3–18 Current, Resistance, and DC Circuits

Current: The flow of electricity. Current I is considered positive (due to old convention). We now know that the electrons flow, but think of current as positive. To talk about actual electron flow we must say electron current or negative current. Positive current flow follows the direction of the electric field, so negative flow is counter to the electric field.

$\boxed{I = \frac{\Delta Q}{\Delta t}}$ It's a rate (divided by time). But, it is unlike velocity where we measure the distance the car went. Instead we stand still and count how many charges, Q (large amount of charged particles), go by in an amount of time (1 second).

Resistance: When water flows down a stream it runs into resistance, such as rocks and sand, etc. When current flows in a length of wire, Fig 18.1, internal properties of the wire slows the current. Resistance is like friction countering the forward progress of the electrons. Conductors slow the current very little, while insulators have lots of resistance, and slow it drastically. All appliances, and even the sources of electricity like batteries have resistance. There are also actual resistors built into circuits to help control electrical flow to exact quantities in various parts of the circuit.

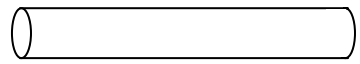

Fig 18.1

$\boxed{R = \frac{\rho \ell}{Area}}$ Resistance is a function of resistivity, ρ, wire length, ℓ, and cross sectional area. Resistivity, ρ, is like the coefficient of friction. It is derived by experimentation. Different materials have different natural resistances. Gold has very low resistance, while copper is not quite as good, but it is cheaper. So let's worry about length and cross section of wire. Make length small and area big, so the answer is d. The longer the wire the more resistance it has. And resistance is like friction. What type of energy does some of the KE turn into when an object is slowed by friction? Heat. What kind of energy is produced when charges are slowed down by resistance? Heat. What do you feel when you touch an electrical component, like a stereo? It gets hot. Heat loss is disadvantageous. You're losing valuable energy, wasting money on you electrical bill, and increasing entropy. Hot wires also have more resistance. Minimizing resistance is advantageous. But, sometimes you need to create resistance if you have components that can only handle certain amounts of power, energy, voltage, etc. In addition wires themselves have like resistors. One goal in circuit design is to shorten the wires between components to minimize power loss and heat. How much energy is lost in the transmission wires from Hoover Dam?

Important equations for circuits.

$\boxed{V = IR}$ $\boxed{P = IV}$ $\boxed{P = \frac{W}{t}}$ $\boxed{P = I^2 R \ \ (not \ \ given)}$ $\boxed{P = \frac{V^2}{R} \ \ (not \ \ given)}$

DC Current: Direct Current is created in batteries, by an electrochemical reaction. These reactions follow entropy and run in one direction producing one way current that is also even in the amount that is produced. The reaction can be reversed, as entropy can, if you put more energy into recharging the battery than you will recover from the battery when it is used. Direct Current, means it travels in one direction only following the electric field lines. The battery pumps charges by creating a potential difference (voltage) between the ends of the circuit. The positive terminal (positive plate) is a region of high potential energy. At the other end of the circuit (wires and components) is a negative terminal (negative plate) that is a region of low potential energy. In a 12 V battery the positive plate is the 12 V plate, while the negative plate is the 0 V plate. Positive current (positive charge) wants to fall toward the ground (negative plate) through the potential difference. This is the direction of the electric field, which is the direction positive charge moves. (Just remember the electrons really flow, so it's all backwards. But, mathematically you get the same numbers).

AC Current: This current comes from generators and is best understood when looking at electromagnetic induction. For now AC current is a current that decelerates to a stop and then accelerates in the opposite direction for a while, then it repeats this process over and over again. The charges move back and forth at 60 Hz (60 times a second) in US circuits. Not only does direction change, but so does the amount of current. The slowing, stopping, and speeding up creates a sinusoidal current over time.

Skier Analogy: A ski lift (battery or generator) elevates skiers (charge) from the lodge (negative plate, 0 V) to the top of 12 V Mountain (positive plate, 12 V) raising both they're potential ($V = Ed$) and potential energy ($U_E = qV$). The skiers (charge) must follow the gravitational field (electric field) back to the lodge (negative plate, 0 V) through the ski resort (circuit). There are several possible runs (wires) for the skiers (charge) to use. Because the skiers (charge) are losing potential energy as they fall, and because energy must be conserved, the potential energy must be turning into another form of energy. It is turning into the kinetic energy of the skiers (charge). Then the skiers (charge) run through gates (appliances, light bulbs, etc.) and they transfer kinetic energy to the gates doing useful work (browning toast, lighting up your room). Unfortunately, the skiers also loose some energy in the gates (appliance, lamp, etc.) to friction (resistance), which creates heat. Also the mountain is covered with moguls (resistors) put on the slopes to purposely slow the skiers (current). As they ski (flow) down the mountain they loose potential energy. They use up all of their potential (height) and potential energy going through gates (appliances, lights, etc.) and moguls (resistors). The skiers (charge) arrive at the lodge with no energy and no potential. They are sent through the process until the switch is opened (resort is closed).

