2. Electrostatics

THIS IS A ROUGH DRAFT. Your comments are welcome: hochstim@netside.net

Electostatic force, described below, refers to forces arising from stationary charges.

2.1 Charge and Coulomb's Law

Charge is a funimental property of matter. Like energy, charge is a conserved quantity; in any physical or chemical process the sum total of all charges will remain constant

The charge on a proton is positive, while the charge on an electron is negative. The magnetude of the charge on the proton equals that of the electron. This quantity is known the **elementary charge***, e, (a.k.a. funimental or unit charge).* The value of *e* in SI units is:

$$e = 1.60 \times 10^{-19} \text{C}$$

where *C* is the SI unit of charge known as the **Coulomb.**

Like charges experience a repulsive electrostatic force when placed near each other, while unlike charges are subject to an atractive electrostatic force. The magnitude of this force may be found by applying **Coulomb's Law:**

$$F = k\frac{q_1 q_2}{r^2}$$

where k is a proportionality constant equal to 9.0 x 10^9 N·m/C^2, q_1 and q_2 are the magnitude of the two charges in Coulombs, r is the separation between the charges in meters, and F is the **Coulombic force,** in Newtons.

assignment ►

2.2 Electric Fields

Electric Fields

■ The **electric field,** *E,* is a vector quantity that describes the direction and magnetude of force that a charge will experience. The word *field* is use to describe quantities that are defined over an extended region of space rather than at a speciic point.

►**Electric fields are caused by the presents of charge,** so when a small positive charge known as a *test charge,* q_o, is placed near another charge, *Q,,* an electric field emminating from Q*,* will cause an electrostatic force, *F,* on q_o, (and visa versa). The magnetude of E is given by:

$$\mathbf{E} = \frac{\mathbf{F}}{q_o}$$

where the SI units for the electric field are N/C, since F is in Newtons and q_o is in coulombs. **The direction of E is the same as the direction of F**. Remember that the test charge (which is used to *test* for the magnetude and direction of *E*) is positive. Therefore, the direction of E will radiate away from a positive Q, and toward a negative Q. Shortly, we'll see this represented graphically.

The electric field strength at a distance *r* from a charge *Q*, may be found by use of equations#■ and#■ :

$$F = k\frac{q_o Q}{r^2}, \quad F = Eq_o, \quad Eq_o = k\frac{q_o Q}{r^2}, \ \ldots$$

$$E = k\frac{Q}{r^2}$$

Equation 3.1 Electric field due to a point charge *Q*.

The charge Q is called a point charge, since it is considered to occupy a single point in space. Note that E obeys the inverse square law, i.e., E decrease by the inverse sqaure of the distance from Q.

assignment ►

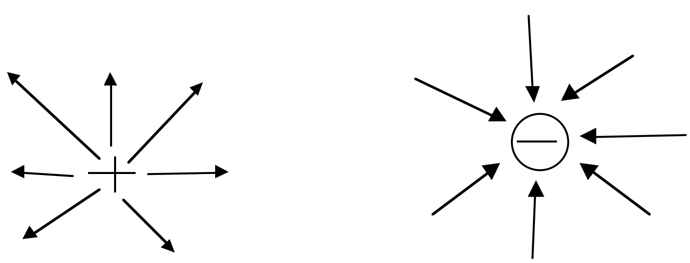
show vector nature

Electric Field Lines

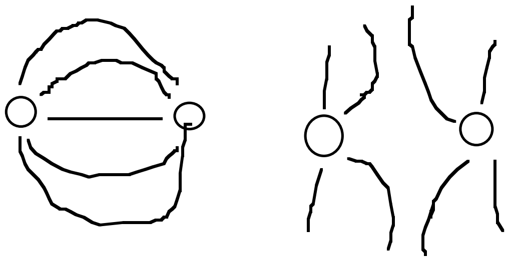
The direction and magnetude of an electric field may be represented by a series of arrows. These arrows are also known as lines of force, because they represent the direction and strength of the force caused by the electric field on q_o. A few simple rules concerning electric field lines follow:

►Field lines radiate away from positive charges and toward negative charges.

►As the field strenght increases, the seperation between field lines decreases.



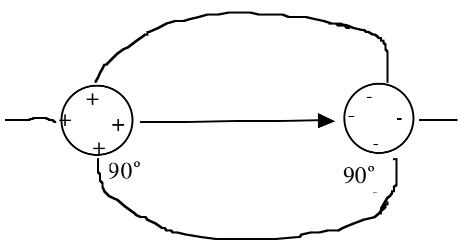
►When two or more charges are present, the electric field is the result of the vector sum of all individual field lines.



Conductors and Insulators

Conductors are materials in which charge freely flows, while in **insulators** charge flows with difficulty, or not at all. **When a conductor takes on a charge, the excess charge distributes itself evenly through out the surface of the object.** The reason for this behavior is based on Coulomb's law. Since like charge repel, the excess charges move as far away from each other as possible, i.e., to the surface. Since all the excess charge resides at the surface, the suface may be considered to be nothing more than a number of equally distributed individual point charges. From this follows the final rule regarding field lines:

►At the surface of a conductor, all field lines are perpendicular to the surface.



