DEPARTMENT OF EDUCATION
SCHOOLS DIVISION OF NEGROS ORIENTAL
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CURRENT, RESISTANCE AND ELECTROMOTIVE FORCE

for GENERAL PHYSICS 2/ Grade 12/ Quarter 3/ Week 4

SELF-LEARNING KIT

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FOREWORD

This Self–Learning Kit will serve as a guide for you, Grade 12 STEM learners, to understand the basic concepts of electric circuits. We will begin by learning how to distinguish between conventional current and electron flow, then apply the concept of current as the amount of charge that passes a given point in a given amount of time through problem solving. We will also learn about the nature of conductors and considering how they are affected by temperature. We will find out why a short, fat, cold copper wire is a better conductor than a long, skinny, hot steel wire.

This Self–Learning Kit will provide a short and learner-friendly content that stirs your curiosity, develop understanding, and support critical thinking.

The writer hopes that this Kit can serve its purpose to you, as the target learners. Mastery of the content is encouraged before proceeding to the next learning competency.

OBJECTIVES

At the end of this Self–Learning Kit, you should be able to:

K: distinguish between conventional current and electron flow;
: explain the relationship between temperature and resistance;
: describe the ability of a material to conduct current in terms of resistivity and conductivity;

S: apply the relationship charge = current x time to new situations or to solve related problems;
: solve problems related to the relationship of the proportionality between resistance and the length and cross-sectional area of a wire; and

A: value the importance of electricity, current and charge in improving our quality of life.

LEARNING COMPETENCIES

Distinguish between conventional current and electron flow **(STEM_GP12EMIIId-32).**

Apply the relationship charge = current x time to new situations or to solve related problems **(STEM_GP12EMIIIe-33).**

Describe the effect of temperature increase on the resistance of a metallic conductor **(STEM_GP12EMIIIe-35).**

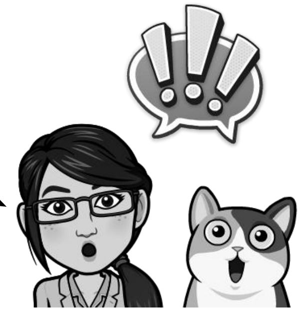
Describe the ability of a material to conduct current in terms of resistivity and conductivity **(STEM_GP12EMIIIe-36).**

Apply the relationship of the proportionality between resistance and the length and cross-sectional area of a wire to solve problems **(STEM_GP12EMIIIe-37).**

I. WHAT HAPPENED

Hello Scientists! Did you know? The flicker of numbers on a handheld calculator, nerve impulses carrying signals of vision to the brain, an ultrasound device sending a signal to a computer screen, the brain sending a message for a baby to twitch its toes, an electric train pulling its load over a mountain pass, a hydroelectric plant sending energy to metropolitan and rural users—these and many other examples of electricity involve electric current, the movement of charge?

Wow! That's awesome! Humankind has indeed harnessed electricity, the basis of technology, to improve our quality of life. In this module, we will explore and gain new insights about the nature of electricity. Are you ready to learn my fellow scientists? LET'S BEGIN!



Let's have a simple self-check first. We will find out how much do you know about our lesson for today.

PRE-TEST:

Directions: Identify what is asked in the statements below. Choose the correct answer from the words found inside the boxes. Write them on your notebook/worksheet.

SET A *(For number 1–10):*

current	current density
electron flow	electric circuit
ampere	electric field
drift velocity	steady acceleration
conventional current	sign

1. It is any motion of charge from one region to another.
2. It is the movement of negative charges (electrons) opposite to the direction of the electric field.
3. It is the unit of current.
4. It is the average velocity reached by charged particles, such as electrons, in a material due to an electric field.
5. It behaves as if the positive charge carriers cause current flow.
6. The current per unit cross-sectional area is called the ___.
7. It is a conducting path that forms a closed loop in which charges move.
8. It causes charges to flow.
9. A __________ in the direction of $\vec{F}$ will result from the charged particle moving in vacuum, in which after some time the charged particle would be moving in that direction at high speed.
10. The current and current density don't depend on the _____ of the charge.

SET B *(For number 11–20):*	
resistivity	zero
resistance	insulators
amount of resistance	conductor's length
$\Omega \cdot \mathrm{m}$	greater
conductivity	decrease

11. It is the resistance to the flow of an electric current with some materials resisting the current flow more than others.
12. It depends on the material of which the object is composed.
13. The amount of electrical current which flows is restricted by the ____ present.
14. The unit for resistivity.
15. It is the reciprocal or inverse of resistivity.
16. A perfect conductor has ____ resistivity.
17. ____ have highest resistivities.
18. It is one of the factors wherein the electrical resistance between two points can depend on.
19. The longer the conductor (or wire), the ____ is its electrical resistance.
20. If we increase the conductor's cross-sectional area, it's resistance will ___.

II. WHAT I NEED TO KNOW
DISCUSSION

CURRENT AND DIRECTION OF CURRENT FLOW

Electric Circuit

An **electric circuit** is a conducting path that forms a closed loop in which charges move. In these circuits, energy is carried from one place to another.

Current

A **current** is any motion of charge from one region to another. In this lesson we will discuss currents in conducting materials. This kind of currents are applied on charges in motion on vast majority of technologies.

Current is defined to be the amount of charge that passes a given point in a given amount of time.

$$I = \frac{dQ}{dt}$$

where:

$I = Current$

$dQ = amount\ of\ charge$

$dt = amount\ of\ time$

Current has units of $Ampere = \frac{1\ Coulomb}{1\ sec}$

An **electric field** in a conductor causes charges to flow.