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Circuits Containing Resistors

Series: All resistors are in line. Resistors are like sections of wire, designed to slow current. Examine the resistivity of two sections of wire placed in series, as shown in Fig 18.2. $R = \dfrac{\rho \ell}{Area}$

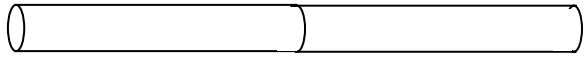

Fig 18.2

ℓ is doubled, but cross sectional area stayed the same. So R doubles. If there were three wires R would triple. This makes sense. Lets pretend they make your commute on the freeway longer, but they didn't build more lanes to widen the road. So you experience the same traffic (resistance) for two or three times as long a road. So in series Resistance adds $\boxed{R_s = \sum_i R_i}$ or $R_s = R_1 + R_2 + R_3 + \ldots$

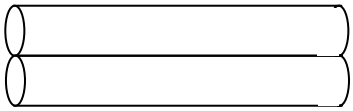

Fig 18.3

Now xamine the resistivity of two sections of wire placed in parallel, shown in Fig 18.3. ℓ stays the same, but cross sectional area doubles. It's more complicated than above. Area is in the denominator. If ***Area*** doubles R is cut in half. If there were three wires R would be cut in third. This makes sense. Its like they expanded the freeway from four lanes to 8 or even 12. You travel the same distance as before but now have less traffic and congestion.

So in parallel $\boxed{\dfrac{1}{R_p} = \sum_i \dfrac{1}{R_i}}$ or $\dfrac{1}{R_p} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \ldots$ **Please don't solve for $1/R_P$. Invert you final answer.**

Current in Circuits: Charge is conserved quantity. If the battery pushes 1 A of charge it is pushing 1 *C* every second into the circuit. Those charges must travel through the rest of the circuit at that rate and must arrive back at the battery at that rate. So in a series circuit, with one path only, the rate that charges move must be the same everywhere. So in a series circuit charge stays the same. But, in a parallel circuit current arrives at a junction and splits up. If 1 A arrives at the junction, then 1 C is arriving every second. Some charges will take one path, while the others will go the other way (ways). But the 1 A splits up, so the current in each section of the parallel circuit must add up to 1 A. You can't have more current in the branches than you had leading up to the branches.

Voltage in Circuits: $V = Ed$. So voltage depends on how far away you are from the battery. If you have a 12 V battery, for example, the positive terminal is 12 V, while the negative terminal is 0 V. As charges move through the circuit they fall away from the positive plate and towards the negative plate. They are farther and farther away from the 12 V plate. Each appliance or resistor uses up some of the voltage. So every time there is resistance voltage is subtracted. The voltage must drop to 0 V when the charges reach the battery, so the resistance in the circuit must use up, subtract all 12 V, in this example. In a series circuit the voltage of the resistors and/or appliances must add to the same value as the battery produces. In a parallel circuit the current takes different paths but, but you travel the same distance from the battery regardless of the path. So in a parallel circuit voltage stays the same.

Series Current stays the same (resistors in line slow traffic in the whole circuit) $I_S = I_1 = I_2 = I_3 = \ldots$
Voltage adds $V_S = V_1 + V_2 + V_3 + \ldots$ (cars are all pushed down a single path)

Parallel Current adds $I_S = I_1 + I_2 + I_3 + \ldots$ (current can choose paths, but the total must split between paths available)
Voltage stays the same $V_S = V_1 = V_2 = V_3 = \ldots$ (cars have an equal pressure down any path)

Ohm' Law: $V = IR$ for devices in electrical circuits.

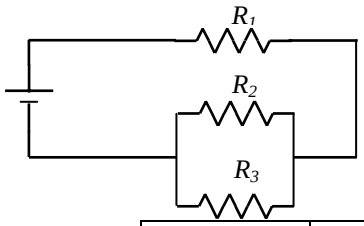

Fig 18.4

Redrawn on the right to match.the skier analogy

	V	I	R
Battery	+21 V	12 A	1.75 Ω
R_1	-12 V	12 A	1 Ω
R_2	-9 V	9 A	1 Ω
R_3	-9 V	3 A	3 Ω

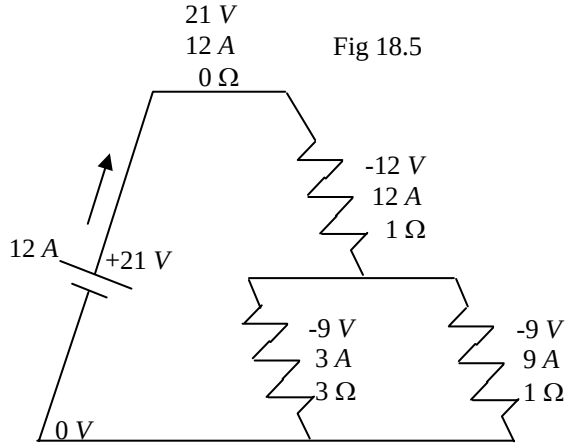

Fig 18.5

<u>Solve the problems on the DC Circuit Worksheet to become familiar with these and other similar computations.</u>

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Kirchhoff's Rules: Useful for complicated circuits, where there may be more than one battery, and the directions of the batteries even oppose each other in portions of the circuit. Refer to Fig. 18.4 and 18.5 on the previous page.