2.3 Electrical Potential Energy and Electrical Potential

Electrical Potential Energy and Potential

We have seen that the gravitational potential energy of an object depends the mass of an object and its height. Analogously, the **electrical potential energy,** *EPE,* depends on the charge on an object and its distance *r* from some location. Gravitational PE may be found by multipling force (mg) times displacemnt (h). EPE is found the same way:

$$F = k\frac{q_1q_2}{r^2}, \quad F \cdot r = k\frac{q_1q_2}{r},$$

The electrostatic force (F) times the displacement (r) gives:

$$\boxed{EPE = k\frac{q_1q_2}{r}}$$

Note that when q_1 and q_2 are like charges EPE is positive, and that when q_1 and q_2 are oppositely charged EPE is negative.

When a small positive test chrage q_o is moved from infinity to a location near a postive charge *Q*, positive work *W* will need to be done against the repulsive electrostatic force. This work will be equal to the EPE which will also be positive. Conversley, when *Q* is negative, q_o will be attracted to *Q*. In this case *W* is still equal to the EPE, but both are negative because energy is released.

■ The **electrical potential,** or **potential,** *V,* is a scalar quatity defined as the EPE of q_o divided by the charge of q_o. Its value is given relative to infinity, at which point *V* is arbitarially set to be zero.

$$V = \frac{EPE}{q_o} \quad \textbf{OR} \quad V = \frac{W}{q_o}$$

The SI unit of electrical potential is the volt (V). 1 volt is equal to 1 joule/coulomb.

►While EPE is a measure of energy, **potential is the energy per unit charge.**

The voltage due to *Q* can be found in a few easy steps (recall, work = force·displacement):

$$F = k\frac{q_o Q}{r^2}, \quad EPE = W = F \cdot r, \quad \frac{F \cdot r}{q_o} = \frac{kQ}{r}, \ldots$$

$$V = \frac{kQ}{r}$$

Equation 3.2 Voltage due to a point* charge *Q*
(*A *point* charge refers to charge which is confined to a small volume.)

Two important distinctions between the electric field and electric potential are:

►*E* is a vector and *V* is a scalar

►*E* varies with the inverse square of distance, while *V* varies by the inverse of distance.

assignment ►

ask about where E and V is zero.

■ The **potential diffrence** or **voltage** is the change in the potential from one point *A,* to another point *B.* This may be expressed as V_{AB}, or simply as *V* (the same as potential!).

Imagine that q_o moves from point *A* to point *B*. The potential difference $V_{AB} = \Delta V = V_B - V_A$. Therefore:

$$V_{AB} = \frac{EPE_{AB}}{q_o} \quad \textbf{OR} \quad V_{AB} = \frac{W_{AB}}{q_o}$$

Where $EPE_{AB} = \Delta EPE = EPE_B - EPE_A$ and $W_{AB} = \Delta W = W_B - W_A$, respectively. When q_o moves from one point to another, the quantity of work done (i.e., ΔEPE) is independent of the path that q_o takes. From Equation#■, we can see that only the potential difference V_{AB} and the value of q_o are relivant in determining the work ($W = \Delta V \cdot q_o$).

Finally we may use EQ#■ to derive an additional formulation of potential:

$$V_{AB} = kQ\left[\frac{1}{r_B} - \frac{1}{r_A}\right]$$

In Equation#■ the poptential difference between two points *A* and *B*, is given as a function of their distance *r*, from a point charge *Q*. **Note that when *r* remains constant there is no change in the potential around *Q*.**

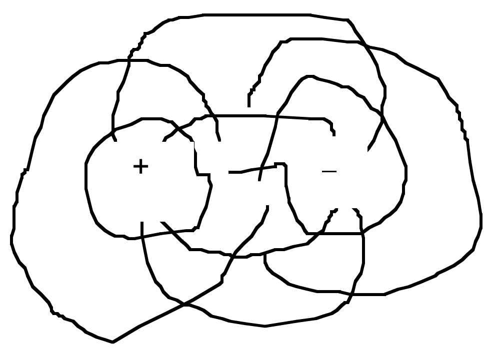
Equipotental Surfaces and Lines

An **equipotental surface** is a surface with a constant electrical potential. An **equapotential line** is any cross-section cut through an equipotional surface. As an example imagine a point charge *Q*. at the center of an infinite number of concentric sphereical shells. According to Eq#■ each shell is an equipotential surface. Now imagine cutting a cross-section through these shells. Each circular ring is an equipotential line.

