greatest? the least? In which circuit is the voltage across the pair of bulbs the greatest? the least?

2. Determine the voltage across the lettered elements in the following circuits. All bulbs are identical. Explain your reasoning.



SPH4C: Resistance and Ohm's Law

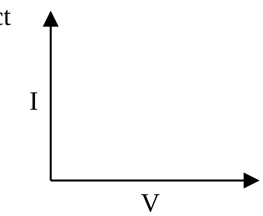
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

We have explored the effects of a potential difference on a light bulb – current flows and the bulb lights up. But we have not yet answered one key question: for a given bulb or element of a circuit, *how much* current will flow due to a potential difference? It is time to answer this question.

A: Current through a Resistor

A resistor is a special circuit element (often made from metal or carbon) that has the same resistance value no matter how much current flows through it. We change the potential difference across our resistor and measure the amount of current that flows through.

1. A single resistor is connected to a single battery. As we increase the voltage of the battery, predict what will happen to the current flowing through the resistor. Explain. Sketch a graph of your predicted relationship.

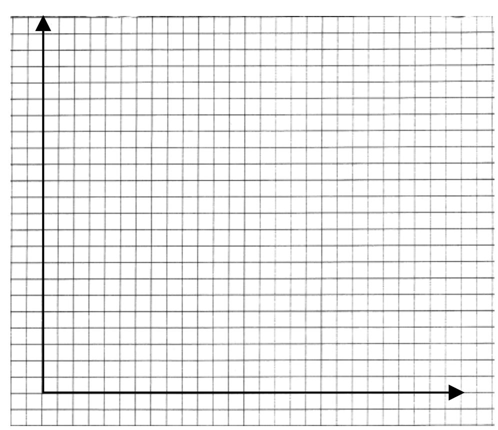


2. Construct a circuit to test your prediction. You can either adjust the voltage of the battery or connect more batteries in series. Set up a voltmeter to measure the voltage drop across the resistor and an ammeter to measure the current through the resistor. Sketch your circuit below. Record your data in the table.

   Note that the symbol for a resistor is: 

Number of Batteries	*I* (amps)	Δ*V* (volts)
0		
1		
2		
3		
4		

3. Graph your results with the **current on the horizontal axis**. Calculate the slope including units. What is the significance of the slope of the graph?



4. Aside from the change in axes, how does the shape of your graph compare with your predictions?

The resistance of a circuit element is defined as $R = \Delta V/I$, where ΔV is the potential difference across the element and I is the current flowing through it. When the potential difference is measured in volts and the current in amperes, the unit of resistance is the *ohm* (Ω, the greek letter 'omega'). One amp of current flowing through an element with a 1 ohm resistance will lose 1 J of energy.

5. Based on your graph, what can you say about the value R for a resistor – is it constant, or does it change as the current flowing through it changes?

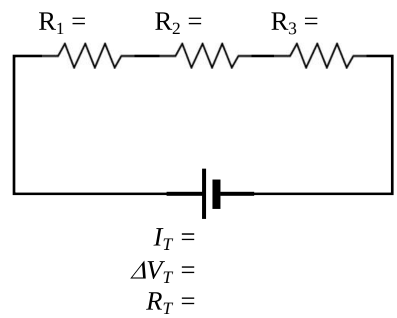
When a circuit element, like the resistor, has the same resistance over a wide range of conditions, it is called *ohmic*. This is because it obeys *Ohm's law*, $\Delta V = IR$. Ohm's law shows that the current I flowing through an element in a circuit is proportional to ΔV.

B: Resistors in Series

1. Imagine we connect three **different** resistors in series. What do you think the total, or *equivalent resistance* to the flow of electrical current of the three resistors will be equal to? Explain using your previous observations with bulbs and batteries.

2. Construct the circuit shown to the right. Label the three resistors with their values (right click to change resistances).

3. Describe the method you are using to predict the equivalent resistance (use the symbols R_1, R_2 and R_3) and then calculate the value.



Predicted R_{eq} = ___________ Ω

4. Measure the voltage across the battery and current through the battery. Record these measurements below the symbol for the battery.

5. Since we know the current and voltage for the battery, we can use Ohm's Law to calculate the total resistance the battery experiences due to the three resistors. Show your work.

