Physics 7B

DLM 13 Overview

Model/Approach: Energy Density Model

AC-6.2.3 Applying the Transport Equation to an Electric Circuit (~ 35 min)

Learning Goals:

- Develop understanding of electric circuits by analogy to fluid circuits.
- Understand the transport equation as applied to electric circuits.

Act-6.2.4 Making Sense of Simple Circuits (~ 70 min)

Learning Goals:

- Practice applying the electric transport equation to simple electric circuits.
- Deepen understanding of the meaning of complete circuits.
- Develop understanding of how V, I, and R "work" when there is more than one simple loop.
- Develop understanding of relative currents in battery and bulb circuits in terms of the basic ideas of conservation of charge and energy conservation expressed in terms of the transport equation ($\Delta V = \mathcal{E} - IR$).
- Deepen awareness of one's own way of approach to making sense of simple circuits and how this approach is or is not consistent with the energy-density model
- Practice changing unproductive thinking patterns to ones that are more productive

AC6.2.5 Parallel and Series Resistors (~ 35 min)

Learning Goals:

- Same as in 6.4.2, and in addition
- Making use of $\Delta V = \mathcal{E} - IR$ to verify the formulas for series and parallel resistors.
- Getting deeper understanding of resistors and batteries in series and in parallel.
- Getting practice reducing multiple resistor circuits to a single battery and resistor.

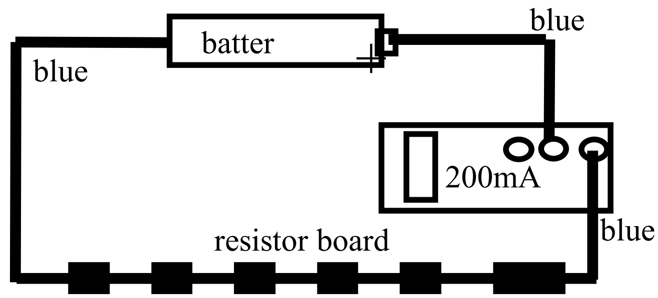
Announcements

- **Reading Assignment** - Read Summary and Review pages 130-132 and finish reading Unit 6.

- You should be use the resources on the web page to improve your understanding of the course materials, in particular playing with the circuits applet will help with this unit's concepts and solving the very many practice problems will prepare you for the exams and the final.

Applying the Transport Equation to an Electric Circuit

Your Job: Determine the Resistances



(1) Add labeled points to the diagram and apply the transport equation (with subscripts showing the points where you start and stop) from one end of the entire set of electrical resistances you used in the previous activity to the other end.

(2) **Measure** the voltage drops across each resistor and record these ΔV's using the points you have labeled on the diagram as subscripts. Also, **measure** and record the voltage drop across the entire "string" of resistors. Record the current in the circuit.

(3) **Calculate** the value of the resistance of each resistor using the transport equation (with terms applicable for the section between the appropriate points) and the measured values of voltage drops and current. **Show some of your work on the board, but leave room for (5) and (6) below.**

(4) Calculate the value of the total resistance of the string of resistors using the transport equation and your measured value of the voltage drop across the entire string of resistors and current.

(5) What is the relation of the **measured voltage drop** across the entire string of resistors to the separate voltage drops? What is the relation of the **measured resistance** of the entire string of resistors (in series) to the separate resistances?

(6) Develop a logical explanation for the relationships you found in the measured quantities in (5) using the transport equation. **Put your responses to (5) and (6) on the board.**

Your Job: Apply the Transport Equation around the entire circuit

(1) Pick a point at the negative end of the battery. Moving in a direction that starts out by going through the battery, write down each term in the transport equation all the way around the circuit back to your starting point. Do this first in symbols and then with numbers (re-measure the voltage drops across each element in the circuit if you need to). For example, in symbols, you would first come to the battery (or power supply, and would write $\mathcal{E}$ for the emf of the battery or voltage source)

(2) When you go completely around the circuit, what does conservation of energy applied to charge density tell you the sum of all the terms must be equal to? Why?