Drift Velocity

In Physics, a **drift velocity** is the average velocity reached by charged particles, such as electrons, in a material due to an electric field. In general, an electron in a conductor will propagate randomly at the Fermi velocity, resulting in an average velocity of zero. Applying an electric field adds to this random motion a small net flow in one direction; this is the drift.

Consider Figure 1, a conducting wire of cross-sectional area $\boldsymbol{A}$, having $\boldsymbol{n}$ free charge-carrying particles per unit volume with each particle having a charge $\boldsymbol{q}$ with particles moving at $\vec{v}_d$

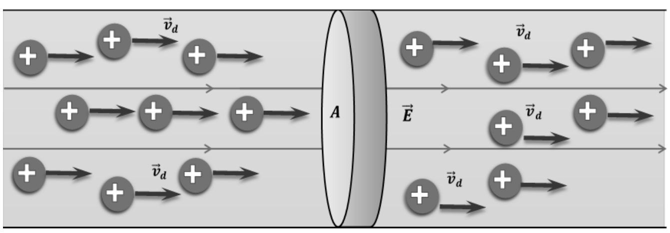


Figure 1

The total charge moving past a given point is then given by

$$dQ = nqv_d A dt$$

The current is then given by

$$I = \frac{dQ}{dt} = nqv_d A$$

or

$$I = nqv_d A$$

where:

$I = Current$
$dQ = amount\ of\ charge$
$dt = amount\ of\ time$
$q = charge$
$n = free\ electrons$
$v_d = drift\ velocity$
$A = Area$

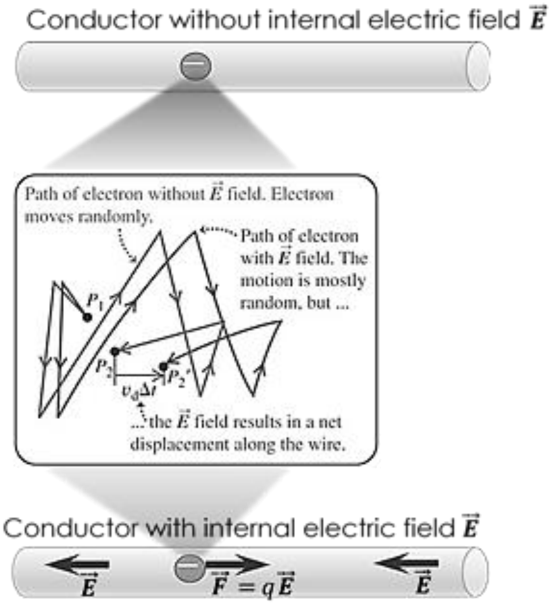
During electrostatic situations, the electric field $\vec{E}$ is zero everywhere in the conductor, and there is no current. This does not imply that all charges inside the conductor are at rest. Some of the electrons are free to move within the conducting material, (e.g., copper or aluminum). These free electrons move randomly in all directions and do not escape from the conducting material, because they are attracted to the positive ions of the material. Since the motion of the electrons are random, there is no net flow of charge in any direction and therefore, no current.

What happens when a constant, steady electric field $\vec{E}$ is established inside a conductor? A charged particle (such as a free electron) inside the conducting material is then subjected to a steady force $\vec{F} = q\vec{E}$. A steady acceleration in the direction of $\vec{F}$ will result from the charged particle moving in vacuum, in which after some time the charged particle would be moving in that direction at high speed. This charged particle moving in the conductor frequently collides with the massive, nearly stationary ions of the material. These collisions cause random change on the particle's direction of motion. *The random motion of the charged particles within the conductor along with a very slow net motion or* ***"drift"*** *of the moving charged particles as a group in the direction of the electronic force $\vec{F} = q\vec{E}$ is the net effect of the electric field $\vec{E}$*. This motion is what we call ***drift velocity*** $\vec{v}_d$ of the particles. A **net current in the conductor** is the result.

Figure 2

An electron moves randomly from point P_1 to P_2 in a time Δt if there is no electric field inside the conductor. (See the blue line)

If an electric field $\vec{E}$ is present, the electric force $\vec{F} = q\vec{E}$ imposes a small drift (greatly exaggerated in the figure) that takes the electron to P'_2 in the direction of the force.



(Young and Freedman 2012)

An electron has a negative charge q, so the force on it due to the $\vec{E}$ field is the direction opposite to $\vec{E}$.

DIRECTION OF CURRENT FLOW

The electric field $\vec{E}$ does work on moving charges which results to kinetic energy (KE). This energy is then transferred to the conductor through collisions with ions. This phenomenon increases the average vibrational energy of the ions as well as the temperature of the conductor.

The charges of the moving particles may be positive or negative in different current-carrying materials.

Electron flow (Figure 3-a) is the movement of negative charges (electrons) opposite to the direction of the electric field. **Conventional current** (Figure 3-b) is the flow of positive charges from the positive to the negative terminal. It behaves as if the positive charge carriers cause current flow.

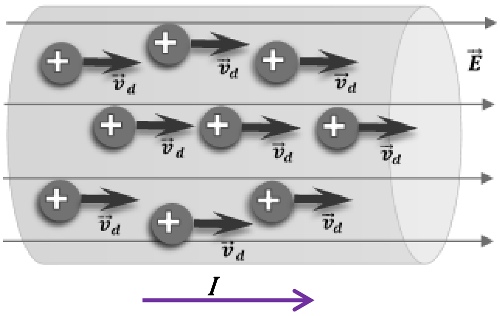


Figure 3-a: *Positive charges moving in the direction of the electric field* $\vec{E}$.