Note that the total resistance means the total resistance of the circuit the battery is connected to and **not** the resistance of the battery.

6. How does the total resistance experienced by the battery compare with your prediction for the equivalent resistance of the three resistors?

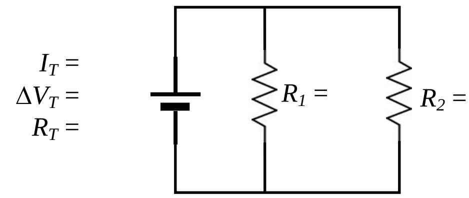
7. On the basis of your experimental results, devise a general mathematical equation that describes the equivalent resistance when n different resistors are wired in series. Use the notation R_{eq} and $R_1, R_2, \ldots R_n$ in your equation.

C: Resistors in Parallel

1. Imagine we connect two identical resistors in parallel. Would the total resistance be greater than, less than or the same as a single resistor? Explain.

2. Choose two identical resistors. Predict what you think the total resistance of the two will be when wired in parallel. Explain your prediction. If you are not sure, make a guess and move on.

3. Construct the circuit shown to the right. Label the two resistors with their values. Measure the voltage across the battery and current through the battery. Record these measurements beside the symbol for the battery.



4. Since we know the current and voltage for the battery, we can use Ohm's Law to calculate the total resistance the battery experiences due to the two resistors. Show your work.

5. How does the total resistance experienced by the battery compare with your prediction for the equivalent resistance of the two resistors?

The equivalent resistance of a group of resistors connected in parallel is given by the expression: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

When connecting resistors in parallel, *the equivalent resistance decreases*.

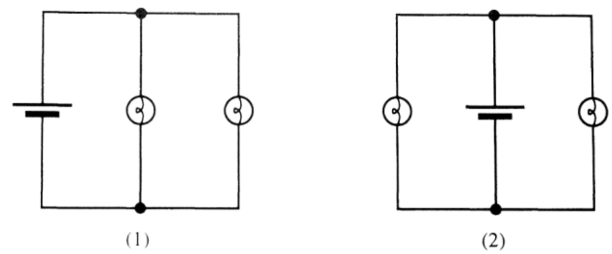
Adapted from *Workshop Physics Activity Guide: 4 – Electricity and Magnetism,* Laws, John Wiley & Sons, 2004

Homework: Electrical Connections

An important skill for understanding electrical circuits is being able to recognize when two circuits that are drawn differently actually function in the same way.

1. Consider the following dispute between two students. Which student is correct? Who you agree with. Why?

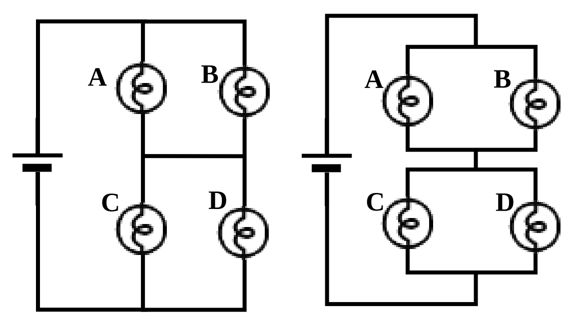
   Student 1: "*Circuit 1 and circuit 2 are different circuits. In circuit 2 the bulbs are the same distance from the battery, but in circuit 1 one bulb is closer to the battery. So the brightness of the bulbs could be different in the two circuits*."