Electric Fields Revisited

In Figure#■ equipotential lines and electric field lines are drawn for the cross-section of the space around a positive and a negative charge.

p 537 cut/John



You should note that the **equapotential lines are always perpendicular to the electric field lines**. This allows us to view the electric field in a new way. Instead of regarding them in terms of force per unit charge, we may instead view them as running from high to low potential. In fact instead of measuring the electric field strength in terms of N/C, we may find the average magnitude of the electric field by measuring the change in voltage per meter or:

$$\overline{E} = \frac{\Delta V}{\Delta r}$$

EQ#■ may be used to find the *average* electric field strenght, $\overline{E}$, for regions with a varying E-field (as *Δr* is reduced $\overline{E}$ approaches *E*.). For regions with a constant *E* an exact value may be found. The SI units for *E* as expressed in EQ#■ is *V/m,* which is equivalent to *N/C.*

assignment ►

Do a diagram, at which point is E-field constant (where lines parrelel)

2.4_Capacitors

Conductors and Insulators

Electrical conductors are substances (usually metals) that readily allow the flow of electrons. **Insulators** are materials (usually nonmetals) which do not exhibit any apprichable degree of electron mobility.

Capacitors

Capacitors are devices that store charge; they are composed of both conductors and insulators. The simplest type of capacitor is the parralel plate capacitor. It consists of two flat conducting plates which are separated by an insulating material known as a **dielectric.** The seperation between the two plates *d* is constant. Each plate stores an equal but opposite quantity of charge *q.*

In Figure#■ we initially see an uncharged capacitor. Next we connect each plate to a battery. which removes electrons from one plate and deposits an equal number ofelectrons on the other. This causes the plates to become charged, resulting in a potential diference *V* which is equal to the voltage of the battery. **Capacitance,** *C,* is a measure of the amount of charge that can be stored as a function of *V,*

$$C = \frac{q}{V}$$

where *q* is the quantity of charge in Coulombs on **one** plate. The SI unit of capacitance is the **farad,** *F.* 1F = 1 Coulomb/Volt. Because the farad is a very large unit, capacitance is often reported in microfarads, nanofarads, or picofarads ($1\ \mu F = 10^{-6}$ F; $1\ nF = 10^{-9}$ F; $1\ pF = 10^{-12}$ F).

assignment►

If a 12 V battery is attached to a parrelel plate capacitor with a plate area of overlap of 0.05 m^2 and a seperation of 0.06 cm^2. What will be the electric field strength at in the interior of the capacitor? $E = V/d$ or $\Delta V/\Delta r$

The value of the capacitance is a function of the area *A* over which the plates overlap, the separation between the plates *d,* and the elctrical properties of the dielectric, which is represnted by κ the dielectric constant.

$$C = \frac{\kappa \varepsilon_o A}{d}$$

The term ε_o is a constant called the **permittivity of free space,** which is equal to 8.85×10^{-12} F/m. The dielectric constant is a unitless number equal to one when the dielectric is a vacuum or air, and is greater than one for other substances.

example►

show V and E for parrlel plat cap. show how lines bend at end se fig 16-2 p378 Ginancoli

Dielectrics and the Electric field

Energy Stored in a Capacitor

The quantity of energy stored in a capacitor may be found when the capactance and voltage are known by the use of EQ#■ .

$$\text{Energy} = \tfrac{1}{2}CV^2$$

2.5_Electrical Dipoles

Need to do see Shat p. 127 Also see John/Child p.457

Electric Circuits

3.1_Direct Current

Current and Electromotive Force

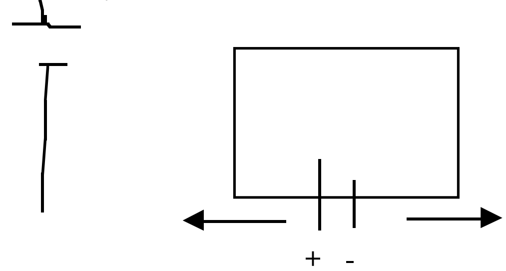
A **battery** is a device that stores electrical energy. Most batteries have two **terminals** (*conducting surfaces)*, one positive (*high potential*), the other negative (*low potential*). When a conducting loop of wire is placed on each of a battery's terminals a circuit is formed. A **circuit** refers to any closed conducting loop. Due to a potential difference (voltage) arising from chemical reactions within the battery, electrons flow out of the negative terminal, through the wire, and into the positive terminal. This unidirectional flow of charge is called **direct current,** ***I.*** Mathamatically, current is defined as the quantity of charge *q* that passes through a cross-section of a conductor in a given unit of time:

$$I = \frac{q}{t}$$

The SI unit of current is the **ampere** *A*. 1 A = 1C/s.

Before it was known that electrons where the charge carriers responsible for current, a hypothetical construction called **conventional current (a.k.a. current)** was adopted, and remains in use today. **Current** is imagined to be composed of *positive* charge carriers. As a result, **current flows in the opposite direction as electrons do,** i.e., current flows from high to low potential. Fig#■ depicts the direction of electron flow and of current.

p 554-555 cut/john also talk about how to depect the battery and about EMF



The voltage across the terminals of a battery when no current is present is called the **electromotive force** or **emf,** $\mathcal{E}$. In Fig#■ the battery has an emf of 12 volts.