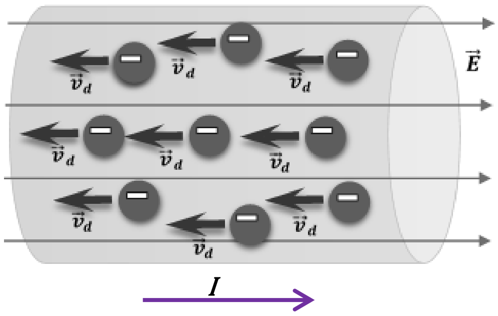


Figure 3-b: *Negative charges moving at the same speed in the direction opposite to the electric field* $\vec{E}$.

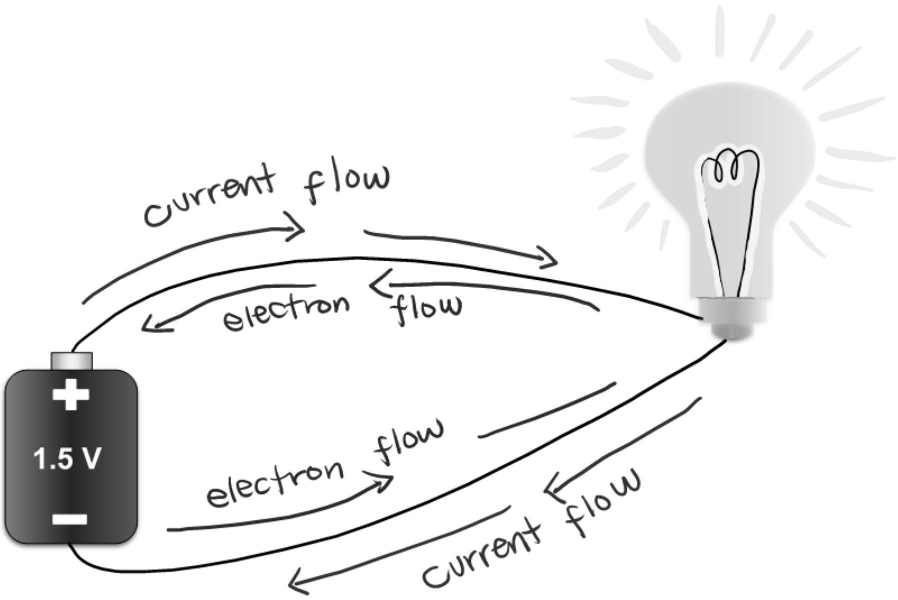


Figure 4: *Electron Flow and Conventional Current Flow*

It is significant to distinguish the difference between electron flow and conventional current, but it is also important to realize that the difference between this two does not affect any real-world behavior and computational results in any way. In general, analyzing an electrical circuit produces results that are independent of the assumed direction of current flow. Conventional current flow is the standard that most all of the world follows.

CURRENT DENSITY

The current per unit cross-sectional area is called the ***current density J:***

$$J = \frac{I}{A} = nqv_d$$

where:

$J = Current\ Density$ $n = free\ electrons$
$I = Current$ $v_d = drift\ velocity$
$q = charge$ $A = Area$

The units of current density are amperes per square meter (Amp/m^2).

The current and current density don't depend on the sign of the charge.

Sample Problem 1: Current Density and Drift Velocity in a Wire

An 18-gauge copper wire (the size usually used for lamp cords), with a diameter of $1.02\ mm$, carries a constant current of $1.67 Amp$ to a 200-W lamp. The free-electron density of the wire is $8.5 \times 10^{28} m^{-3}$. Find (a) the current density and (b) the drift velocity.

Solution:

IDENTIFY and SET UP: This problem uses the relationships among current I, current density J, and drift velocity. We are given I and the wire diameter d, so we use Eq. $J = \frac{I}{A} = nqv_d$ to find J. We will use the same equation to find v_d from J and the known electron density n.

***Execute:* (a)** The cross-sectional area is

$$A = \frac{\pi d^2}{4} = \frac{\pi(1.02 \times 10^{-3} m)^2}{4} = 8.17 \times 10^{-7} m^2$$

The magnitude of the current density is then

$$J = \frac{I}{A} = nqv_d = \frac{1.67\ Amp}{8.17\ \times 10^{-7} m^2} = 2.04 \times 10^6\ Amp/m^2$$

(b) From Eq. $J = \frac{I}{A} = nqv_d$ for the drift velocity magnitude v_d, we find

$$v_d = \frac{J}{nq} = \frac{2.04 \times 10^6\ \cancel{Amp}/\cancel{m}^2}{(8.5\ \times 10^{28} \underset{m}{\cancel{m^{-3}}})(-1.60 \times 10^{-19}\ \underset{s}{\cancel{C}})}$$

$$= 1.5 \times 10^{-4}\ m/s = 0.15\ mm/s$$

Note:
C = Amp/s

Sample Problem 2: Calculating Currents: Current in a Truck Battery and a Handheld Calculator

(a) What is the current involved when a truck battery sets in motion 720 C of charge in 4.00 s while starting an engine? (b) How long does it take 1.00 C of charge to flow through a handheld calculator if a 0.300-mA current is flowing?

Strategy:

We can use the definition of current in the equation $\boldsymbol{I} = \frac{\boldsymbol{dQ}}{\boldsymbol{dt}}$ to find the current in part (a), since charge and time are given. In part (b), we rearrange the definition of current and use the given values of charge and current to find the time required.

Solution for (a):

Entering the given values for charge and time into the definition of current gives

$$\boldsymbol{I = \frac{720\ C}{4.00\ s} = 180\ {}^{C}\!/_{s} = 180\ Amp}$$

Discussion for (a):

This large value for current illustrates the fact that a large charge is moved in a small amount of time. The currents in these "starter motors" are fairly large because large frictional forces need to be overcome when setting something in motion.