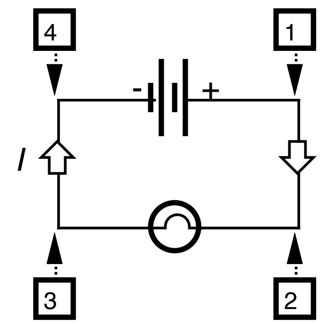
(3) Do the measured sums of voltage drops agree with your conclusion in (2)? Do the algebraic signs work? Show these steps on the board.

(4) Make a "schematic drawing" of this circuit using the symbols for a battery and resistor used in the Course Notes and showing a voltmeter as a circle with a "V" inside and an ammeter as a small circle with an "A" inside. Remember, ammeters are "in series" in the circuit and voltmeters are wired "across" a particular element.

Be prepared to share your responses to these last questions with the entire class.

Making Sense of Simple Circuits

A) Use the Transport Model



1) Consider the electrical circuit at right, with an ideal battery with emf $\mathcal{E}$ and a light bulb of fixed resistance *R*, connected by wires of negligible resistance. Use the appropriate form of the transport equation to answer (explain and justify) the following questions. Keep your answers in terms of the two variables, $\mathcal{E}$ and R (no numbers).

(a) What are the currents at points [1], [2], [3], and [4]?.

(b) Determine the voltages ☐, ☐, ☐, ☐ with respect to the voltage at point [4]

(c) Now determine the voltages with respect to the voltage at point [1].

2) For this same electrical circuit consider that the battery has an $\mathcal{E}$ of 6 volts, and the light bulb has a resistance $R = 4.0\ \Omega$. Use the appropriate form of the transport equation to answer (explain and justify) the following questions.

(a) Calculate the current in this circuit.

(b) What is the voltage across the light bulb?

(c) What algebraic expression gives the power output of the battery? Use this expression to calculate the power output of the battery.

(d) What algebraic expressions give the power converted to thermal energy in the light bulb? You should be able to list three.

(e) Calculate the power "dissipated" in the light bulb using each of the three expressions.

(FNTs from previous DL)

In Your Small Group:

B) Get Agreement on the Brightness Outcomes

1) Draw a small neat circuit schematic diagram on the board for each circuit shown in the DLM-12 FNT. Use the symbols VB, B, S, D, VD, and NL to indicate the brightness of each bulb in each circuit. "S" stands for standard brightness, which is the brightness of the bulb in circuit #2. The other symbols stand for
   - VB ⇒ very bright
   - B ⇒ bright"
   - D ⇒ dim
   - VD ⇒ very dim
   - NL ⇒ not lit at all (make sure it really is not lit, rather than just being very very dim)
2) Check out any circuits you are not sure about within your group. Make sure you perform a BRIGHTNESS CHECK with the bulbs you are using. A BRIGHTNESS CHECK consists of wiring all three bulbs you are using across one battery at the same time. This checks that all three bulbs are working and that all bulbs are of the same kind. Bulbs from different strings of lights can have different brightness. We want them to be identical bulbs in this activity.
3) Compare your responses to others' responses by looking at what they have on their board. If you find differences, go back to (2), and if differences still persist, perform (2) ***with*** the group you disagree with.
4) When you get all your group's responses up on the board, help out other groups who are having difficulty. Also, try to come up with additional arrangements of three bulbs and two batteries that are different from the ones shown in the FNT and put the diagram and brightness on the board.

C) Making Sense of the Brightness (current through each bulb)

1) For circuits 1-10 (not 11 yet) in the FNT use the steady-state energy density equation, $\Delta V = \mathcal{E} - IR$, to **find the current through each bulb in each circuit** in terms of the symbols $\mathcal{E}$ and R. If there is a complete loop, take ΔV to be around the entire loop, i.e., the two points are the same. If there is not a complete loop, take the two points to be at the ends. If the current is zero, explain why it is zero. Do these on paper with your group. In some cases you will also have to use the idea of continuity.
2) Put your results for the currents on the board on each circuit.
3) Be prepared to share how you determined each current with the whole class.

D) Thinking about why this is or is not hard

1) Discuss in your group which of these circuits gave you the most difficulty. Try to figure out why they were difficult. Think specifically about what you were thinking that kept you from making progress. Were there things you didn't know, or were there things you misunderstood?
2) Discuss in your group what steps you should take when trying to make sense of an electrical phenomenon you have not seen before. Make a list of these steps. Put it on the board
3) Be prepared to share with the whole class.