Resistance and Ohm's Law

Under ordinary circumstances the amount of current in a circuit is directly proportional to the voltage, or $V \propto I$. For a given voltage the magnetude of the current depends on the *resistance*. The **resistance,** *R,* is analogous to friction; the greater the resistance, the more electrical energy is converted into heat. As a result the current is greatest when the voltage is large and the resistance is low, or I = V/R. This expresion is known as **Ohm's law** and is commonally writen as::

$$\boxed{V = IR}$$

where the SI units of *R* are given in ohms, *Ω*. 1 Ω = 1 volt/ampere (V/A). Components in a circuit that have an significant resistance are called **resistors.**

Internal Resistance

As current moves through a circuit the energy per unit charge (that's the voltage) falls due to resistance. This resistance is present not only in the wire, but also in the battery. When a battery generates a current, the voltage across its terminals (**terminal voltage**) is less than its emf. This is due to resistance within the battery called **internal resistance,** R_{IN}. Lets use Ohm's law to solve for R_{IN}:

example ►

A 12.0 V battery is found to have a terminal voltage of 11.8 V and a current of 0.50 A when a wire forms a circuit at the battery's terminals. What is the battery's internal resistance?

solution:

To solve for R_{IN} we may rearrange Ohm's Law:

$$R_{IN} = \frac{\Delta V}{I}$$

ΔV is the drop in voltage due to R_{IN}, or 12.0 V – 11.8 V = 0.20 V; I is given as 0.50 A, so:

$$R_{IN} = \frac{0.20\ \text{V}}{0.50\ \text{A}} = 0.40\ \Omega \ \blacklozenge$$

assignment ►

What is the resistance of the wire in the previous example?

solution:

The voltage drop across the wire is 11.8 V. The current is 0.50 A. Using Ohm's law to solve for R we get:

$$R = \frac{11.8\ \text{V}}{0.50\ \text{A}} = 23.6\ \Omega \ \blacklozenge$$

►Referring to example and assignment above:

- Since the current had only one path to follow, the same quantity of charge must flow through both the battery and in the wire. Current is analogous the the flow rate of water. If there is only one pipe, the quantity of water flowing through the pipe must be identical through out the pipe.
- Resistance in a circuit acts like a series of waterfalls. The drop in voltage ($\Delta EPE/q$) is analogous to the drop in pressure (ΔPE_{grav}/volume) as water loses potential energy.
- The battery acts like a pump increasing the potential (pressure) of the current. When the current has completed its path around the circuit the drop in voltage is equal to the emf of the battery or:

$$V_{total} = \Delta V_{IN} + \Delta V_{wire}$$
$$V_{total} = IR_{IN} + IR_{wire}$$
$$V_{total} = I(\Delta V_{IN} + \Delta V_{wire})$$
$$12 = 0.5(0.4 + 23.6)$$

- In this example the resistance of the battery and the wire were of central importance, however **in most cases the resistance of the battery and the wire are negligable.** On the MCAT you may ignore these terms unless you are given specific information about them, or reason to believe that these variables are relivant to the question.

Variables effecting Resistance

When water moves through a long and narrow pipe there is a greater resistance to flow than when a shorter pipe with a larger diameter is used. By analogy, long wires with small diameters offer greater restance to the flow of current than shorter wires with a larger cross-sectional area do. This relationship is quantified below:

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

Where *L*and *A* are the length and cross-sectional area of the conducting material, respectively. The **resistivity,** ρ, is a proportionality constant dependent on the conducting material and its temperature. Note that while resistivity is a constant for a given material at a specific temperture, resistance depends on the reisistivity and the geometric of the conducting substance.

Power

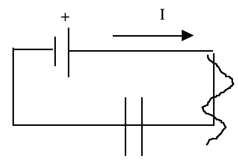
When current flows through a ressistor power is dissapated in the form of heat. The power loss may be found by:

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

where *V* is the voltage drop across the ressistor (*not necessarily across the whole circiut)*.

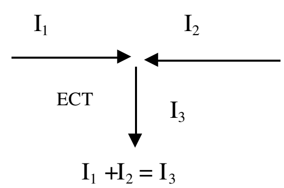
Circuit Diagrams

The following symbols are conventually used to represent components within a circuit:

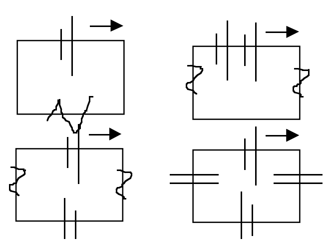


3.2 Kirchoff's Rules

►**Junction Rule:** **At any junction in a circuit the quantity of current flowing in will equal the quantity of current flowing out.** This situation depicted in Fig#■ is analogous two water pipes converging; the volume flow rate in pipe 3 will be equal to the volume flow rate in pipe 1 plus pipe 2.

