# HW 5

**Due: 11:59pm on Sunday, February 23, 2014**

You will receive no credit for items you complete after the assignment is due. Grading Policy

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## An Introduction to EMF and Circuits

**Learning Goal:**

To understand the concept of electromotive force and internal resistance; to understand the processes in one-loop circuits; to become familiar with the use of the ammeter and voltmeter.

In order for the current in a conductor to exist continuously, the conductor must be part of a loop, that is, a closed path through which the charged particles can move without creating a "build-up." Such build-up, if it occurs, creates its own electric field that cancels out the external electric field, ultimately causing the current to stop.

However, having a loop, or a *closed circuit*, is not enough to maintain the current; there must also be a source of energy. Its necessity is fairly obvious: As charged particles move along the circuit, they lose potential energy. In fact, electrostatic forces always push the particles in the direction that leads to a decrease in potential energy. At some point, each charged particle would reach the location in the circuit where it has the lowest possible potential energy. How can such a particle move toward a point where it would have a higher potential energy?

Such a move requires that nonelectrostatic forces act upon the charged particle, pushing it toward higher potential energy despite the presence of electrostatic forces. In circuits, such forces exist inside a device commonly known as a *battery*. In a circuit, the battery serves as the energy source that keeps the charged particles in continuous motion by increasing their potential energy through the action of some kind of nonelectrostatic force.

The amount of work that the battery does on each coulomb of charge that it "pushes through" is called (inappropriately) the *electromotive force* (pronounced "ee-em-ef" and abbreviated emf or denoted by $\mathcal{E}$). Batteries are often referred to as *sources of emf* (rather than sources of energy, even though they are, fundamentally, sources of energy). The emf of a battery can be calculated using the definition mentioned above: $\mathcal{E} = W/q$. The units of emf are joules per coulomb, that is, volts.

The terminals of a battery are often labeled $+$ and $-$ for "higher potential" and "lower potential," respectively. The potential difference between the terminals is called the *terminal voltage* of the battery. If no current is running through a battery, the terminal voltage is equal to the emf of the battery: $V_{\rm ab} = \mathcal{E}$.

However, if there is a current in the circuit, the terminal voltage is less than the emf because the battery has its own internal resistance (usually labeled $r$). When charge $q$ passes through the battery, the battery does the amount of work $\mathcal{E}q$ on the charge; however, the charge also "loses" the amount of energy equal to $Ir$ ( $I$ is the current through the circuit); therefore, the increase in potential energy is $\mathcal{E}q - qIr$, and the terminal voltage is

$$V_{\rm ab} = \mathcal{E} - Ir.$$

In order to answer the questions that follow, you should first review the meaning of the symbols describing various elements of the circuit, including the ammeter and the voltmeter; you should also know the way the ammeter and the voltmeter must be connected to the rest of the circuit in order to function properly.

Note that the internal resistance is usually indicated as a separate resistor drawn next to the "battery" symbol. It is important to keep in mind that this resistor with resistance $r$ is actually inside the battery.

In all diagrams, $\mathcal{E}$ stands for emf, $r$ for the internal resistance of the battery, and $R$ for the resistance of the external circuit. As usual, we'll assume that the connecting wires have negligible resistance. We will also assume that both the ammeter and the voltmeter are ideal: That is, the ammeter has negligible resistance, and the voltmeter has a very large resistance.

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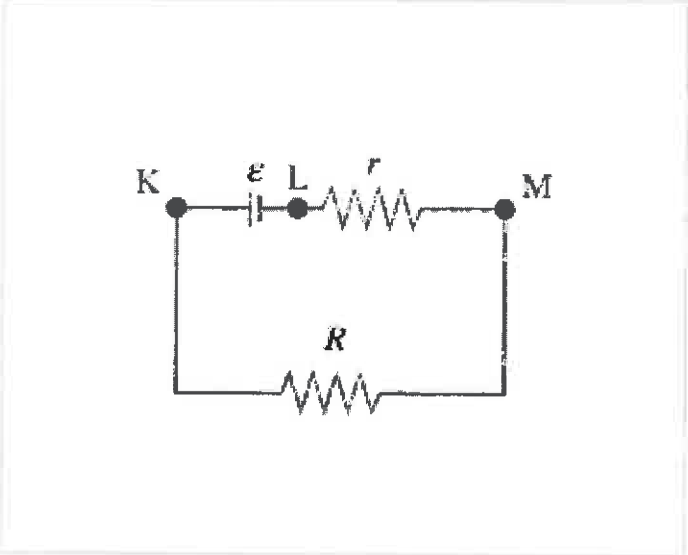
### Part A

For the circuit shown on the left in , which potential difference corresponds to the terminal voltage of the battery?