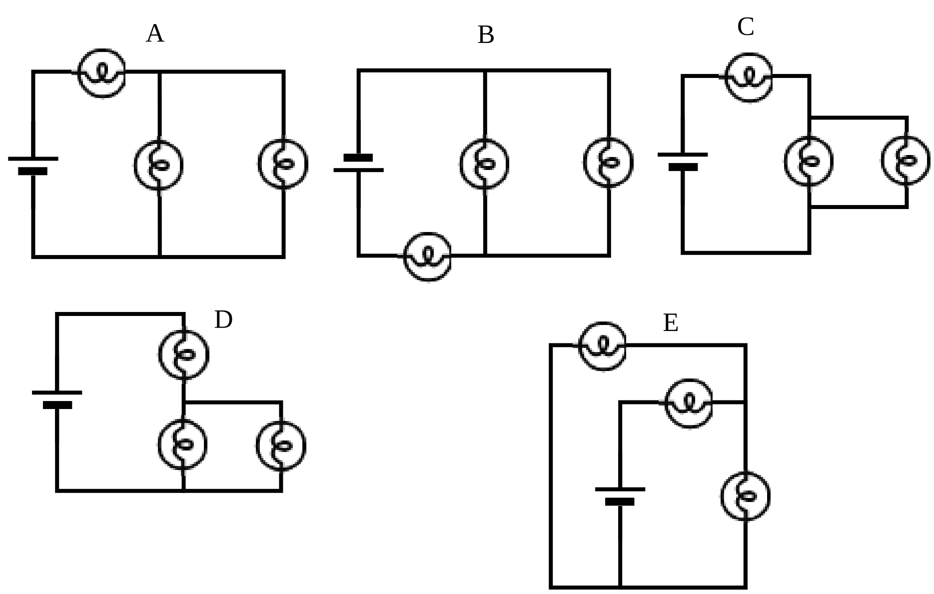
   Student 2: "*Circuit diagrams don't show physical layout, only electrical connections. In each diagram, the electrical connections are the same. There is a direct path from the positive battery terminal to each bulb. And each bulb is then connected directly to the negative battery terminal. So the brightness of the bulbs will be the same in each circuit. Both diagrams represent the same circuit*."

We can decide whether circuits are equivalent by following the paths from one circuit element to another and check whether the same connections are present.

2. Are the two circuits shown to the right equivalent? Explain.



3. Which circuits below are equivalent?



SPH4C: Circuit Decomposition

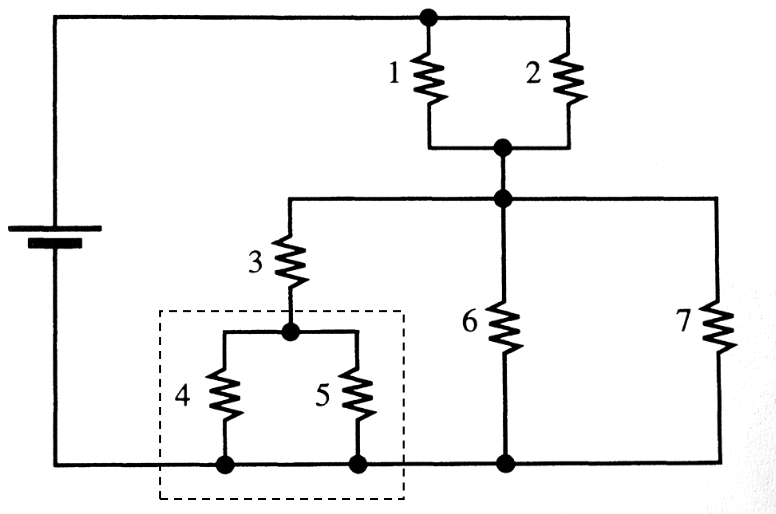
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

The electrical circuits found in most electronic devices consist of many different elements combined in combinations of series and parallel *networks*. A network is just a part of a larger circuit and does not necessarily form a complete loop or closed circuit. We can analyze complicated circuits by identifying smaller parts or networks whose parts are connected strictly in series or parallel and *decompose* the complex circuit into simpler parts.

A: Find the Networks

Here is a complex circuit! It contains one 9.0 V battery and seven identical 100 Ω resistors. To find the equivalent resistance of all seven resistors we must proceed in steps:

- Identify a network of two or more resistors that are connected strictly in series or parallel
- Find the equivalent resistance of the network
- Replace the network by a single resistor of that value
- Repeat the process until there is only one resistor left



1. Examine the circuit. Are there any resistors connected in series?

2. Are there any resistors connected in parallel?

It is usually best to start with elements deepest in the circuit and work outwards. Resistors 4 and 5 are an example of two connected in parallel.