Solution for (b):

Solving the relationship $\boldsymbol{I} = \frac{\boldsymbol{dQ}}{\boldsymbol{dt}}$ *for time* $\boldsymbol{dt}$*, and entering the known values for charge and current gives*

$$\boldsymbol{dt = \frac{dQ}{I} = \frac{1.00\ \cancel{C}}{0.300 \times 10^{-3}\ \cancel{C}/s} = 3.33 \times 10^{3} s}$$

Discussion for (b):

This time is slightly less than an hour. The small current used by the hand-held calculator takes a much longer time to move a smaller charge than the large current of the truck starter. So why can we operate our calculators only seconds after turning them on? It's because calculators require very little energy. Such small current and energy demands allow handheld calculators to operate from solar cells or to get many hours of use out of small batteries. Remember, calculators do not have moving parts in the same way that a truck engine has with cylinders and pistons, so the technology requires smaller currents.

Sample Problem 3: Calculating Drift Velocity in a Common Wire

Calculate the drift velocity of electrons in a 12-gauge copper wire (which has a diameter of 2.053 mm) carrying a 20.0-Amp current, given that there is one free electron per copper atom. (Household wiring often contains 12-gauge copper wire, and the maximum current allowed in such wire is usually 20 Amp.) The density of copper is 8.80 × 103 kg/m^3.

Strategy:

We can calculate the drift velocity using the equation $\boldsymbol{I = nqv_d A}$. The current **I = 20.0 Amp** is given, and **q = –1.60×10^{-19} C** is the charge of an electron ***(C = Amp.s).*** We can calculate the area of a cross-section of the wire using the formula **A = πr^2**, where r is one-half the given diameter, **2.053 mm**. We are given the density of copper, **8.80 × 10^3 kg/m^3** and the periodic table shows that the atomic mass of copper is **63.54 g/mol**. We can use these two quantities along with Avogadro's number, **6.02 × 10^{23} atoms/mol**, to determine n, the number of free electrons per cubic meter.

Solution:

First, calculate the density of free electrons in copper. There is one free electron per copper atom. Therefore, is the same as the number of copper atoms per m^3. We can now find n as follows:

$$\boldsymbol{n = \frac{1e^-}{\cancel{atom}} \times \frac{6.02 \times 10^{23}\ \cancel{atoms}}{\cancel{mol}} \times \frac{1\ \cancel{mol}}{63.54\ \cancel{g}} \times \frac{1000\ \cancel{g}}{1\ \cancel{kg}} \times \frac{8.80 \times 10^3\ \cancel{kg}}{1\ m^3}}$$

$$\boldsymbol{= 8.342 \times 10^{28} e^-/m^3}$$

The cross-sectional of the wire is

$$\boldsymbol{A = \pi r^2 = 3.141592654\left(\frac{2.053 \times 10^{-3} m}{2}\right)^2 = 3.141592654(1.0265 \times 10^{-3} m)^2}$$

$$\boldsymbol{= 3.141592654(1.05370225 \times 10^{-6} m^2) = 3.310 \times 10^{-6} m^2}$$

Rearranging $\boldsymbol{I = nqv_d A}$ *to isolate drift velocity gives*

$$\boldsymbol{v_d = \frac{I}{nqA} = \frac{20.0\ Amp}{(8.342 \times 10^{28} e^-/m^3)(-1.60 \times 10^{-19}\ \mathrm{C})(3.310 \times 10^{-6} m^2)}}$$

Note, the unit C or Coulomb is equal to $\mathbf{Amp \cdot s}$*, therefore,*

$$\boldsymbol{v_d = \frac{20.0\ \cancel{Amp}}{(8.342 \times 10^{28} e^-/\cancel{m^3})(-1.60 \times 10^{-19}\ \cancel{\mathrm{Amp}} \cdot \mathrm{s})(.310 \times 10^{-6} \cancel{m^2})}}$$

m

$$\boldsymbol{v_d = -4.53 \times 10^{-4}\ m/s}$$

Discussion for Sample Problem 3:

The minus sign indicates that the negative charges are moving in the direction opposite to conventional current. The small value for drift velocity (on the order of 10^{-4} m/s) confirms that the signal moves on the order of 10^{12} times faster (about 10^{8} m/s) than the charges that carry it.

CONDUCTION OF ELECTRICITY AND HEAT

Good electrical conductors are often good heat conductors, too. This is because large numbers of free electrons can carry electrical current and can transport thermal energy.

RESISTANCE AND RESISTIVITY

Resistivity

Resistivity of materials is the resistance to the flow of an electric current with some materials resisting the current flow more than others. The resistivity of a material is a key factor in determining the electrical resistance of a conductor, and it is the part of the equation for resistance that considers the differing characteristics of different materials.

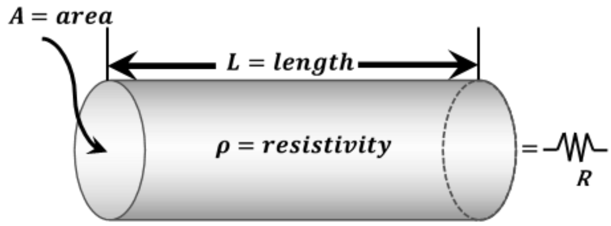
Ohms Law states that when a **voltage (V)** source is applied between two points in a circuit, an **electrical current (I)** will flow between them encouraged by the presence of the potential difference between these two points. The amount of electrical current which flows is restricted by the **amount of resistance (R)** present. In other words, the voltage encourages the current to flow (the movement of charge), but it is resistance that discourages it.