ANSWER:

- ○ between points K and L
- ○ between points L and M
- ☒ between points K and M

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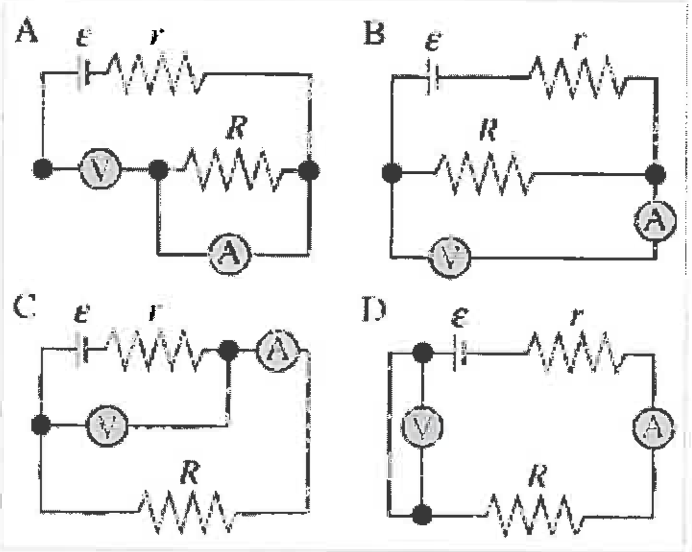
The next several questions refer to the four diagrams on the left in shown here labeled A, B, C, and D.



## Part B

In which diagram(s) (labeled A - D) is the ammeter connected correctly to measure the current through the battery?

**Select the letter(s) corresponding to the correct diagram(s).**

You did not open hints for this part.

ANSWER:

☐ A
☐ B
☒ C
☒ D

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## Part C

In which diagram is the current through the battery nearly zero?

### **Hint 1.** How to approach the problem

In order to determine the current through the battery we must follow the current loop through the circuit. Whichever loop has the highest resistance will have the lowest current. Keep in mind that the voltmeter has a very high internal resistance.

ANSWER:

● A
○ B
○ C
○ D

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## Part D

In which diagram or diagrams does the ammeter correctly measure the current through the resistor with resistance $R$?

**Select the letter(s) corresponding to the correct diagram(s).**

### **Hint 1.** How to approach the problem

Note that current is conserved through a wire, and in order for an ammeter to measure the correct current passing through an element, it must be in series with that element.

ANSWER:

☐ A
☐ B
☒ C
☒ D

## Part E

In which diagram does the voltmeter correctly measure the terminal voltage of the battery? Choose the best answer.

**Hint 1.** How a voltmeter works

A voltmeter works by measuring the voltage of anything to which it is connected in parallel in the circuit. As a result, we would like the voltmeter to have a very internal resistance so that not much current flows through it.

ANSWER:

- ○ A
- ○ B
- ☒ C
- ○ D

## Part F

In which diagram does the voltmeter read almost zero?

**Select the letter(s) corresponding to the correct diagram(s).**

ANSWER:

- ☐ A
- ☐ B
- ☐ C
- ☒ D

## Part G

In which diagram or diagrams does the ammeter read almost zero?

**Select the letter(s) corresponding to the correct diagram(s).**

ANSWER:

- ☒ A
- ☒ B
- ☐ C
- ☐ D

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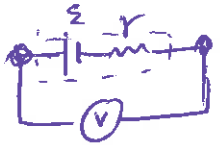
The last group of questions refers to a battery that has emf 12.0 volts and internal resistance 3.00 ohms.

## Part H

A voltmeter is connected to the terminals of the battery; the battery is not connected to any other external circuit elements. What is the reading of the voltmeter $V$?

**Express your answer in volts. Use three significant figures.**

ANSWER:



$V$ = 12 V

no current comes out
much of battery

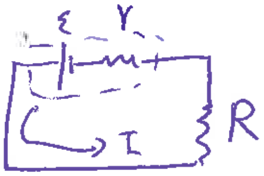
$V = \varepsilon - Ir = \varepsilon$

## Part I

The voltmeter is now removed and a 21.0-ohm resistor is connected to the terminals of the battery. What is the current $I$ through the battery?

**Express your answer in amperes. Use two significant figures.**

ANSWER:



$I$ = 0.5 A

$-IR - Ir + \varepsilon = 0$

$I = \frac{\varepsilon}{R+r} = \frac{12}{24} = 0.5$

## Part J

In the situation described in Part I, what is the current $I$ through the 21.0-ohm resistor?

**Express your answer in amperes. Use two significant figures.**

ANSWER:

$I$ = 0.5 A

## Part K

What is the potential difference $V$ across the 21.0-ohm resistor from Part I?

**Express your answer in volts. Use three significant figures.**

$V_{21\Omega} = I \cdot R$
$= 0.5 \times 21$
$= 10.5$ V

**Hint 1.** How to approach the problem

The best way to find the potential difference $V$ across a resistor $R$ when a current $I$ is flowing is to use Ohm's law:

$$I = \frac{V}{R}.$$

ANSWER:

$V$ = 10.5 V

## Part L

What is the terminal voltage $V$ of the battery connected to the 21.0-ohm resistor from Part I?

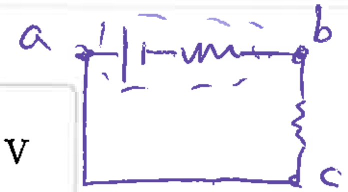
**Express your answer in volts. Use three significant figures.**

**Hint 1.** Kirchhoff's voltage law

Kirchhoff's voltage law states that the voltage difference across all the elements in a circuit (in this case just one resistor) is equal to the voltage at the terminals from the source (in this case a battery).

ANSWER:

$V$ = 10.5 V



$V_{ab} = V_{cb} = 10.5$ V

## Part M

How much work $W$ does the battery connected to the 21.0-ohm resistor perform in one minute?

**Express your answer in joules. Use three significant figures.**

**Hint 1.** How to approach the problem

Find the charge that passes through the battery, and then use the definition of emf.

**Hint 2.** Find the charge

How much charge $q$ passes through the battery in one minute?

