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Chapter 9: Current and Resistance

Background/Summary:

In this unit, we will delve into non-static situations in which charges are induced by a conductor to move as part of an electric current due to an electric potential.

Major Topics, Vocabulary, and Formulae:

1. Electric Current

   Electric current (I) refers to the rate at which charges move with respect to time. We can find the average current and the instantaneous current using the following formulae:

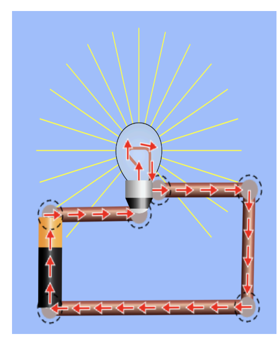
   $$I_{average} = \frac{\Delta\, charge}{\Delta\, time} = \frac{\Delta Q}{\Delta\, t} \quad [Amperes] = \frac{[Coulombs]}{[seconds]}$$

   $$I_{instantaneous} = \frac{dQ}{dt}$$ aka the time derivative of charge

   These charges move because an electric force acts on the charges. We can calculate this force by using the following formula:

   $$Force = qE \qquad [Newtons] = [Coulomb * \frac{Newtons}{Coulomb}]$$

   We measure conventional current, meaning we are tracking the movement of positive charges. However, as we learned in previous units, protons do not actually move, but electrons do, generating a current (it is an American quirk to track conventional current). You can see this current using the Phet Simulation. In the example on the right, the current moves from the (+) end of the battery, with the current causing the lightbulb to light, to the (-) end of the battery.

2. Resistivity and Resistance

   Resistivity (ρ): An inherent quality that varies depending on the material, referring to the ease at which electrons flow through that material; this value is determined experimentally. Although we don't see this equation often, the following is the equation for material resistance based on resistivity (ρ) to current, the material's length (L), and the conductor's cross-sectional area (A).

   $$Resistance\ (R) = resistivity * \frac{length}{cross\ sectional\ area} = \rho \frac{A}{L}$$

$$[Olms\ or\ \Omega\ =\ [olms/meter\ *\ \frac{meter}{meter^2}]$$

Resistance (R): In contrast to the electric field and force pushing charges, there is a resistance (R) to the movement of those charges. We measure this value in terms of ohms (Ω).

Potential difference (V): Potential difference refers to a difference in the electric potential of two points. We measure this value in terms of volts (V).

3. Ohm's Law

We can use Ohm's Law, which is a very important formula and recurring concept in this course, to relate current, resistance, and potential difference. Ohm's Law is as follows:

$$Current\ (I)\ =\ \frac{potential\ difference}{resistance}\ =\ \frac{V}{R} \qquad [Amps]\ =\ \frac{[Volts]}{[Ohms]}$$

Technically, only Ohmic conductors follow this law, but, in this course, we only focus on Ohmic conductors.

4. Resistor Codes

Resistors provide resistance to current flow, making them an essential component of a circuit. Each resistor has it's resistance marked by a "resistor code," which is a series of colored stripes. The 1st strip indicates the 1st digit of resistance, the 2nd band the 2nd digit, the 3rd band the exponent, and the fourth band the tolerance (aka the range within which the resistance is). Following are the colors and their corresponding digits.

Color	Number	Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	+/- 2%
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	

Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^-1	+/- 5%
Silver		10^-2	+/- 10%
No color			+/- 20%

The example above would have a resistance of $10*10^2$ with a tolerance of +/- 5%

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5. Electric Energy and Power

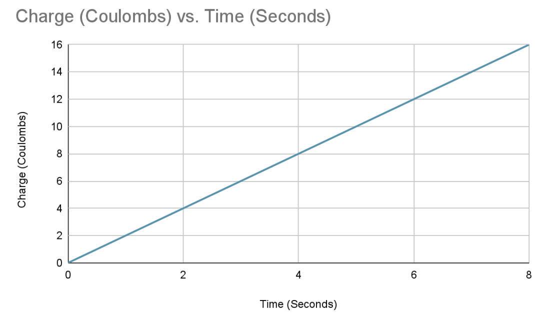
Power: Power is the energy required to move a charge from one point to another. This value uses the unit "Watts" or "W." We can calculate this value with many different formulae (which we obtain by substituting differnet forms of Ohm's Law):

$$Power\ =\ current\ *\ potential\ difference\ =\ IV \qquad [Watt]\ =\ [Amps][Volts]$$
$$Power\ =\ current^2\ *\ resistance\ =\ I^2R \qquad [Watt]\ =\ [Amps]^2[Ohms]$$
$$Power\ =\ potential\ difference^2/\ resistance\ =\ V^2/R \qquad [Watt]\ =\ [Volts]^2/[Ohms]$$