For a given shape, the resistance depends on the material of which the object is composed. Different materials offer different resistance to the flow of charge. We define the resistivity $\boldsymbol{\rho}$ of a substance so that the resistance $\boldsymbol{R}$ of an object is directly proportional to $\boldsymbol{\rho}$. Resistivity $\boldsymbol{\rho}$ is an intrinsic property of a material, independent of its shape or size. The resistance $\boldsymbol{R}$ of a uniform cylinder of length $\boldsymbol{R}$, of cross-sectional area $\boldsymbol{A}$, and made of a material with resistivity $\boldsymbol{\rho}$, is

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

where:

$R = Resistance$
$L = Length$
$\rho = resistivity$
$A = Area$



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

Figure 5. A uniform cylinder of length L and cross-sectional area A. Its resistance to the flow of current is similar to the resistance posed by a pipe to fluid flow. The longer the cylinder, the greater its resistance. The larger its cross-sectional area A, the smaller the resistance.

Table 1 gives representative values of resistivity $\boldsymbol{\rho}$. The materials listed in the table are separated into categories of conductors, semiconductors, and insulators, based on broad groupings of resistivities. Conductors have the smallest resistivities, and insulators have the largest; semiconductors have intermediate resistivities.

Table 1. Resistivities ρ of Various materials at 20° C

Material	**Resistivity ρ ($\Omega \cdot m$)**
Conductors	
Silver	1.59×10^{-8}
Copper	1.72×10^{-8}
Gold	2.44×10^{-8}
Aluminum	2.65×10^{-8}
Tungsten	5.6×10^{-8}
Iron	9.71×10^{-8}
Platinum	10.6×10^{-8}
Steel	20×10^{-8}
Lead	22×10^{-8}
Manganin (Cu, Mn, Ni alloy)	44×10^{-8}
Constantan (Cu, Ni alloy)	49×10^{-8}
Mercury	96×10^{-8}
Nichrome (Ni, Fe, Cr alloy)	100×10^{-8}

Material	Resistivity ρ ($\Omega \cdot m$)
Semiconductors[1]	
Carbon (pure)	3.5×10^5
Carbon	$(3.5 - 60) \times 10^5$
Germanium (pure)	600×10^{-3}
Germanium	$(1–600) \times 10^{-3}$
Silicon (pure)	2300
Silicon	0.1–2300
Insulators	
Amber	5×10^{14}
Glass	$10^9 - 10^{14}$
Lucite	$>10^{13}$
Mica	$10^{11} - 10^{15}$
Quartz (fused)	75×10^{16}
Rubber (hard)	$10^{13} - 10^{16}$
Sulfur	10^{15}
Teflon	$>10^{13}$
Wood	$10^8 - 10^{11}$

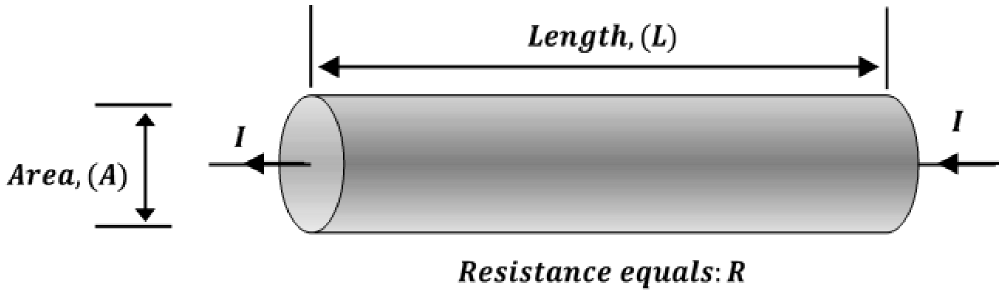
Adapted from https://courses.lumenlearning.com/austincc-physics2/chapter/20-3-resistance-and-resistivity/

The unit of resistivity is the ohm-meter $(\mathbf{\Omega \cdot m})$. The reciprocal of resistivity is conductivity. Its units are $(\mathbf{\Omega \cdot m})^{-1}$. A perfect conductor would have zero resistivity, while a perfect insulator would have infinite resistivity.

Resistivity $\boldsymbol{\rho}$ usually is constant at a certain temperature and does not depend on electric field. Materials with constant $\boldsymbol{\rho}$ is called ohmic conductor.

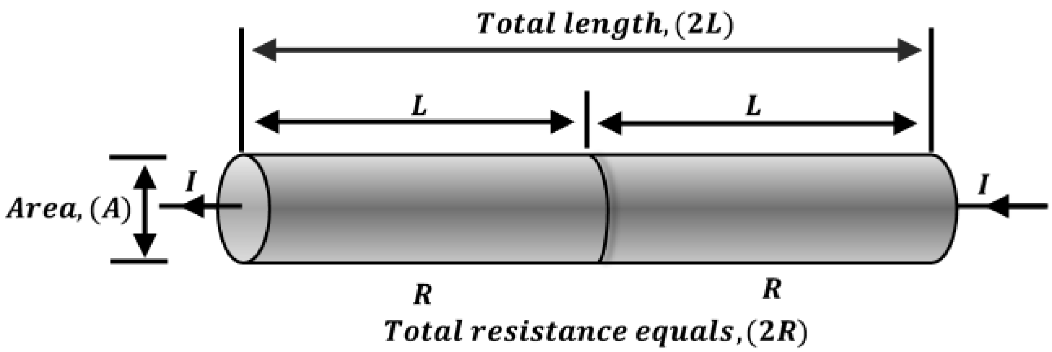
The electrical resistance between two points can depend on many factors such as **the conductor's length**, **its cross-sectional area, the temperature, as well as the actual material from which it is made.** For example, let's assume we have a piece of wire (a conductor) that has a length $\boldsymbol{L}$, a cross-sectional area $\boldsymbol{A}$ and a resistance $\boldsymbol{R}$ as shown.