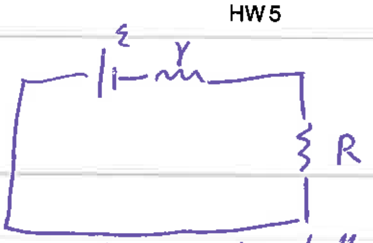
**Express your answer in coulombs. Use three significant figures.**

**Hint 1.** Definition of current

Recall that current is defined as the number of units of charge that pass through a wire per second.

ANSWER:

$q$ = C



ANSWER:

$W$ = 360 J

The work done by battery include work on R and r.
or can be calculated by emf

$P = IV = 0.5 \times 12 = 6$ watt (J/s)

(1 min)

$W = P \cdot t = 6 \times 60 = 360$ J

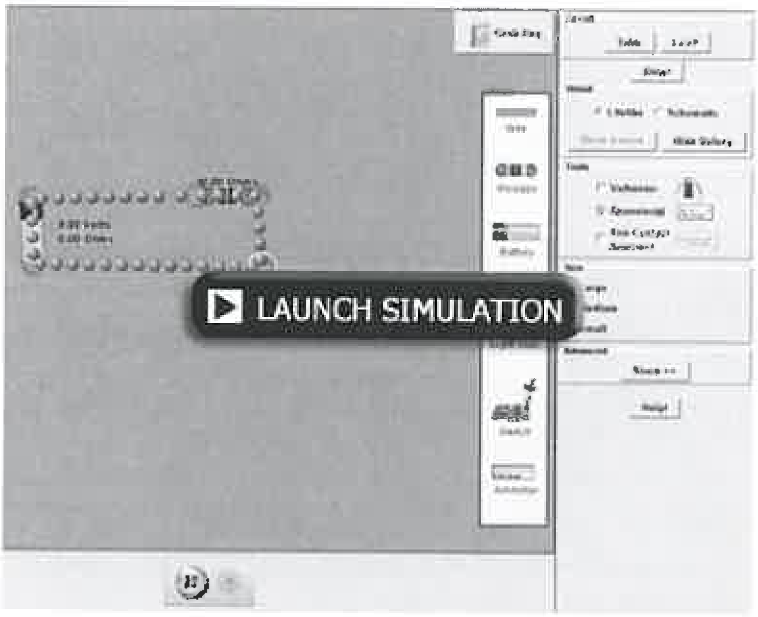
~~$P = I^2R$~~
~~$= (0.5)^2 \times 21$~~
~~$5.25$ watt (J/s)~~
~~for 1 min → 60 s~~
~~$W = P \cdot t = 5.25 \times 60$ =~~

## PhET Tutorial: Circuit Construction Kit – Ohm's Law and Power

**Learning Goal:**

To understand the relationships between voltage, current, resistance, and power for a simple circuit containing one resistor and one battery.

For this tutorial, use the PhET simulation *Circuit Construction Kit (DC Only)*. This simulation allows you to build circuits using wire, resistors, batteries, and other circuit components. The voltage across any two locations on the circuit can be measured using a voltmeter, and the current can be measured using an ammeter. In this tutorial, only direct current (DC) circuits are considered.



Start the simulation. When you click the simulation link, you may be asked whether to run, open, or save the file. Choose to run or open it.
You should see a variety of circuit components (named and pictured) near the right edge of the blue panel. You can click and drag any of these components into the blue panel and construct a circuit. The components can be connected to each other by overlapping the red circles (the junction becomes a brown circle). Each component can be rotated by dragging it by the red circle, and the wire can also be lengthened or shortened this way. To disconnect two components, right-click (or control-click) on the brown circle of the junction and select **Split Junction** in the small menu that appears. To change the resistance of a resistor or the emf of the battery, right-click (or control-click) the component, select the appropriate choice in the pop-up menu, and make the adjustment using the pop-up adjustment panel.

The two tools you will use in this tutorial are the voltmeter and the noncontact ammeter. The voltmeter gives you the voltage (potential difference) between the two locations of the probes. Simply drag the red and black probes and place to each other by overlapping the red circles (the junction becomes a brown circle). Each component can be rotated by dragging it by the red circle, and the wire can also be lengthened or shortened this way. To disconnect two components, right-click (or control-click) on the brown circle of the junction and select **Split Junction** in the small menu that appears. To change the resistance of a resistor or the emf of the battery, right-click (or control-click) the component, select the appropriate choice in the pop-up menu, and make the adjustment using the pop-up adjustment panel.

The two tools you will use in this tutorial are the voltmeter and the noncontact ammeter. The voltmeter gives you the voltage (potential difference) between the two locations of the probes. Simply drag the red and black probes and place the tips at any two locations on the circuit. The output of the voltmeter is the potential of the red probe minus the potential of the black probe. The noncontact ammeter allows you to measure the current simply by dragging the transparent circle (with cross hairs) over a wire.

Feel free to play around with the simulation. When you are done, click **Reset All** before beginning Part A.

## Part A

Drag a battery into the construction panel, and use the voltmeter to determine which end of the battery is the positive terminal. The positive terminal has a higher potential than the negative terminal (recall that the voltmeter measures the potential difference between the red probe and the black probe).
Which end of the battery is the positive terminal?