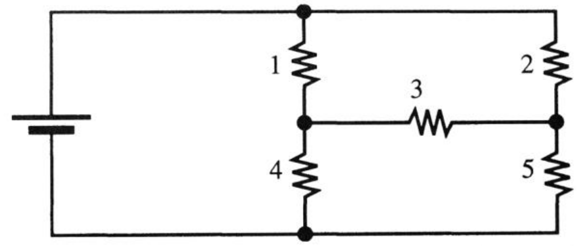
3. Draw a box around the network of resistors 4 and 5. Determine the equivalent resistance of this network. Use the symbol R_{45} for their equivalent resistance. Show your work here.

4. Write R_{45} = 50 Ω next to the box. You should now think of that box as a single resistor with a resistance of 50 Ω.

5. Continue this process. Your boxes will become larger and larger (draw them neatly so things don't get too messy!) Show all your calculation below. Be sure to label the equivalent resistance of each box.

6. What is the total resistance the battery will experience? Calculate the current flowing through the battery. Show your work.
7.

Consider the discussion about the circuit shown to the right.

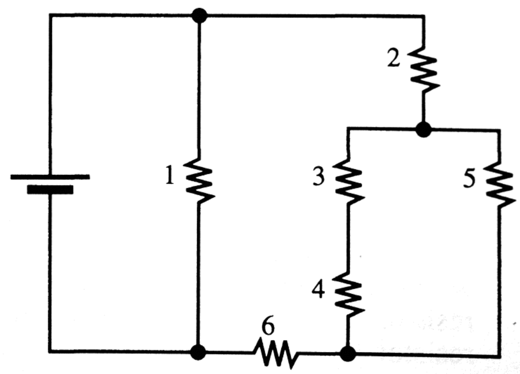


Student 1 says: "*I can't decompose this circuit in to series and parallel parts.*"

Student 2 says: "*You have to take it step by step. 1 and 2 are in parallel. Let's call that A. 4 and 5 are in parallel. Let's call that B. Then A and 3 and B are one after another in series.*"

Student 2 is not correct. Describe the errors that student 2 has made.

8. Find the equivalent resistance of the circuit to the right. Each resistor has a resistance of 30 Ω. Show your work.



9. Is the circuit above basically a series circuit or a parallel circuit?

10. Suppose the resistance of resistor 5 is increased. Explain in detail, but without numbers:
   (d) what happens to the current through resistor 1?

   (e) what happens to the current through the battery?

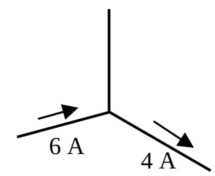
SPH4C: Kirchhoff's Laws

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

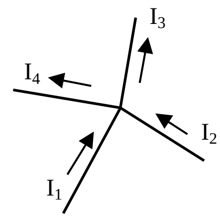
Throughout this unit, we have been developing a set of rules which help us understand what happens to voltage and current in more complicated circuits. Today we put all this together in the form of two powerful laws.

A: Kirchhoff's Current Law – The Junction Law

1. Consider the diagram of a junction to the right. 6 amps of current flows into the junction and 4 amps flows out of the junction along one path. Explain how much current flows through the third path and in what direction.



2. The diagram to the right shows another junction. In terms of the quantities I_1, I_2, I_3 and I_4, how much current is travelling *into* the junction? How much is travelling *out* of the junction?



3. How should the total current travelling into the junction compare with the total current travelling out of the junction? Why?

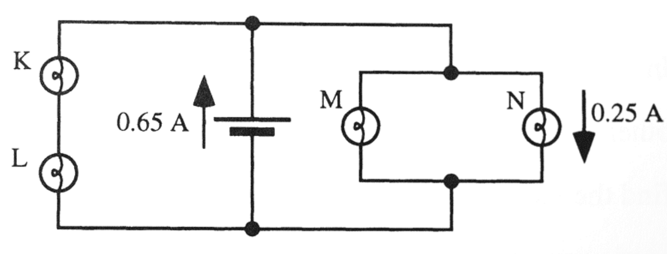
4. Write an algebraic equation that describes how the currents into and out of the junction are related.

The total current flowing out of a junction is equal to the total current flowing into a junction. This is known as *Kirchhoff's Junction or Current Law*. It is an expression of the idea of the conservation of charge – charge at any point in a closed circuit can't be gained or lost. This means that the total number of amperes flowing into a junction must equal the total number of amperes flowing out.