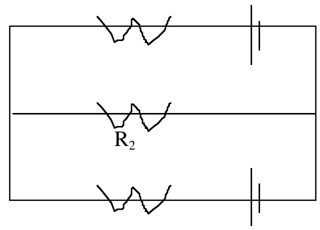


►**Loop Rule:** **The rise in potential equals the drop in potential around any closed circuit loop** By analogy, we may imagine water being pumped up hill. The water pressure increases as a result of increased gravitational potential energy. As the water flows around and back down to the pump it returns to its original position and pressure. As you may have guessed the pump is analogous to the battery, and the pressure is analogous to the potential. Some examples are given below.



example ►

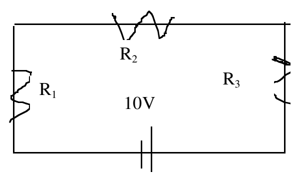
What is the voltage drop across resistor R_2?



3.3_Series and Parellel Wiring

Resisters in Series

When circiut components are connected in a single file arrangement they are said to be wired **in series.** The three resisters below are wired in series.



■ *Since each resister lies on the same path without any branching, the current that runs through each resister must be the same.* As current passes through the battery its potential is raised by ten volts. As the current passes through each resister its potential drops, in accord with Kirchokov's loop rule.

assignment ►

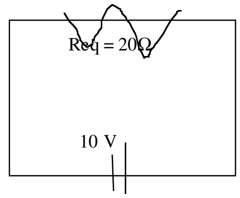
Refering to Fig #■, if the voltage drop across R_1 is 2V, and across R_2 is 3V, what is the voltage drop across R_3?

solution: need to solve it loop rule

Resistances in series are additive. This means that we may reduce the three resistors in Fig#■ to one *equivalent resistor.* An **equivalent resistor** is an imaginary circuit componet that is used to simplify a circuit diagram. The imaginary resistance through an equivalent resistor is called the **equivalent resistance,** R_{eq}. In this case we may say $R_{eq} = R_1 + R_2 + R_3$, or for the more general case:

$$R_{eq} = R_1 + R_2 + R_3 \ldots$$

Refering again to Fig#■, if R_1, R_2, and R_3 are 4.0 Ω, 6.0 Ω, and 10 Ω respectively, we may now redraw the circuit to include just one equivalent resisitor in place of R_1, R_2, and R_3:

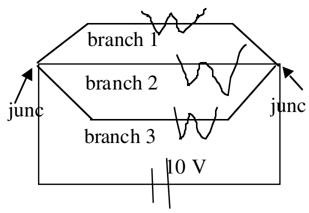


If we wished to solve for the total power consumed by this circuit we could simply use the battery's emf and the R_{eq}, to give:

$$P = \frac{V^2}{R_{eq}}, \quad P = \frac{(10\ V)^2}{20\ \Omega} = 5\ W$$

Resisters in Parrelel

"Branches" exist where ever a circuit junction is present. In order for components to be wired **in parrelel** only one component may be present on a branch, and each branch must begin and end at the same junctions. The three resisters below are wired in parrelel.



■ *Since each resister lies on parelel paths the voltage drop across each resistermust be the same.* In this case the voltage drop from junction 1 to junction 2 will be 10 V, therefore all resistors will share the same 10 V drop

assignment► neeed solve it junction rule rule

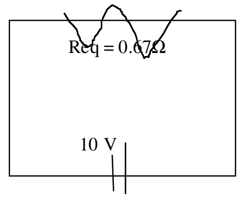
> Referring to Fig#■, if the battery geneates a curent of 20 A, and 8 A pass through R_1 and 4 A pass through R_2, what is the current through R_3?

Resistances in parelel are added as recipricals. This means that we may reduce the three resistors in Fig#■ to one equivalent resistor by use of the following equation:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

Refering again to Fig#■, if R_1, R_2, and R_3 are each 2.0 Ω, we may now redraw the circuit to include just one equivalent resisitor in place of R_1, R_2, and R_3:

$$\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2}, \qquad \frac{1}{R_{eq}} = \frac{3}{2}, \qquad R_{eq} = \frac{2}{3} \text{ or } 0.67\ \Omega$$



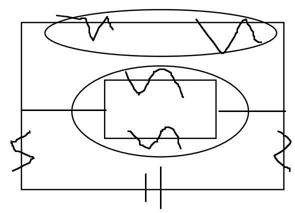
Note that had these three resistors been wired in series the equivalent resistance would have been larger (1.5 Ω rather than 0.67 Ω). This result can be generalized: **When a group of resistors are wired in series, their equivalent resistance will always be greater than when they are connected in parrelel.**

Resistors in Complex Circuits

In circuits containing resistors connected in both series and parellel, the two methods illustrated above are both used to solve for the equivalent resistance. Here's an example:

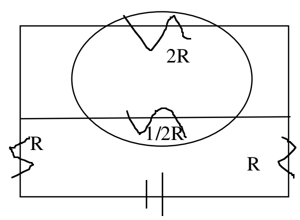
example ►

In the circuit below all resistances are equal to 0.50 Ω, and the emf of the battery is 12.0 V. Solve for the current, and for the power dissapated.