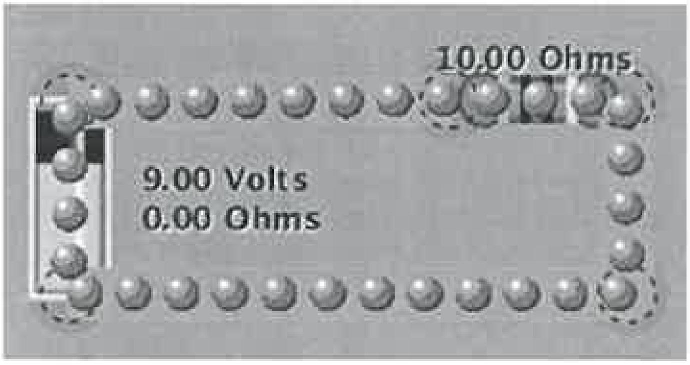
You did not open hints for this part.

ANSWER:

○ the grey end
☒ the black end

## Part B

Construct a circuit containing one battery, one resistor, and wire to close the circuit. The order and orientation doesn't matter, but it should look something like the figure below. You can show the values of the components by right-clicking (control-clicking) on each component and selecting **Show Value** in the pop-up menus. Use the default values of the battery and resistor.



You should see the blue electrons flowing through the circuit.

In what direction is the *current* flowing through the circuit? Recall that current is the flow of positive charge.

ANSWER:

○ The current flows from the negative terminal, through the wires and resistor, and into the positive terminal.
☒ The current flows from the positive terminal, through the wires and resistor, and into the negative terminal.

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## Part C

Use the noncontact ammeter to measure the current flowing through the circuit.
What is the current?

ANSWER:

○ 10 A
☒ 0.9 A
○ 9 A
○ 90 A

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## Part D

For the circuit in the previous part, the current flowing in the wire between the positive terminal of the battery and the resistor is ____________ the current flowing between the resistor and the negative terminal of the battery.

ANSWER:

☒ equal to
○ less than
○ greater than

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## Part E

Double the resistance of the resistor by changing it from 10 $\Omega$ to 20 $\Omega$. What happens to the current flowing through the circuit?

ANSWER:

○ The current does not change.
○ The current decreases by a factor of four.
☒ The current decreases by a factor of two.
○ The current increases by a factor of two.

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## Part F

For the circuit containing one resistor and one battery, what happens to the current if the voltage is doubled?

ANSWER:

○ The current decreases by a factor of two.
○ The current increases by a factor of four.
○ The current does not change.
● The current increases by a factor of two.

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## Part G

For the circuit containing one resistor and one battery, what happens to the current if the voltage is tripled *and* the resistance is doubled?

ANSWER:

○ The current does not change.
● The current increases.
○ The current decreases.

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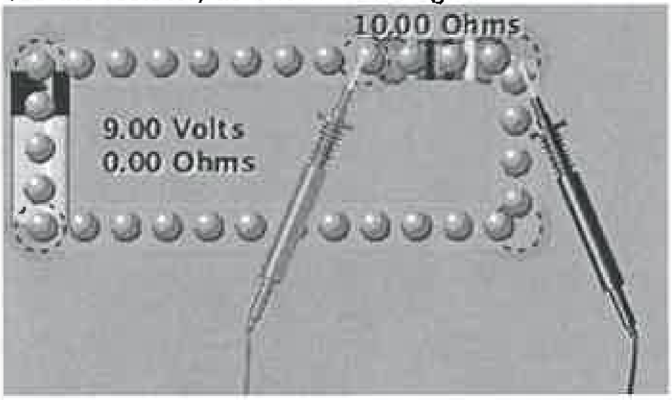
## Part H

What is the voltage reading across the resistor, as shown in the figure below?



ANSWER:

○ $-9.0\ \mathrm{V}$
○ $-4.5\ \mathrm{V}$
● $9.0\ \mathrm{V}$
○ $4.5\ \mathrm{V}$

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## Part I

A light bulb is basically a resistor that gets so hot that it glows, emitting light. For this tutorial we will assume the resistor in the light bulb is ohmic (that means Ohm's law applies to the resistor).
The rate of energy emitted by the light bulb is its output power, commonly referred to as *luminosity* (brighter means more luminous).

Hook up a light bulb to a 5-$\mathrm{V}$ battery. Right-click (or control-click) on the light bulb, and change its resistance. How does the brightness of the light bulb depend on its resistance?

ANSWER:

○ The brightness of the light bulb is independent of its resistance. It only depends on the voltage of the battery.
☒ The light bulb gets dimmer as the resistance is increased.
○ The light bulb gets brighter as the resistance is increased.

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## Part J

In Part H, you discovered that the luminosity of a light bulb increases if the current increases. The rate at which electric potential energy is converted into heat depends on the current flowing through the bulb and the voltage across the bulb. This energy is supplied by the battery. Mathematically, the luminosity $P$ of the light bulb is given by $P = \Delta V I$, where $\Delta V$ is the voltage across the bulb and $I$ is the current.

What happens to the luminosity of the light bulb if the voltage of the battery is doubled? (Note that the PhET simulation does not display a numerical value for the luminosity, so you should use the relationship between the luminosity, the voltage across the bulb, and the current.)

**Hint 1.** How to approach the problem

The luminosity is given by $P = \Delta V I$, and the voltage is doubled. By how much does the current increase? (You can use the ammeter to measure the new current, or use Ohm's law.)