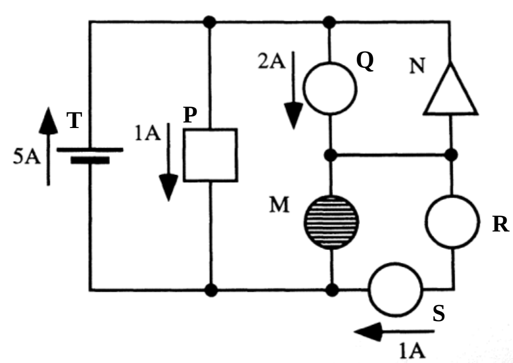
B: Using the Current Law

To use the current law, choose a point in the circuit as your junction. Make a guess for the direction of the current along each path connecting to the junction. Write out an algebraic equation for the current going into and out of the junction.

1. The diagram to the right shows a more complicated circuit with four *identical* bulbs. Determine the amount of current flowing through each bulb. Use symbols like I_K to represent the current flowing through bulb K.

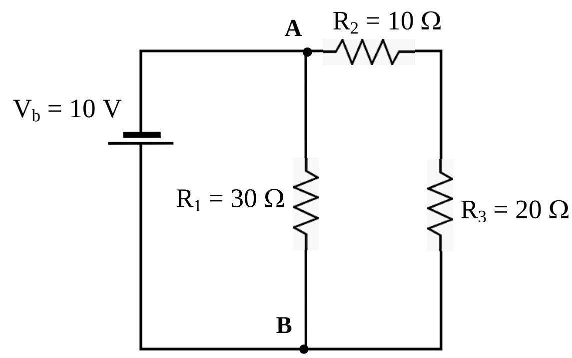


2. The circuit to the right consists of a variety of different circuit elements, represented by the various shapes. Find the current through elements M and N.



C: Kirchhoff's Voltage Law – The Loop Law

The circuit shown to the right consists of three resistors and a 10 V battery.



1. Use two colours to draw two different loops in the circuit that both pass through the battery.

2. Consider the loop that contains resistor 2 and 3. Which elements in this loop will the current pass through and gain energy? In which will they lose energy? In which will they lose the most? Explain.

3. Write an equation using the symbols V_b, V_2 and V_3 that relates the total voltage rise with total voltage drop in the loop.

4. Write a similar equation for the other loop of the circuit.

5. Build the circuit and measure the voltages of each resistor. Record these values on the diagram. Verify whether the two voltage equations you created in the previous questions hold true.

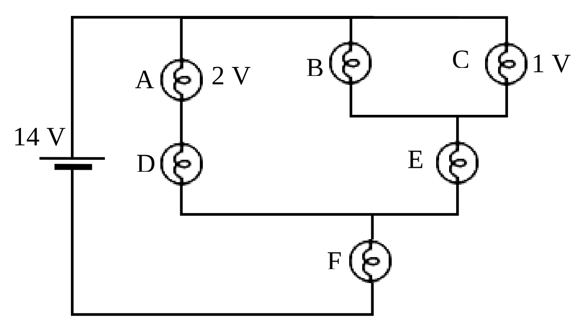
In any loop of a circuit, the total voltage rise equals the total voltage drop. This is known as *Kirchhoff's Voltage or Loop Law*. It is an expression of the law of conservation of energy in an electric circuit – any energy gained by the charges through the source is lost through the other elements of the circuit. For simplicity, we choose loops that contain the source, but this is not necessary.

6. There are two paths in the circuit between junction points A and B. Compare the total voltage drop along each path.

An alternative way of using the loop law is to notice that the sum of the voltages along any path is the same for all paths between two points.

7. We did not predict the voltages of R_1 and R_2, we simply measured them. If we didn't have these readings, how could we predict these individual voltages? One way is to use Kirchoff's current law to find the current through those resisters and then use Ohm's law to calculation the voltages. Can you think of a second way?

8. The circuit to the right contains six **identical** light bulbs. Find the voltage of all the bulbs. For certain bulbs it is easier to use the path trick mentioned above, for others analyze the whole loop. Show your work carefully by writing down the algebraic equations.



Adapted from *Physics by Inquiry,* McDermott and PEG U. Wash, © John Wiley and Sons, *1996*

SPH4C: Circuit Analysis

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

We have developed a complete set of tool to help us analyze simple electric circuits. In this investigation, you will learn how to apply all of them to completely analyze an electric circuit.