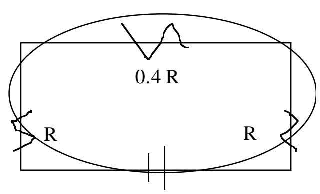


solution:

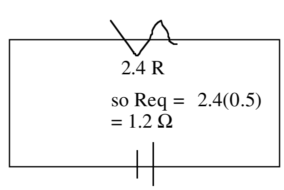
First we ect. (since all R's are same lets leave them as R for now)



Then ect



then



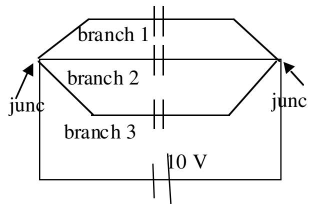
The curent may now be found tc $I = V/R = 12/1.2 = 120$ A. & $P = IV = (120)(12) = 144$ W. or I^2R or V^2/R.

assignment ►

Ask about solving for voltage drop , current, and power for one o more resisters.

Capacitors in Parrelel

The three capacitors below are wired in parrelel:



■ *Since each capacitor lies on parelel paths the voltage drop across each capacitor must be the same.* In this case the voltage drop from junction 1 to junction 2 will be 10 V, therefore all capacitors will share the same 10 V drop

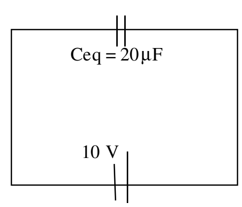
assignment ►

If the one of the three capacitors in Fig #■ has a capacitance of 1.0×10^{-6} F what is the magnitude of the charge stored on each plate of this capacitor?

Capacitances in parrelel are aditive. This means that we may reduce the three capacitors in Fig#■ to one *equivalent* capacitor. An **equivalent capacitor** is an imaginary circuit componet that is used to simplify a circuit diagram. The imaginary capacitance through an equivalent capacitor is called the **equivalent capacitance,** C_{eq}**.** In this case we may say $C_{eq} = C_1 + C_2 + C_3$, or for the more general case:

$$C_{eq} = C_1 + C_2 + C_3 \ldots$$

Refering again to Fig#■, if C_1, C_2, and C_3 are 4.0 μF, 6.0 μF and 10 μF respectively, we may now redraw the circuit to include just one equivalent resisitor in place of C_1, C_2, and C_3:

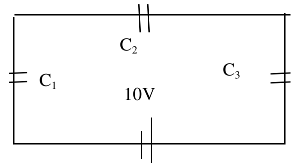


If we wished to solve for the total charge stored in this circuit we could simply use the battery's emf and the C_{eq}, to give:

$$q = C_{eq} \cdot V, \quad q = (20 \times 10^{-6}\ \mu F)(10\ V) = 2.0 \times 10^{-4}\ C$$

Capacitors in Series

The three capacitors below are wired in series.



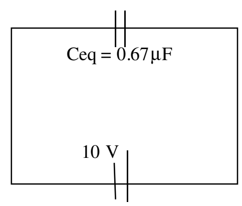
■ *Since each capacitor lies on the same circuit, the quantity of charge transferred from the battery to each plate of each capacitor must be the same.* The current that is produced by the battery causes equal quantities of charge to be deposited and removed from each plate of each capacitor. As the capacitors are charged to capacity the flow of current slows and eventually stops due to increasing Coulombic forces. Note that while q will be the same for all capacitors, the voltage drop across each capacitor will be inversely proportional to the capacitace ($q = C \cdot V$).

Capacitances in series are added as recipricals. This means we may reduce the three capacitors in Fig#■ to one equivalent capacitor though the use of the following equation:

$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \dots}$$

Refering again to Fig#■, if C_1, C_2, and C_3 are each 2.0 μF, we may now redraw the circuit to include just one equivalent capacitor in place of C_1, C_2, and C_3:

$$\frac{1}{C_{eq}} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2}, \qquad \frac{1}{C_{eq}} = \frac{3}{2}, \qquad C_{eq} = \frac{2}{3} \text{ or } 0.67\ \mu F$$

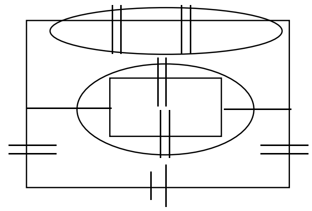


Note that had these three capacitors been wired in parrelel the equivalent capacitance would have been larger (1.5 μF rather than 0.67 μF). This result can be generalized: **When a group of Capactitors are wired in parrelel, their equivalent capacitance will always be greater than when they are connected in parrelel.**

Capacitors in Complex Circuits

assignment ►

In the circuit below all capacitances are equal to 0.50 μF, and the emf of the battery is 12.0 V. Solve for the the total charge and power stored by this system.