ANSWER:

R = constant for light bulb

○ The luminosity increases by a factor of eight.
○ The luminosity doubles.
○ The luminosity does not change.
☒ The luminosity increases by a factor of four.

$$P = \frac{V^2}{R}$$

PhET Interactive Simulations
University of Colorado
http://phet.colorado.edu

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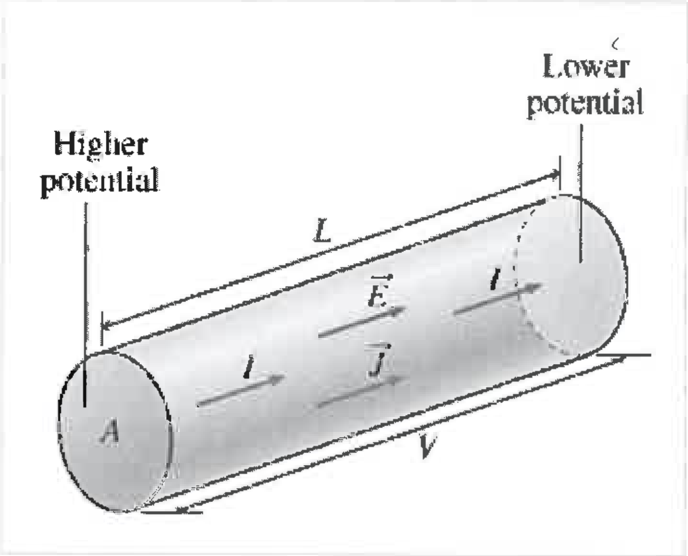
# Resistance from Microscopic Ohm's law

Your task is to calculate the resistance of a simple cylindrical resistor with wires connected to the ends, such as the carbon composition resistors that are used on electronic circuit boards. Imagine that the resistor is made by squirting material whose conductivity is $\sigma$ into a cylindrical mold with length $L$ and cross-sectional area $A$ . Assume that this material satisfies Ohm's law. (It should if the resistor is operated within its power dissipation limits.)



### Part A

What is the resistance $R$ of this resistor?

**Express the resistance in terms of variables given in the introduction. Do *not* use $V$ or $I$ in your answer.**

You did not open hints for this part.

$\sigma$ = conductivity = $\frac{1}{\text{resistivity}}$ = $\frac{1}{\rho}$

ANSWER:

$R = \rho\frac{L}{A} = \frac{L}{A\sigma}$

## ± Electrical Safety

Most of us have experienced an electrical shock one way or another in our lives. Most electrical shocks we receive are minor ones from wooly sweaters or from shoes. However, some shocks, especially from outlets or power mains, can be fatal. This question will show you how to estimate the current through a human body when subject to an electrical shock.

Imagine a situation in which a person accidentally touches an electrical socket with both hands. By modeling the arm and the chest to be a cylindrical tube with a total length $L = 2.0\ \mathrm{m}$, cross-sectional area $A = 10\ \mathrm{cm}^2$, and resistivity $\rho = 1.5\ \mathrm{ohm \cdot m}$, you can calculate the current in amperes through the person when a potential difference of $V = 110\ \mathrm{V}$ is applied across the two hands. Assume that the current flows only through the modeled cylindrical tube.

### Part A

What is the current flow through the body?

**Express your answer numerically to two significant figures.**

$10 \text{ cm}^2 \times \frac{1}{100^2} \frac{\text{m}^2}{\text{cm}^2} = 10^{-3} \text{ m}^2$

You did not open hints for this part.

$R = \rho \frac{L}{A} = 1.5 \times \frac{2}{10^{-3}} = 3 \times 10^3 \ \Omega$

ANSWER:

$I = \frac{V}{R} = \frac{110}{3 \times 10^3} = 0.037$ A

## ± Resistance of a Heater

A 1500-W heater is designed to be plugged into a 120-V outlet.

### Part A

What current will flow through the heating coil when the heater is plugged in?

**Express your answer for the current numerically, to three significant figures.**

You did not open hints for this part.

$1500 = P = \frac{V^2}{R} = \frac{(120)}{R}$

ANSWER:

$R = \frac{(120)^2}{1500} = 9.6 \ \Omega$

$I = \frac{V}{R} = \frac{120}{9.6} = 12.5$ A

### Part B

What is $R$, the resistance of the heater?

**Express your answer numerically, to three significant figures.**

You did not open hints for this part.

ANSWER:

$R = 9.6$ ohms

### Part C

How long does it take to raise the temperature of the air in a good-sized living room

$(3.00\mathrm{m} \times 5.00\mathrm{m} \times 8.00\mathrm{m})$ by $10.0^\circ \mathrm{C}$? Note that the specific heat of air is 1006 $\mathrm{J/(kg \cdot ^\circ C)}$ and the density of air is $1.20\ \mathrm{kg/m^3}$.

**Express your answer numerically in minutes, to three significant figures.**

You did not open hints for this part.

$$\underbrace{Q}_{\text{energy needed}} = \underbrace{\underbrace{3\times5\times8}_{\substack{V\\ \text{volume}}} \times \underbrace{1.2}_{\substack{d\\ \text{density}}}}_{\text{mass}} \times \underbrace{10}_{\Delta T} \times \underbrace{1006}_{\substack{C\\ \text{specific heat}}} = 1448640$$

ANSWER:

$t$ = 16.1 minutes

$$t = \frac{Q}{P} = \frac{1448640}{1500} = 965.76\,(s) = 16.096\,(min)$$

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## Video Tutor: Resistance in Copper and Nichrome

First, launch the video below. You will be asked to use your knowledge of physics to predict the outcome of an experiment. Then, close the video window and answer the question at right. You can watch the video again at any point.

