Section	Group	Name	Signature
Grade			
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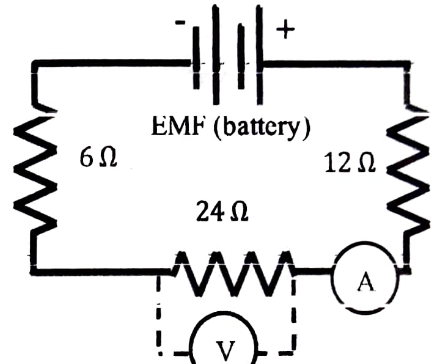
Materials: • PhET Circuit Construction Kit: DC

After this activity you should know: • *Ohm's Law* • *how to determine the meaning of slopes of graphs* • *how resistance depends on geometry and temperature of conductor/resistor* • *definition of current density, conductivity and resistivity* • *ohmic and non-ohmic devices.*



1. Use the PhET simulation PhET Circuit Construction Kit: DC to build the circuit shown. Adjust the resistances to the values shown. Set the battery to 9 volts. Note the copper end is the high voltage side of the battery.
   a. Place the voltmeter to measure the voltage across the 24 Ω resistor. The voltmeter measures the voltage difference $V_{red} - V_{black}$. Make sure you attach the voltmeter so the red lead is at the higher voltage in order to obtain a positive value for the voltmeter reading.
   b. What is the direction of the current through the 24 Ω resistor (left or right)? Remember that the moving blue dots represent electrons.

      Right

   c. Use the non-contact ammeter to check that the current going in and out of the 24 Ω resistor is the same. Check that the current is the same everywhere in this circuit.
   d. Adjust the battery voltage so that the voltage across the 24 Ω resistor is approximately 5V. You won't be able to get this exactly – just get close. Fill in the first column in the table below. Include units on all measurements.
   e. Repeat the measurements for the voltage across the 24 Ω resistor to be approximately 10V, 15V, 20V, 25V and 50V. You don't need to get these voltages exactly, just report the values you measure. Fill in the table below.

Battery Voltage	9V	17.5V	26.5V	35V	44V
Voltage difference across 24 Ω resistor	5.14V	10.V	15.14V	20V	25.14V
Current thru 24 Ω resistor	0.21 A	0.42 A	0.63 A	0.83 A	1.05 A

   f. Input the data from your table into a software package (see instructions on making graphs and fitting data with EXCEL at end of activity) and make a graph of **current** vs. **voltage across the resistor** (<u>current</u> on the <u>vertical</u> axis and voltage across the resistor on the horizontal). Include graph with when you submit your work.
   g. What is value of the slope? Don't forget to include units on the slope.

      $0.0418\cancel{4}\ \frac{A}{V}$

h. For a ohmic material $\Delta V_R = IR$. What is the relation between the I vs. ΔV slope and the resistance R?

- $R = \text{slope}$
- $R = 2^{*}\text{slope}$
- $R = \dfrac{1}{slope}$
- $R = \dfrac{2}{slope}$
- $R = slope^2$

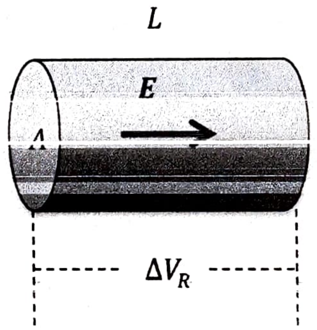
i. Use your measured value of the slope to find the resistance. Show work including the numbers that you used.

$$R = \frac{1}{0.0418} = 23.92\ \Omega$$

2. We want to determine how the resistance of a conductor (or any object) depends on the geometry of the object.

a. The electric field inside a conductor is zero if the conductor is in electrocstatic equilibrium. This is no longer true when there is a current.

A cylinder has conductivity σ, a length L and a cross-sectional area A. The voltage across the ends of the cylinder is ΔV_R. A uniform electric field of magnitude E is directed down the length of the cylinder. Write an expression for E in terms of ΔV_R, L, and/or A. (Take ΔV_R as the absolute value of the voltage difference.)



$$E = \frac{\Delta V}{ds} = \frac{\Delta V}{L}$$

b. The current density J is the current per cross sectional area. The larger the electric field E, the larger the larger the current density. For an ohmic material

$$J = \sigma E = \frac{1}{\rho}\, E$$

where $\rho = 1/\sigma$ is the resistivity. Use your previous result for E to write J in terms of ρ, ΔV_R, L, and/or A.

$$J = \frac{\Delta V}{\rho L}$$

c. Write the current I in terms of ρ, ΔV_R, L and/or A.

$$I = \frac{V}{R} = \cancel{\frac{\Delta V A}{\rho L}} \quad \frac{\Delta V \cdot A}{\rho L}$$

d. Solve for ΔV_R in terms of ρ, I L, and/or A.

$$\Delta V_R = \frac{I \cdot \rho \cdot L}{A}$$

e. Ohm's law is usually written as $\Delta V_R = I\,R$. Use your previous expression to write R in terms of ρ, L and A.

$$R = \frac{V}{I} = \frac{\cancel{\Delta V}\cdot \rho \cdot L}{\cancel{\Delta V}\cdot A} = \frac{\rho \cdot L}{A}$$

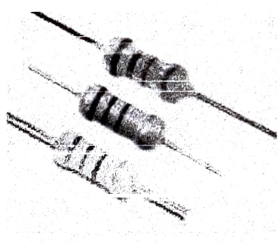
f. The resistivity is a property of the material that the cylinder is made of. Determine the SI unit of resistivity in terms of Ω (ohms), m (meters), s (seconds) and/or C (Coulombs). Show work.

$$\Omega = \frac{\rho \cdot \cancel{m}}{m^{\cancel{2}}} \qquad \rho = \Omega \cdot m$$

g. Determine the SI unit of **resistance** in terms of *J* (Joules), m, s, and/or C. Show work.

$$R = \frac{V}{I} = \frac{V}{A} = \boxed{\frac{J\cdot s}{C^2}} = \frac{kg\, m^2\, s}{s^2\, C^2} =$$

h. A 10 Ω resistor has a length of 0.8 cm and a diameter of 0.5 mm. The resistor is made out carbon doped with impurities. Carbon is a semi-conductor wtih typical resistivities of between $10^{-4}\ \Omega \cdot m$ to $1\ \Omega \cdot m$ depending on doping. What is the impurity doped carbon resistivity? Show work.



$$10 \cdot 0.08 = .8$$

$$10^{-4} - .8 < \rho < 1 - .8 \qquad \boxed{10^{-4} \cdot .8 < \rho < 0.1}$$

i. The resistivity of metals increase with temperature. Four cylindrical wires are made of the same metal. Which wire has the largest resistance?

- ~~the long, fat, hot wire.~~
- the long, thin, cold wire.
- the short, thin, hot wire.
- the long, fat, cold wire
- the short, fat, hot wire
- the short, thin, cold wire
- $\boxed{\text{the long, thin, hot wire}}$
- the short, fat, cold wire
- all resistances are the same.

j. Newton's Laws are always correct (if written in relavistic form) but Ohm's Law is more of a rule of thumb that often works very well. An example of a non-Ohmic device is a incandescent light bulb in which the "resistance" increases rapidly with current. Which graph best represent the current versus voltage difference for a light bulb?