A Single Conductor



The electrical resistance, $\boldsymbol{R}$ of this simple conductor is a function of its length, $\boldsymbol{L}$ and the conductor's area, $\boldsymbol{A}$. Ohms law tells us that for a given resistance $\boldsymbol{R}$, the current flowing through the conductor is directly proportional to the applied voltage as $\boldsymbol{I} = \boldsymbol{V}/\boldsymbol{R}$. Now what if we connect two identical conductors together in a series combination as shown.

Doubling the Length of a Conductor

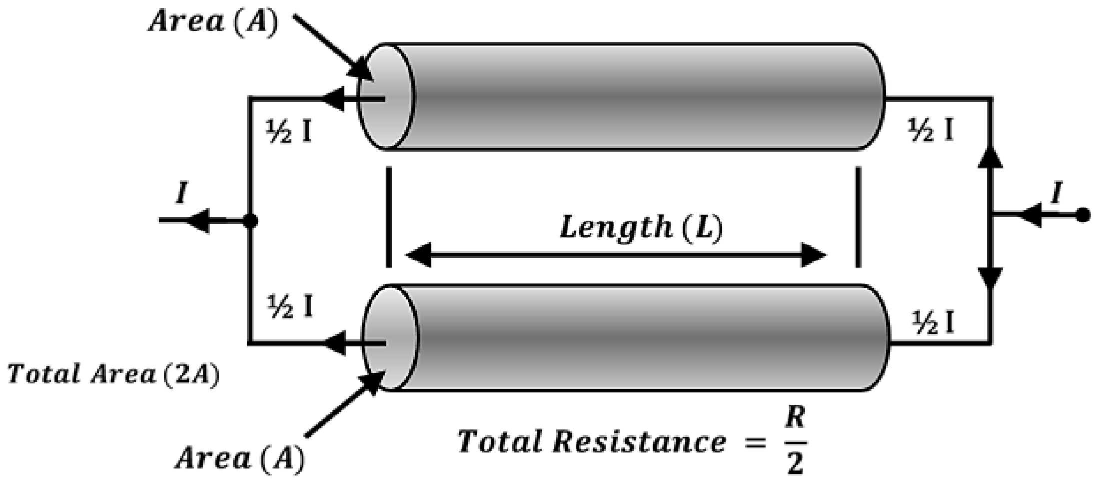


In this section, by connecting the two conductors together in a series combination, that is end to end, we have effectively doubled the total length of the conductor ($\boldsymbol{2L}$), and the total resistance of the conductor, giving $\boldsymbol{2R}$ as: $\boldsymbol{1R}$ + $\boldsymbol{1R}$ = $\boldsymbol{2R}$. While the cross-sectional area ($\boldsymbol{A}$) remains exactly the same as before.

Therefore, we can see that the resistance of the conductor is proportional to its length, that is: $\boldsymbol{R} \propto \boldsymbol{L}$. We would expect that the longer the conductor (or wire), the greater is its electrical resistance.

Observe also that by doubling the length and therefore the resistance of the conductor ($\boldsymbol{2R}$), to force the same current, $\boldsymbol{I}$ to flow through the conductor as before, we need to **double (increase)** the applied voltage as now $\boldsymbol{I}$ = $(\boldsymbol{2V})/(\boldsymbol{2R})$. Next suppose we connect the two identical conductors together in parallel combination as shown.

Doubling the Area of a Conductor



In this example, by connecting the two conductors together in a parallel combination, we have effectively doubled the total area giving $\mathbf{2A}$, while the conductors length, $\boldsymbol{L}$ remains the same as the original single conductor. But as well as doubling the area, by connecting the two conductors together in parallel we have effectively halved the total resistance of the conductor, giving $\mathbf{1/2R}$ as now each half of the current flows through each conductor branch.

Therefore, the resistance of the conductor is inversely proportional to its area, that is: $\boldsymbol{R}\ \mathbf{1}/\propto \boldsymbol{A}$ or $\boldsymbol{R} \propto \mathbf{1}/\boldsymbol{A}$. Which means that we would expect the electrical resistance of a conductor (or wire) to proportionally decrease as its cross-sectional area increases.

Also by doubling the area and therefore halving the total resistance of the conductor branch ($\mathbf{1/2R}$), for the same current, i to flow through the parallel conductor branch as before we only need half (decrease) the applied voltage as now $\boldsymbol{I} = (\mathbf{1/2V})/(\mathbf{1/2R})$.

The resistance of a conductor is directly proportional to the length ($\boldsymbol{L}$) of the conductor, that is: $\boldsymbol{R} \propto \boldsymbol{L}$, and inversely proportional to its area ($\boldsymbol{A}$), $\boldsymbol{R} \propto \mathbf{1}/\boldsymbol{A}$.

Electrical Conductivity

Electrical conductivity is simply defined as the inverse of resistivity, so a high resistivity means a low conductivity, and a low resistivity means a high conductivity. Mathematically, the conductivity of a material is represented by:

$\sigma = \frac{1}{\rho}$

where:

$\rho = resistivity$

$\sigma = conductivity$

where σ is the conductivity and ρ is the resistivity, as before. Of course, you can re-arrange the equation for resistance to express this in terms of the resistance, R, cross-sectional area A of the conductor and the length L, depending on the problem.

Sample Problem 4: Calculating Resistor Diameter: A Headlight Filament

A car headlight filament is made of tungsten and has a cold resistance of **0.350 Ω**. If the filament is a cylinder **5.00 cm long** (it may be coiled to save space), what is its diameter?

Strategy:

Let's rearrange the equation $R = \rho \frac{L}{A}$ to find the cross-sectional area A of the filament from the given information. Then its diameter can be found by assuming is has a circular cross-section.

Solution:

The cross-sectional area, found by rearranging the expression for the resistance of a cylinder given in $= \rho \frac{L}{A}$, is $A = \rho \frac{L}{R}$.