1. The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction. $\boxed{\sum I_{in} = \sum I_{out}}$.

   This explains the parallel portion of the preceding circuit. Let's look closer at the parallel junctions in Fig 18.4, isolated and enlarged here in Fig 18.6.

   12 A of current enters the junction at point A. Charge is conserved so all 12 A must leave the junction at point A. The amount going down the two paths is controlled by and proportional to the amount of resistance. The 1 Ω resistor receives 9 A, while the larger 3 Ω prevents current flow to a higher degree, and only receives 3 A.

   The current going through the two branches unites again at point B. The 9 A and 3 A coming into the junction equals the 12 A leaving the junction.

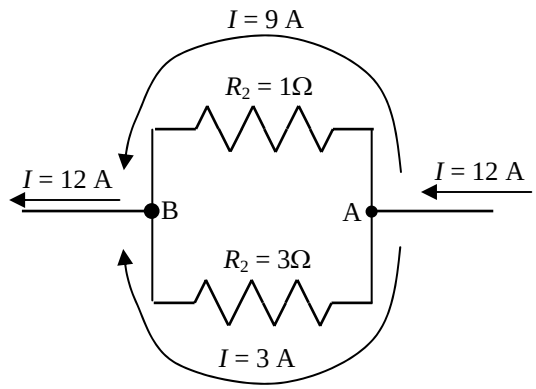

Fig 18.6

2. The sum of the potential differences across all circuit components of any closed loop must be zero. $\boxed{\sum \Delta V = 0}$. Batteries and generators are thought of as pumps that raise the charges to a higher potential. From this higher potential the charges can fall through the circuit and do work (light lights, run microwave ovens, etc.). So, when charges move through a battery the voltage is positive. When they are traveling back down hill, through the components in the circuit, the voltage is negative. If you look at the chart below Fig 18.4, on the previous page, you will see that the signs on the voltages have been included. Added together they total to zero. After all, if the ski lift starts at the lodge and goes up 400 m, the ski runs better go down 400 m to finish there. Otherwise the it will be a very strange resort.

Electromotive Force: ε or *emf*. Not really a force. It is a potential, or voltage, created to make electrons move.

Sources of *emf*: A source of electric field (battery or generator), that makes electrons flow through the circuit. Since *emf* is essentially an electric potential it substitutes into many equations that contain electric potential V (voltage). As an example: under certain circumstances $\boxed{V = IR}$ can be written as $\boxed{\varepsilon = IR}$. Let's see when this is true.

Internal Resistance: *r*. Every device consists of wires that electricity must pass through, so every device has resistance. This is true of sources of *emf* as well (batteries and generators). The resistance of a battery or generator is known as internal resistance, and is denoted with a small r to distinguish it from the resistance of other components (capital R). Let's look at a battery, with internal resistance, in the circuit in Fig 18.7. in greater detail.

The whole battery is drawn as a rectangle, from point A to point B. It consists of some plates where an electrochemical reaction generates ***electromotive force, emf***, $\varepsilon = 6$V. However, the battery is not perfect. It has an ***internal resistance*** of $r = 1\Omega$. This internal resistance subtracts voltage from the emf. The voltage that is left over is called the ***terminal voltage***. It would be the voltage between points A and B.

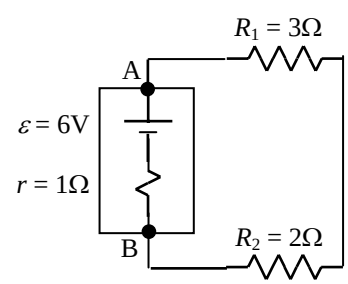

Fig 18.7

Example 18-1: emf, Internal resistance, and terminal voltage.

Treat this like any circuit problem. You can use the rules for current, voltage, and resistance. It is helpful to use a chart, like the one below Fig 18.4, on the previous page. You can also use Kirchhoff's Rules. Just treat the internal resistance like any other circuit component. This means it has negative voltage. This is a series circuit $R_s = \sum R_i = 1 + 2 + 3 = \boxed{6\Omega}$. Plug in *emf* and total R into $V = IR$, $I = \frac{V}{R} = \frac{6V}{6\Omega} = \boxed{1A}$. Since this is a series circuit (including r), $I_S = I_1 = I_2 = I_3 = \ldots$

	V	I	R
emf	+6 V	1 A	6 Ω
r	-1 V	1 A	1 Ω
R_1	-2 V	1 A	2 Ω
R_2	-3 V	1 A	3 Ω

Use $V = IR$ to complete the each row of the chart. Notice that *emf* was used instead of the battery. The reason is that the battery is composed of both the *emf* and the internal resistance. The terminal voltage of the battery is found using $\boxed{V = \varepsilon - Ir}$.

$V = 6 - (1)(1) = \boxed{5V}$

<u>When a problem says that internal resistance is negligible, then it is so close to zero as not to matter mathematically</u>. So, $V = \varepsilon - Ir = \varepsilon - 0$ In this case $\boxed{V = \varepsilon}$, and in these problems V and ε are completely interchangeable.

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