A: Your Toolbox – Rules for Electric Circuits

Summarize the tools that you will use to analyze a circuit. For each situation listed below, describe the rule or "tool" you would use to analyze that situation and include a simple equation as an example.

1. The total resistance of elements connected in series:

2. The total resistance of elements connected in parallel:

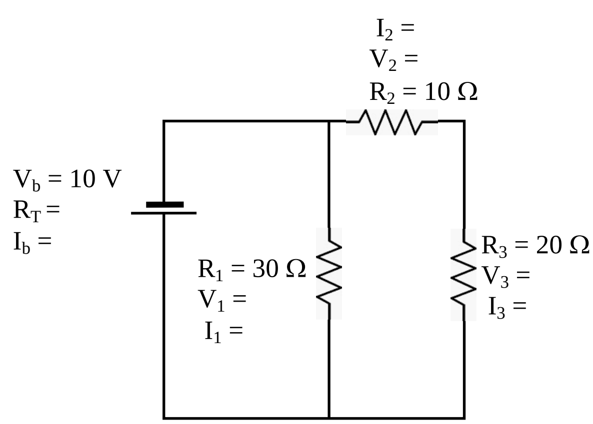
3. Current flowing in and out of a junction:

4. Voltage rise or drops along a circuit loop :

5. Relationship between current, voltage and resistance for a single element:

B: Circuit Analysis – A Walk Through

Let's walk through one example together which is a circuit we have studied earlier. There are two good habits we would like to cultivate: (1) record the results of your calculations along side the circuit element, and (2) carefully show your logic using algebraic equations.



1. Examine the information you are given. Since we know the resistances, we can find the total resistance of the entire circuit ($R_T = R_{123}$). Find this now.

2. When we know two quantities about a circuit element, we can always find the third using Ohm's Law. Try this.

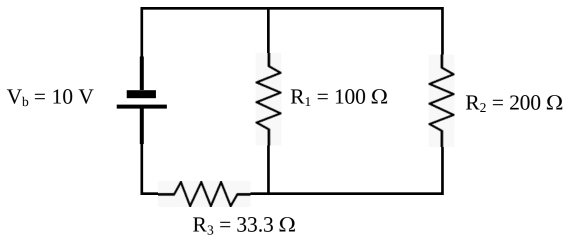
3. The current divides after leaving the battery. We don't want to guess how much goes along each branch of the circuit – we want to calculate this. We can if we know the voltage of R_1. Use the voltage law to find V_1 and the find I_1.

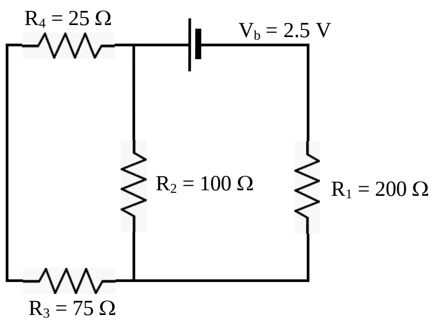
4. Use the current law to find I_2 and I_3.

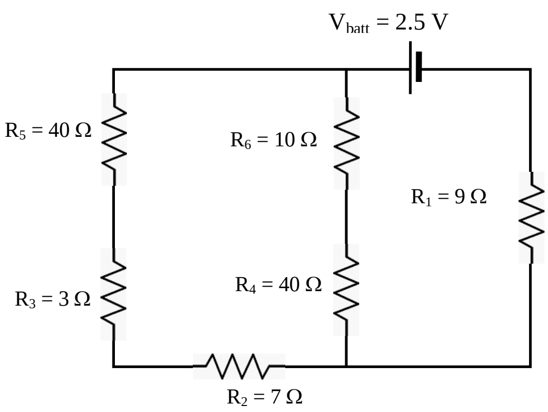
5. Calculate the voltages V_2 and V_3.

C: Circuit Analysis

Now it's your turn! Completely analyze each circuit by finding the current, voltage and resistance for every element. Always show your work.







Super Challenge Problem: A 3 amp current enters the resistor cube through wire A shown to the right. What is the equivalent resistance of the cube? What is the voltage drop across each 1 Ω resistor?