Substituting the given values, and taking ρ from Table 1, results to

$$A = (5.6 \times 10^{-8}\Omega \cdot m)\left(\frac{5.00 \times 10^{-2}m}{0.350\,\Omega}\right)$$

$$A = (5.6 \times 10^{-8}\Omega \cdot m)\left(1.4285714286 \times 10^{-1}\frac{m}{\Omega}\right)$$

$$A = 8.0 \times 10^{-9}m^2$$

The area of a circle is related to its diameter D by

$$A = \frac{\pi D^2}{4}$$

Solving for the **diameter D**, and substituting the value found for **A**, gives

$$D = 2\left(\frac{A}{\pi}\right)^{\frac{1}{2}} = 2\left(\frac{8.0 \times 10^{-9}m^2}{3.14}\right)^{\frac{1}{2}} = 2(2.5477707006 \times 10^{-9}m^2)^{\frac{1}{2}}$$

$$= 2(5.047545 \times 10^{-5}\,m)$$

$$D = 10.1 \times 10^{-5}m$$

Discussion:

The diameter is just a tenth of a millimeter. It is quoted to only two digits, because $\boldsymbol{\rho}$ is known to only two digits.

Temperature Dependence of Resistivity

The resistivity of a metallic conductor nearly always increases with increasing temperature.

As $\boldsymbol{T}$ increase, the ions of the conductor vibrate with greater amplitude, making it easier for electrons to collide with an ion.

This will decrease drift velocity $\boldsymbol{v_d}$ and reduce the current $\boldsymbol{I}$.

Over relatively small temperature changes (about 100°C or less), resistivity $\boldsymbol{\rho}$ varies with temperature change $\Delta\boldsymbol{T}$ as expressed in the following equation

$$\boldsymbol{\rho = \rho_0(1 + \alpha\Delta T)}$$

where: $\boldsymbol{\rho_0}$ =the original resistivity
$\boldsymbol{\alpha}$ = the temperature coefficient of resistivity
$\Delta\boldsymbol{T}$ = temperature change

Always remember that $\boldsymbol{\alpha}$ is positive for metals, meaning their resistivity increases with temperature. Some alloys have been developed specifically to have a small temperature dependence. Also note that $\boldsymbol{\alpha}$ is negative for the semiconductors meaning that their resistivity $\boldsymbol{\rho}$ decreases with increasing temperature. They become better conductors at higher temperature, because increased thermal agitation increases the number of free charges available to carry current.

This property of decreasing resistivity $\boldsymbol{\rho}$ with temperature is also related to the type and amount of impurities present in the semiconductors. The resistance of an object also depends on temperature since resistance $\boldsymbol{R_0}$ is directly proportional to resistivity $\boldsymbol{\rho}$**.** For a cylinder we know $\boldsymbol{R} = \boldsymbol{\rho}\frac{\boldsymbol{L}}{\boldsymbol{A}}$, and so, if $\boldsymbol{L}$ and $\boldsymbol{A}$ do not change greatly with temperature, $\boldsymbol{R}$ will have the same temperature dependence as $\boldsymbol{\rho}$**.** Thus, the temperature dependence of the resistance of an object is,

$$\boldsymbol{R = R_0(1 + \alpha\Delta T)}$$

Where $\boldsymbol{R_0}$ is the original resistance and $\boldsymbol{R}$ is the resistance after a temperature change $\Delta\boldsymbol{T}$**.**

Table 2. Tempature Coefficients of Resistivity α

Material	Coefficient α (1/°C)[2]
Conductors	
Silver	3.8×10^{-3}
Copper	3.9×10^{-3}
Gold	3.4×10^{-3}
Aluminum	3.9×10^{-3}
Tungsten	4.5×10^{-3}
Iron	5.0×10^{-3}
Platinum	3.93×10^{-3}
Lead	3.9×10^{-3}
Manganin (Cu, Mn, Ni alloy)	0.000×10^{-3}
Constantan (Cu, Ni alloy)	0.002×10^{-3}
Mercury	0.89×10^{-3}
Nichrome (Ni, Fe, Cr alloy)	0.4×10^{-3}
Semiconductors	
Carbon (pure)	-0.5×10^{-3}
Germanium (pure)	-50×10^{-3}
Silicon (pure)	-70×10^{-3}

Retrieved from https://courses.lumenlearning.com/austincc-physics2/chapter/20-3-resistance-and-resistivity/

Let's try understanding the temperature dependence of resistivity better by analyzing the sample problem on the next page.

Sample Problem 2: Calculating Resistance: Hot-filament Resistance

Although caution must be used in applying $\boldsymbol{\rho = \rho_0(1 + \alpha\Delta T)}$ and $\boldsymbol{R = R_0(1 + \alpha\Delta T)}$ for temperature changes greater than 100°C, for Tungsten the equations work reasonably well for very large temperature changes. What, then, is the resistance of tungsten filament in the previous example if its temperature is increased from room temperature (20°C) to a typical operating temperature of 2850°C? The original resistance $\boldsymbol{R_0 = 0.350\ \Omega}$.

Strategy:

We can directly use the equation $\boldsymbol{R = R_0(1 + \alpha\Delta T)}$, since the original resistance of the filament was given to be $\boldsymbol{R_0 = 0.350\ \Omega}$ and the temperature change $\boldsymbol{\Delta T = 2850℃ - 20℃ = 2830℃}$.