Summary

Component:	**Wired in:**	**All share the same:**	**Formula:**
Resistors	**Series**	Current	$R_{eq} = R_1 + R_2 + R_3 \ldots$
Resistors	Parrelel	Voltage	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$
Capacitors	Parrelel	Volatage	$C_{eq} = C_1 + C_2 + C_3 \ldots$
Capacitors	Series	Charge	$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots$

3.4_An Aqueous Anology

INSTRUCTIONS:	The following section may help solidify your understand of Chapters# &■; if not, skip it.

A common anology is the comparison of the flow of water to the flow of charge (curent). Here's a list of aqueous terms followed by their electrical anologs (the "≡" symbol means *is equivalent to)*:

*The **volume** of water flowing through a pipe in a given unit of time is analogous to the quantity of **charge** flowing through a wire in a given unit of time.*

1. volume of H_2O (vol)
≡ **quantity of charge** (q)

2. flow rate (Δvol/Δtime)
≡ **curent** (Δq/Δtime)

The gravitational PE of water, (GmM/r), or (mgh) for small values of Δh, is analogous to the electric PE (kqQ/r), where G and k are constants, m and M are masses, and q and Q are charges.

3. gravitational potential energy (PE_{grav})
≡ **electrical potential energy** (EPE)

Absolute pressure is analogus to potential, while the change in pressure is analogous to voltage.

4. absolute pressure (PE_{grav}/vol) ⟶(ρgh = mgh/vol = PE_{grav}/vol)*
≡ **potential** (EPE/q)

5. Δpressure (ΔPE_{grav}/vol) ⟶(ρgΔh = mgΔh/vol = ΔPE_{grav}/vol)
≡ **voltage** (ΔEPE/q)

The following analogs (dams, waterfalls, resistance, and pumps) complete the list:

6. dams store vol
≡ **capacacitors** store q

7. waterfalls decrease PE_{grav} causing a decrease in pressure.
≡ **resisters** decrease EPE causing a decrease in voltage

8. resistance increases in a pipe of smaller diameter
≡ **resistance** increases in a wire of smaller diameter

9. pumps (increase pressure)
≡ **batteries** (increase potential)

** "ρ" refers to density in this context.*

3.5_Alternating Current

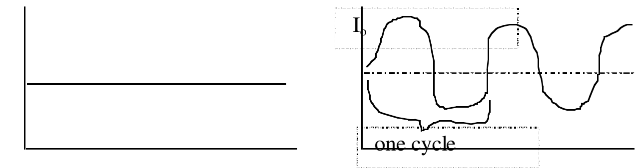
AC Current

Unlike direct current, which flows in one direction, **alternating current** oscilates back and forth. The most common form of alternating current is sinusoidal i.e., is described by the *sine* function. Specifically:

$$\boxed{I = I_o \sin(2\pi f t)}$$

where I_o is the maximum value of the current, I is the value of the current at time t, and f is the frequency of oscilation. Recall that since $2\pi f = \omega$, Eq#■ may be condensed to:

$$\mathbf{I = I_o \sin(\omega t)}$$



Direct Current AC

Unlike direct current which always has a positive value of I, alternating current is bidirectional and thus has both positive, negative and zero values for current at different times. Since $P = I^2R$, the power delivered by an alternating current will be greatest for I_o and zero when I = zero. Note that since I is squared, the power, although continuously changing, will never be negative.

RMS Current and Voltage

Since V = IR, voltage is directly proportional to current. Therefore $V = V_o \sin(2\pi f t)$.

Since P = IV, $P = I_o V_o \sin(2\pi f t)$.

What's the point? Well, since I, and V, and P, are all constantly changing, we need a simple mathamatic method for dealing with this. This method envolves using **root mean square curent and voltage,** I_{rms} ,V_{rms} , to average out these changes. Root mean square current and voltage are defined as:

$$\boxed{I_{rms} = \frac{I_o}{\sqrt{2}}, \qquad V_{rms} = \frac{V_o}{\sqrt{2}},}$$

When working with alternating currents we may use the same equations as we did with direct currents as long as we use I_{rms} for the current and V_{rms} for the voltage. Ohm's law becomes:

$$V_{rms} = I_{rms}R$$

and the **average power,** $\overline{P}$, is:

$$\overline{P} = I_{rms}V_{rms} = I_{rms}{}^2R_{rms} = \frac{V_{rms}{}^2}{R_{rms}}$$

Finally,

$$\overline{P} = I_{rms}V_{rms} = \left(\frac{I_o}{\sqrt{2}}\right)\left(\frac{V_o}{\sqrt{2}}\right) \qquad \text{So…}$$

$$\boxed{\overline{P} = \tfrac{1}{2} I_o V_o}$$

Magnetic Fields

Magnetic fields, *B,* are similar to electric fields, both are vector quantities, that describe the magnetude and direction of force that a charge will experience. Magnetic field lines are used to visualize the dirction and strength of the magnetic field in a similar manner as is done with electric fields.Unlike the electric field, the magnetic field can only exert a force on a *moving* charge.