### Part A

We repeat the experiment from the video, but this time we connect the wires in parallel rather than in series. Which piece of paper is more likely to catch fire?

You did not open hints for this part.

ANSWER:

- ○ Both pieces are equally likely to catch fire.
- ○ The paper draped on the Nichrome wire (resistance 2.7 Ω)
- ☒ The paper draped on the copper wire (resistance 0.1 Ω)

# Power in DC Circuits

A battery does work in moving charge around a circuit i.e. sustaining a current through the circuit. To illustrate this point, consider a resistor with a voltage $V$ across it and a current $I$ flowing through it.

## Part A

Focus on a single charge, $q$, passing through the resistor. Find the work $W$ done on the charge by the electric field in the resistor.

**Express the work $W$ done on the charge in terms of $q$, $V$, and/or $I$.**

**Hint 1.** How to approach this problem

The electric field exerts a force on the charge that moves it through the resistor. Because the force acts in the same direction that the charge is moving, this force does positive work on the charge. Compute the force on the charge, then find the work done by this force.

**Hint 2.** Formula for work

The work done by a constant force of magnitude $F$, acting over a distance $L$ is: $W = FL$.

**Hint 3.** Find the force on the charge $q$

Assume that the length of the resistor is $L$. What is the magnitude of the force that the electric field inside the resistor exerts on the charge?

**Express $F$ in terms of $L$, $q$, $V$, and/or $I$.**

**Hint 1.** Electric field inside the resistor

The (uniform) electric field $\vec{E}$, inside the resistor is related to the voltage drop $V$ across the resistor by the following integral over the length of the resistor: $V = \int \vec{E} \cdot d\vec{l}$.

ANSWER:

$F$ =

ANSWER:

$W$ = $q \cdot V$

## Part B

When thinking about an electric circuit, you usually focus not on the motion of individual charges, but rather on the continuous current (charge per unit time) flowing through the circuit. Thus, rather than considering the work done on a particular charge, it is useful to compute the work done per unit time on the charge flowing through the circuit, or in other words, the power.

Find the electrical power $P$ delivered to the resistor via the work done on the individual charges passing through it. (Again, this power ultimately appears in the form of heat).

**Express $P$ in terms of quantities given in the problem introduction.**

**Hint 1.** How to approach this problem

You've already found the work done on a single charge $q$ as it passes through the resistor. The total work done on all the charges passing through the resistor is given by: $W(t) = Vq(t)$, where $q(t)$ represents all of the charge that has flowed through the resistor up to time $t$. Use this expression to compute the power, which is the work done per unit time.

**Hint 2.** Formula for power

Power is equal to the work done per unit time: $P = \frac{dW}{dt}$.

**Hint 3.** Find $\frac{dq(t)}{dt}$

What is the value of $\frac{dq(t)}{dt}$?

**Express your answer in terms of quantities given in the introduction.**

ANSWER:

$\frac{dq(t)}{dt}$ =

$$P=\frac{dW}{dt}=\frac{d(q\cdot V)}{dt}=V\cdot\frac{dq}{dt}$$

$$=V\cdot I$$

ANSWER:

$P$ = $V\cdot I$

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## Power Delivered to a Resistor

In this problem you will derive two different formulas for the power delivered to a resistor.

## Part A

What is the power $P$ supplied to a resistor whose resistance is $R$ when it is known that it has a voltage $V$ across it?

**Express the power $P$ in terms of $R$ and $V$.**

$(V = IR \Rightarrow I = \frac{V}{R})$

You did not open hints for this part.

$P = IV = \frac{V^2}{R}$

ANSWER:

$P = \frac{V^2}{R}$

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## Part B

What is the power $P$ supplied to a resistor whose resistance is $R$ when it is known that it has a current $I$ flowing through it?

**Express the power $P$ in terms of $R$ and $I$.**

$(V = IR) \Rightarrow$

$P = IV = I^2R$

**Hint 1.** Find an expression for power

What is the power $P$ supplied to any circuit element that has a voltage $V$ across it and through which a current $I$ flows?

**Express the power in terms of $I$ and $V$.**

ANSWER:

$P$ =

**Hint 2.** Find voltage in terms of current and resistance

Using Ohm's law, what is the voltage across a resistor of resistance $R$ that has a current $I$ flowing through it?

ANSWER:

$V$ =

ANSWER:

$P =$ $I^2R$

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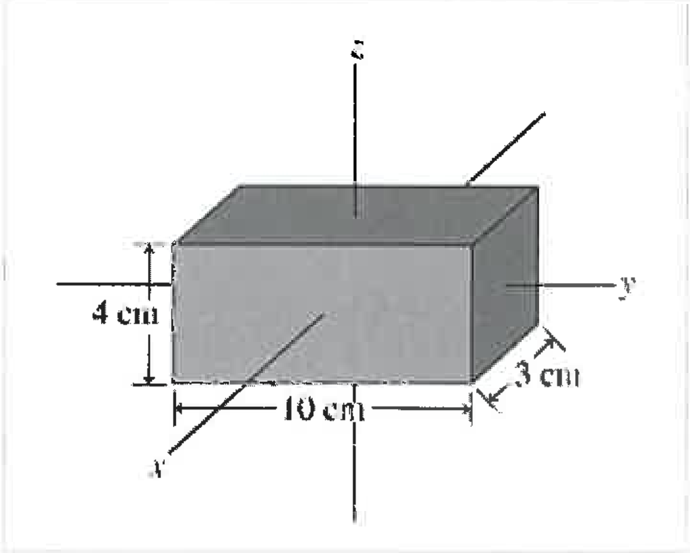
## Dependence of Resistance on Resistor Dimensions Ranking Task

The rectangular block below has front-face dimensions of 10 cm by 4 cm, with a depth of 3 cm. You will be asked to treat this object as an electrical resistor.