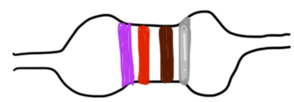
Example Problems/FRQs

1. A lightbulb has a resistance of 6.0 Ω and is connected to a 3.6-volt battery.
    a. Draw a circuit with the stated values/measurements marked
    b. Find the current running through the lightbulb
    c. Find the power dissipated by the lightbulb

2. To the right is a graph of charge vs. time of a circuit with a 2 Ω resistor
    a. Find the equation of the graph above
    b. Find the average current through the circuit from time t = 2 to time t = 6
    c. Find the instantaneous current at time t = 2.



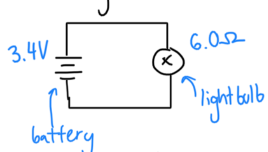
3. Using the resistor image shown to the right, determine the resistance of the resistor. Using this resistance, find the maximum and minimum power dissipated by the resistor if it is in a circuit with a 12 volt battery.



Example Problems/FRQ Answers (Part I)

Problem 1 Solutions:

a) Drawing the circuit:



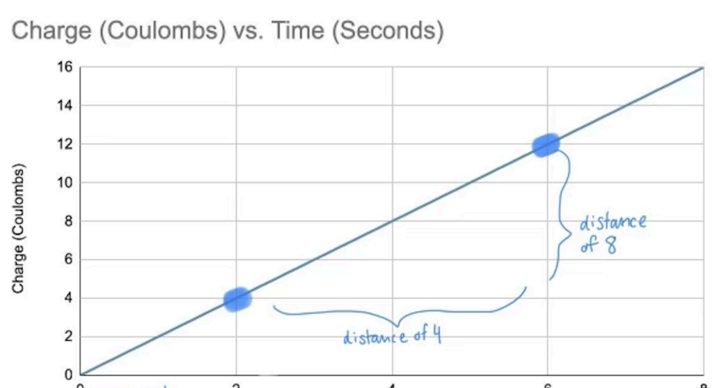
≡ indicates a battery
⊗ indicates a lightbulb
-WW- indicates a resistor

b) Solving for I
→ Using Ohm's Law
$I = \frac{V}{R} = \frac{3.6}{6.0} = \boxed{0.60A}$

c) Solving for P
→ Using $P = I^2R$
$P = I^2R = (0.6)^2(6.0) = \boxed{2.2W}$

Problem 2 Solutions:

a)



$y = mx + b$
$Q = \left(\frac{12-4}{6-2}\right) \cdot 0 = \boxed{2t}$

Use the slope of the line and the 0 ymax to find the equation for the graph

Example Problems/FRQ Answers (Part II)

Problem 2 Solutions (continued):

b) Finding current$_{avg.}$ from $t=2$ to $t=6$

$I = \frac{dq}{dt}$ → using the equation $Q=2t$, whose derivative is 2

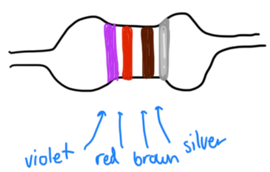
$\boxed{I_{avg.} = 2A}$ → the range doesn't really matter for this problem because the equation is linear and the $\frac{dq}{dt}$ is a constant.

c) $I_{instantaneous}$

↳ Slope @ $t=2$ → same as previous answer for reasons stated above.

so, $\boxed{I_{instantaneous} = 2A}$

Problem 3 Solutions:



$7 \quad 2 \times 10^1 \quad \pm 10\%$

$R = 72\Omega \pm 10\%$ → R_{max} $72 \times 1.1 = 79.2\Omega$; R_{min}: $72 \times 0.9 = 64.8\Omega$

$V = 12V$

→ Using $P = \frac{V^2}{R}$ (max / min)

$P_{max} = \frac{(79.2)^2}{12}$ $\qquad$ $P_{min} = \frac{(64.8)^2}{12}$

$P_{max} = \boxed{523W}$ $\qquad$ $P_{min} = \boxed{350W}$

For this problem, you take into account the tolerance to find the maximum and the minimum resistance based on the resistor color. You add/subtract 10% of the resistance shown in colors because of the silver marker. Then, using each resistance find the max and min power with the max and min resistances respectively.

Great job! If you are reading this, you completed the full review of Unit 9 of AP Physics C E&M.