Charged particals can produce both electric and magnetic fields. While a stationary charge generates only an electric field, *E,* a moving charge produces both an electric and a magnetic field. Magnetic fields are also found surronding certain metalic (typically iron) objects that have been previously exposed to powerful magnetic fields. Such objects are known as **perminant magnets.**

4.1 Magnetic Force

Force on a Moving Charge

When a charged particle *q,* moves at a velocity *v,* through a uniform magnetic field *B,* a **magnetic force** *F* is exseted on the particle, given by,

$$\boxed{\mathbf{F} = q\mathbf{v}\mathbf{B}\sin\theta}$$

where the magnetic field strenght *B* in SI units is the **tesla,** *T.* 1T = 1 N/A·m, and θ refers to the angle between the particle's velocity vector and the direction of the magnetic field. Fig #■ depicts a method (Right Hand Rule-1, *RHR-1*) for determining the direction of F.

explain θ and
…..
…..out of paper
and
xxxx into paper
xxxxx

Using your right hand if you point your thumb in the direction of the velocity vector of a positively charged particle, and your fingers in the direction of B, your palm will face in the direction of F. For a negatively charged particle the direction of F will be reversed. Note that the angle θ is represented by the angle made between your thumb (v) and fingers (B). If v is parrelel to B no force is excerted, but when v and B are perpendicular F is at a maximum.

If a positively charged particle moving to the North encounters a uniform magnetic field directed upward the particle will experience a force *F* directed to the west, as depicted in Fig#■. Since v and B ae pependicular sin θ will be equal to one, and F = qvB. In response to F the partical will accelerate by continuely changing the direction, but not the magnetude, of its velocity vector. As it does the direction of F will continuously change as well. The end result is the particle exhibits uniform circular motion.

PIC HERE
SHOW NORTH

see p602 Cut/John

Since F is always directed toward the center of motion we may say that the magnetic force also acts as the centripital force, or:

$$\mathbf{F}_{\mathbf{mag}} = \mathbf{F}_{\mathbf{c}}$$

$$q\mathbf{v}\mathbf{B} = \frac{m\mathbf{v}^2}{r}$$

$$\boxed{r = \frac{m\mathbf{v}}{q\mathbf{B}}}$$

were *r* is the radius of the circular path.

assignment ►

A particle of mass # moving horizontally encounters a uniform magnetic field of # directed downward. The partical begins to rotate clockwise in circle of radius #. What is the charge (including the sign) on the particle?

solution:

Force on a Current-Carrying Wire

Eq#■ states that a charge which moves through a magnetic field will experence a force, unless θ is 0° or 180°. Therefore, it follows that a curent (moving charges) in a wire will result in a net force on the wire as long as the wire does not run parelel to the magnetic field. The magnetude of this force is given by:

$$\boxed{\mathbf{F} = IL\mathbf{B}\sin\theta}$$

where *I* is the curent, *L* is the length of the wire, a*nd* θ is the angle made between B and I. Fig #■ demenstrates the use of RHR-1 for Eq#■. Recall that the direction of I is always given for the conventional current, which is composed of imaginary positive charge carriers.

Insert Fig#■

4.2_ Magnetic Fields Produced by Current

Long Straight Wires

A current *I* in a long straight curent carrying wire will produce a circular magnetic field whose strength is given by:

$$\boxed{\mathbf{B} = \frac{\mu_o I}{2\pi r}}$$

where μ_o is a constant called the **permitivity of free space** = $4\pi \times 10^{-7}$ T·m/A, *I* is the current, and *r* is the prepndicular distance from the wire. The direction of B is determined through the use of Right Hand Rule-2, *RHR-2,* below.

Insert Fig#■ RHR-2

Loops of Wire

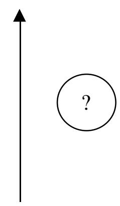
A current I in a loop of wire will also produce a circular magnetic field whose strength at the center of the loop is given by:

$$\mathbf{B} = \frac{\mu_o IN}{2r}$$

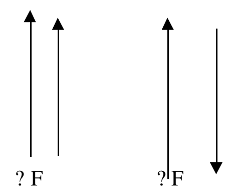
where N is the number of coils (turns) of wire, and r is the radius of the loop.

Insert Fig#■ RHR-2

example ►



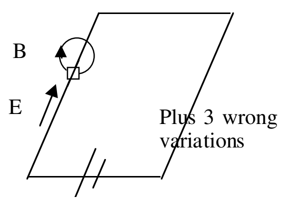
Find B



Find F

example ►

Which of the following corectly depicts the direction of the electric and magnetic fields?



4.3_Current Produced by Magnetic Fields

Current moving though a conductor generates a magnetic field; conversly the movement of a conductor through a magnetic field can generate current. When a conducting material cuts through the lines of a magnetic field, the charged particals in that conductor experience a magnetic force. When a wire cuts across a uniform magnetic field at constant velocity, a direct current of constant magnetude is generated. When a loop of wire is rotated at constant angular velocity across a magnetic field, a sinusuidal alternating curent results.

Possibly a passage on a rail gun and another on a generator could be included here.