### Part A

Rank the block based on its electrical resistance along the three illustrated coordinate directions (*x*, *y*, and *z*).

**Rank from largest to smallest. To rank items as equivalent, overlap them.**

You did not open hints for this part.

ANSWER:

$$R = \rho \frac{L}{A}$$

$$R_y = \rho \frac{10\times10^{-2}}{3\times4\times10^{-4}} = \rho \frac{10}{12}\times10^{2}$$

$$R_x = \rho \cdot \frac{3\times10^{-2}}{10\times4\times10^{-4}} = \rho \frac{3}{40}\times10^{2}$$

$$R_z = \rho \frac{4\times10^{-2}}{3\times10\times10^{-4}} = \rho \frac{4}{30}\times10^{-2}$$

$$R_y > R_z > R_x$$

## Part B

If all of the dimensions of the block double (to become 20 $\mathrm{cm}$ wide, 8 $\mathrm{cm}$ tall, and 6 $\mathrm{cm}$ deep), what happens to the resistance along each axis?

You did not open hints for this part.

ANSWER:

- ○ The resistance quadruples.
- ○ The resistance doubles.
- ○ The resistance stays the same.
- ☒ The resistance is halved.
- ○ The resistance is quartered.

## Exercise 25.4

An 18-gauge copper wire (diameter 1.02 $\mathrm{mm}$) carries a current with a current density of $1.40 \times 10^6 \mathrm{A/m^2}$ . Copper has $8.5 \times 10^{28}$ free electrons per cubic meter.

### Part A

Calculate the current in the wire.

**Express your answer using two significant figures.**

ANSWER:

$I = J \times A$

$= 1.4 \times 10^{6} \times \pi(0.51 \times 10^{-3})^2$

$= 1.14$

$I =$ 1.14 A

---

### Part B

Calculate the drift velocity of electrons in the wire.

**Express your answer using two significant figures.**

ANSWER:

$v_d = \dfrac{J}{nq} = \dfrac{1.4 \times 10^{6}}{8.5 \times 10^{28} \times 1.6 \times 10^{-19}} = 0.103 \times 10^{-3} = 1.03 \times 10^{-4}$ m/s

---

## Exercise 25.23

A current-carrying gold wire has a diameter of 0.87mm . The electric field in the wire is 0.45V/m .

### Part A

What is the current carried by the wire?

**Express your answer using two significant figures.**

ANSWER:

$\rho = \dfrac{E}{J} \Rightarrow$ ~~$J = \rho E$~~

~~$= 2.24 \times 10^{-8} \times 0.45$~~

~~$= 1 \times 10^{-8}$ A/m²~~

$I = $ $I = J \cdot A = J \cdot \pi r^2 = 2 \times 10^{7} \times \pi \times \left(\dfrac{0.87 \times 10^{-3}}{2}\right)^2 = 11.9$ A

$I \quad J = \dfrac{E}{\rho} = \dfrac{0.45}{2.24 \times 10^{-8}} = 2 \times 10^{7}$ A/m²

---

### Part B

What is the potential difference between two points in the wire 6.4m apart?

**Express your answer using two significant figures.**

ANSWER:

$\Delta V = -\int \vec{E} \cdot d\vec{l}$

$= \vec{E} \cdot \Delta x$

$= 0.45 \times 6.4$

$= 2.88$ V

$V =$ 2.88 V

### Part C

What is the resistance of a 6.4-m length of this wire?

$$R = \frac{V}{I} = \frac{2.88}{11.9} = 0.24\ \Omega$$

**Express your answer using two significant figures.**

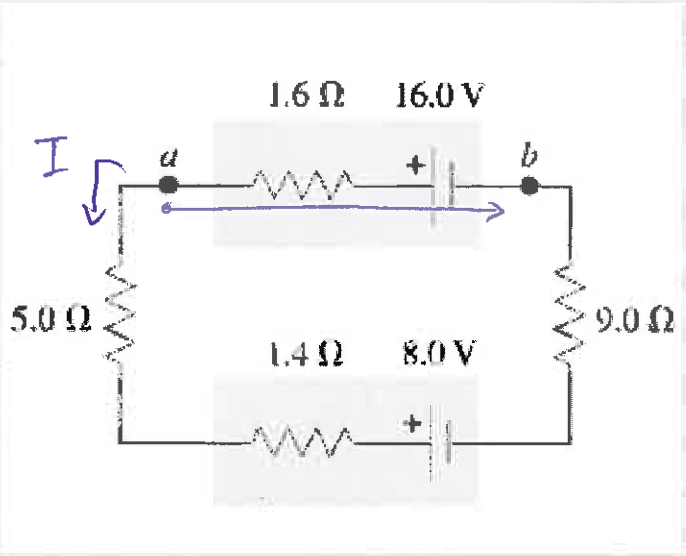
ANSWER:

$R =$ 0.24 Ω

---

## Exercise 25.38

The circuit shown in the figure contains two batteries, each with an emf and an internal resistance, and two resistors.