Solution:

The hot resistance $\boldsymbol{R}$ is obtained by entering known values into the above equation:

$$\begin{aligned} \boldsymbol{R} &= \boldsymbol{R_0(1 + \alpha\Delta T)} \\ &= \boldsymbol{(0.350\ \Omega)[1 + (4.5 \times 10^{-3}/°\cancel{C})(2830°\cancel{C})]} \\ &= \boldsymbol{4.8\Omega} \end{aligned}$$

PERFORMANCE TASK:

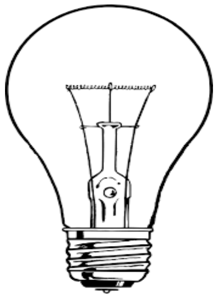
EXAMINING TINY DETAILS: FILAMENT OBSERVATIONS

Objective: Examine the flow of electricity in a filament of a light bulb.

Material: Light bulb

Procedure:

1. Find a light bulb with a filament (See the sample picture at the right).
2. Look carefully at the filament and describe its structure.



Directions: Answer the following questions. Write your answers on your notebook/worksheet.

Questions:

1. Describe the structure of the filament inside the light bulb.
2. To what points is the filament connected?

VI. WHAT I HAVE LEARNED EVALUATION/POST–TEST:

MULTIPLE CHOICE.

Directions: Choose the letter of the correct answer and write it on your notebook/worksheet.

1. It is the movement of negative charges (electrons) opposite to the direction of the electric field.
   a. electron flow
   b. convention current
   c. current flow
   d. current

2. It behaves as if the positive charge carriers cause current flow.
   a. drift velocity
   b. conventional current
   c. electron flow
   d. proton flow
3. The current per unit cross-sectional area is called the ___.
   a. current flow
   b. current density
   c. drift velocity
   d. temperature dependence
4. A __________ in the direction of $\vec{F}$ will result from the charged particle moving in vacuum, in which after some time the charged particle would be moving in that direction at high speed.
   a. steady current
   b. steady speed
   c. steady acceleration
   d. steady flow
5. A large lightning bolt had a 20,000-A current and moved 30.0 C of charge. What was its duration?
   a. 2 ms
   b. 1.5 ms
   c. 3 ms
   d. 2.5 ms
6. It is any motion of charge from one region to another.
   a. current
   b. drift velocity
   c. electric circuit
   d. drift circuit
7. What is the current in milliamperes produced by the solar cells of a pocket calculator through which 4.00 C of charge passes in 4.00 h?
   a. 0.278 mA
   b. 0.479 ma
   c. 0.176 mA
   d. 0.200 mA
8. It is the average velocity reached by charged particles, such as electrons, in a material due to an electric field.
   a. drift velocity
   b. current velocity
   c. electron velocity
   d. proton velocity
9. A 14-gauge copper wire has a diameter of 1.628 mm. What magnitude current flows when the drift velocity is 1.00 mm/s? ((See Sample problem 3: Calculating Drift and Velocity in a Common Wire for useful information.)
   a. $-2.78 \times 10^{1}\,A$
   b. $-1.78 \times 10^{1}\,A$
   c. $-2.78 \times 10^{9}\,A$
   d. $-2.50 \times 10^{1}\,A$
10. It is a conducting path that forms a closed loop in which charges move.
    a. current
    b. drift velocity
    c. electric circuit
    d. drift circuit
11. It is the reciprocal or inverse of resistivity.
    a. resistivity
    b. conductivity
    c. resistance
    d. insulators
12. It is the resistance to the flow of an electric current with some materials resisting the current flow more than others.
    a. insulators
    b. conductivity
    c. resistance
    d. resistivity
13. It depends on the material of which the object is composed.
    a. conductors
    b. conductivity
    c. resistance
    d. resistivity

14. A perfect conductor has ____ resistivity.
   a. large
   b. medium
   c. zero
   d. small
15. It is one of the factors wherein the electrical resistance between two points can depend on.
   a. Conductor's length
   b. Conductor's resistivity
   c. Conductor's current
   d. Conductor's area
16. The amount of electrical current which flows is restricted by the ____ present.
   a. amount of resistivity
   b. amount of resistance
   c. amount of current
   d. amount of conductivity
17. The longer the conductor (or wire), the ____ is its electrical resistance.
   a. smaller
   b. greater
   c. larger
   d. equal
18. If we increase the conductor's cross-sectional area, it's resistance will ___.
   a. increase
   b. decrease
   c. does not change
   d. expand
19. What is the resistance of a 25.0-m-long piece of 12-gauge copper wire having a 2.053-mm diameter?
   a. $1.299 \times 10^{-3}\Omega$
   b. $2.299 \times 10^{-3}\Omega$
   c. $1.299 \times 10^{3}\Omega$
   d. $2.299 \times 10^{3}\Omega$
20. If the 0.100-mm diameter tungsten filament in a light bulb is to have a resistance of 0.300 Ω at 20°C, how long should it be?
   a. $4.31 \times 10^{-18}m$
   b. $4.31 \times 10^{18}m$
   c. $4.21 \times 10^{18}m$
   d. $4.21 \times 10^{-18}m$

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SYNOPSIS AND ABOUT THE AUTHOR

This Self Learning Kit is designed to aid students to independently learn the important concepts about current and direction of current flow.

The discussion and tasks related to the topic are arranged systematically and explained in detail so that the students are guided. The students are expected to master this lesson and value its application to the physical world.

ANSWER KEY

Pre–Test:

1. current
2. electron flow
3. ampere
4. drift velocity
5. conventional current
6. current density
7. electric circuit
8. electric field
9. steady acceleration
10. sign
11. resistivity
12. resistance
13. amount of resistance
14. Ω·m
15. conductivity
16. zero
17. insulators
18. conductor's length
19. greater
20. decrease

Post–Test:

1. a	11. b
2. b	12. d
3. b	13. c
4. c	14. c
5. b	15. a
6. a	16. b
7. a	17. b
8. a	18. b
9. a	19. a
10. c	20. d

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