Series and Parallel Resistors

A) Series and Parallel Resistors

1) Redraw circuits 10 and 11 from the previous activity **on the board, in diagram form**.
   a) Identify exactly which resistors are wired in parallel and which are in series in each circuit. (Note: consider combinations of resistors, as well as single resistors, that might be in parallel or series with another resistor.)

   b) Clearly indicate the parallel and series combinations on your diagram.

   c) For each circuit (10 and 11), compare currents in the parallel parts of the circuit. Using the transport equation, explain why the currents are equal or why one is greater than the other.

For questions 2-7 below, you do not need to put your answers on the board, but every member of your group should be prepared to explain the answers if called upon.

2) What electrical quantity is always the same for two resistors wired in **series**? Explain using the transport equation and/or charge conservation.

3) What electrical quantity is always the same for two resistors wired in **parallel**? Explain.

For questions (4) and (5), refer to the diagrams and formulas for series and parallel resistors on page 71 of the Block 6 Notes.

4) What must be true about the individual IR drops across R_1 and R_2 in the series circuit compared to the IR drop across the equivalent series resistor, R_S? Explain.

5) What must be true about the individual currents in the resistors R_1 and R_2 in the parallel circuit compared to the current in the equivalent parallel resistor, R_P? Explain.

6) When will the current in one of a pair of parallel resistors be very small? Explain.

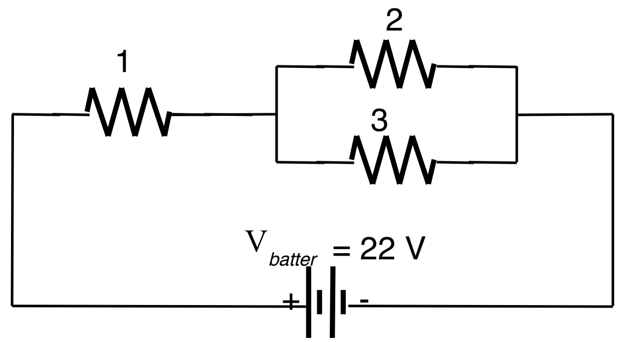
7) When will the current in one of a pair of parallel resistors be very large? Explain? Does the value of the other resistor have a significant effect on the large current (try substituting numbers into the formula for finding the equivalent parallel resistor)? This is situation is often referred to as a "short circuit."

B) Finding Equivalent Resistances

8) Assume all the bulbs in the FNT circuits had the same resistance, R. Find the equivalent resistance of circuits 5, 6, 7, 9, 10, and 11, expressed in terms of R. **Put your answers on the board.**

FNTs:

1) Find the equivalent resistance of all the resistors in this circuit and then determine the current in the battery and the rate at which the battery delivers energy. Let $R_1 = 20\ \Omega$, $R_2 = 30\ \Omega$, and $R_3 = 10\ \Omega$. Find the voltage drop across each resistor and the current in each resistor.



2) What would the voltages across each of the resistors in the preceding circuit be if a wire were placed across the ends of resistor 3 (that is, resistor 3 is shorted out)? Does placing the wire across resistor 3 also short out resistor 2? Explain using the steady-state energy-density model.

3) Look for the power rating on an appliance not listed in the table in the notes. What is the power in watts? What current does this appliance "draw" if the AC voltage applied to is 120 Volts?

4) Consider a 60 Watt light bulb plugged into a 120 Volt socket, and a 100 Watt light bulb plugged into another 120 Volt socket. Recall that a bulb's brightness is related to the amount of power (in Watts) that is dissipated as heat and light.
(a) Which light bulb has the greater current?
(b) Which light bulb filament has more resistance?
(c) If these light bulbs were connected together in ***series*** into the ***same*** 120 Volt outlet, which light bulb will be brighter? Use the model to explain.

5) What ***physical*** property of the bulb determines the wattage rating on an ordinary "old fashioned" incandescent light bulb you buy in the store (the kind that gets too hot to touch)?

6) What energy systems increase in energy in the incandescent bulbs discussed in the previous FNT?

7) Why do small appliances rated for use in a 120 V circuit (the kind we have here in the US) burn out if plugged into an outlet in England or other European country where the voltage of the household outlets is typically 240 V? Explain.