### Part A

$$-5I - 1.4I - 8 - 9I + 16 - 1.6I = 0$$

$$17I = 8 \Rightarrow I = \frac{8}{17} = 0.47\ A$$

Find the magnitude of the current in the circuit.

ANSWER:

$I =$ 0.47 A

### Part B

Find the direction of the current in the circuit.

ANSWER:

○ clockwise
☒ counterclockwise

## Part C

Find the terminal voltage $V_{ab}$ of the 16.0$\mathrm{V}$ battery.

$1.6 \times I - 16 = 1.6 \times 0.47 - 16 = -15.25$

ANSWER:

$V_b - V_a =$ $-15.25$ $\mathrm{V}$

## Exercise 25.49

A 28.0$\Omega$ bulb is connected across the terminals of a 12.0-$\mathrm{V}$ battery having 2.50$\Omega$ of internal resistance.

## Part A

What percentage of the power of the battery is dissipated across the internal resistance and hence is not available to the bulb?

ANSWER:

$\frac{P_r}{P_{\text{total}}} =$ [illegible] $= \frac{I^2 r}{I^2 r + I^2 R} = \frac{r}{r+R} = 8.2\%$ %

$I = \frac{\varepsilon}{R+r} = \frac{12}{28+2.5} = 0.39$ A

## Problem 25.78

Compact fluorescent bulbs are much more efficient at producing light than are ordinary incandescent bulbs. They initially cost much more, but last far longer and use much less electricity. According to one study of these bulbs, a compact bulb that produces as much light as a 100$\mathrm{W}$ incandescent bulb uses only 23.0$\mathrm{W}$ of power. The compact bulb lasts $1.00 \times 10^4$ hours, on the average, and costs \$ 12.0 , whereas the incandescent bulb costs only 76.0 ¢, but lasts just 750 hours. The study assumed that electricity cost 7.00 ¢ per $\mathrm{kWh}$ and that the bulbs were on for 4.0 $\mathrm{h}$ per day.

## Part A

What is the total cost (including the price of the bulbs) to run incandescent bulbs for 3.0 years?

ANSWER:

~~3yr = 3x365x24 = 26280 hr~~

~~Purchase + electricity~~

~~36x0.76+183.96~~
~~$211.32~~

~~26280/750 = 35.04~~
~~⇒ need 36 bulbs~~

~~0.76 + ... x365x24x60x60~~

dollar(s)

~~P x Δt~~
~~0.1 kW x 3x365x24 h~~
~~= 0.3 x 365x24 kWh~~

$ 35.22

~~100 W x 26280 hr~~
~~= 2628 kWh~~

**Part B**

~~2628 x 0.07 = $183.96~~ ~~0.76 + 2628 kWh x 0.07 $/kWh~~

What is the total cost (including the price of the bulbs) to run compact fluorescent bulbs for 3.0 years?

ANSWER:

$ 19.05

dollar(s)

$\frac{4380}{1\times10^4} = 0.438 \Rightarrow 1$ bulb

$0.023\ kW \times 4380\ h = 100.74\ kWh$

$100.74 \times 0.07 = \$7.05$

$12 + 7.05 = 19.05$

$3\times365 = 1095$ days

$1095 \times 4 = 4380$ hrs.

$\frac{4380}{750} = 5.84 \Rightarrow 6$ bulbs

$0.1\ kW \times 4380\ h = 438\ kWh$

$438 \times 0.07 = \$30.66$

cost: $6\times0.76 + 30.66 = 35.22$

**Part C**

How much do you save over 3.0 years if you use a compact fluorescent bulb instead of an incandescent bulb?

ANSWER:

$35.22 - 19.05$ $16.17

dollar(s)

**Part D**

What is the resistance of a "100 $\mathrm{W}$" fluorescent bulb? (Remember, it actually uses only 23 $\mathrm{W}$ of power and operates across 120 $\mathrm{V}$.)

$P = \frac{V^2}{R} \Rightarrow 23 = \frac{(120)^2}{R}$

ANSWER:

$R =$ 626 Ω Ω

## Problem 25.05

**Part A**

A gold wire that is 1.6 mm in diameter and 35 cm long carries a current of 210 mA. How many electrons per second pass a given cross section of the wire? ($e$ = 1.60 × $10^{-19}$ C)

ANSWER:

○ $2.9\times10^{15}$
○ $6.3\times10^{15}$
○ $1.3\times10^{17}$
○ $1.2\times10^{23}$
☒ $1.3\times10^{18}$

$$I = 210\,mA = 210\times10^{-3}\,A$$
$$= 0.21\,A$$

$$I = \frac{\Delta Q}{\Delta t}$$

$$\Delta Q = I\cdot\Delta t = 0.21\times1$$
$$= 0.21\ C$$

$$1\ e^- = 1.6\times10^{-19}\,C$$

$$0.21\ C\times\frac{1}{1.6\times10^{-19}}\ \frac{e^-}{C} = 1.31\times10^{18}\,e^-$$

**Score Summary:**

Your score on this assignment is 0.0%.
You received 0 out of a possible total of 15 points.