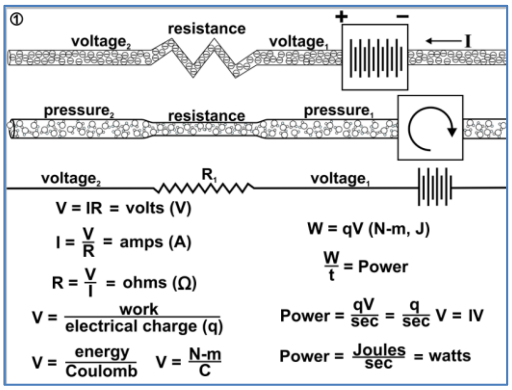
Test, Lesson 12 – Moving Electrical Charges

Introduction to Electricity 1

The flow of electricity is like the flow of water that completely fills a pipe.



The number of electrical charges, not electrons, passing by a fixed point is the current, symbolized by the letter I.

The battery is a pump providing electrical pressure, called voltage, that moves electrical charges through the circuit.

The resistance to water flow is a narrowing in the pipe. Voltage is the water pressure.

A narrowed section of pipe slows the current flow through that section, but because the water completely fills the pipe and water is incompressible, the current slows throughout the entire circuit – before and after the segment of high resistance. The same goes for electrical current. Current flow is the same before and after a resistor.

Mathematically, voltage is current times resistance. Which means that current is voltage divided by resistance. And resistance is voltage divided by current.

The units for current are amps; the units for voltage are volts; and the units for resistance are ohms, symbolized by the Greek letter omega (Ω).

Electrical charges move because of a voltage gradient created by the battery. Voltage is the energy, or work, expended to move one electrical charge a certain distance.

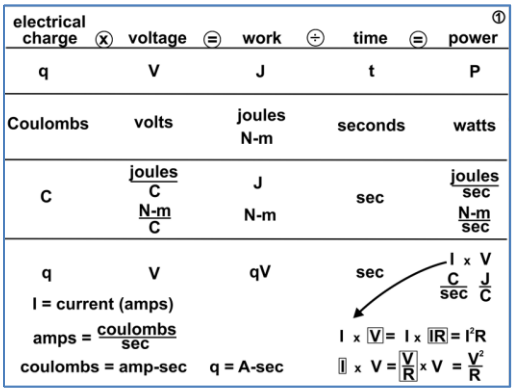
Mathematically, voltage is energy per electrical charge, or energy per coulomb. Energy is force times distance, so voltage is the newton-meters of energy expended to move one coulomb of electrical charge, expressed in newton-meters per coulomb.

The work energy required to move an electrical charge, q, up a voltage gradient is the same as the energy gained when the electrical charge, q, moves down a voltage gradient. That work energy is q times the voltage gradient. The units for work are newton-meters, or joules.

Work per unit time is power. Power, then, is $\frac{qV}{sec}$. The number of electrical charges passing by a fixed point per second is symbolized by q per second. Q per second is current, I, in amps. So current times voltage, I *x* V, is power. The units for power are joules/second, or watts.

Introduction to Electricity 2

Here is a chart showing how electrical charge times voltage equals work energy, and how work per unit time is power.



Notice in the bottom row that electrical work, q times V, per second, is current times voltage.

Current is measured in amps, so amps are coulombs of electrical charge passing by a fixed point per second.

Coulombs, then, are measured in amp-seconds, and q equals amp-seconds.

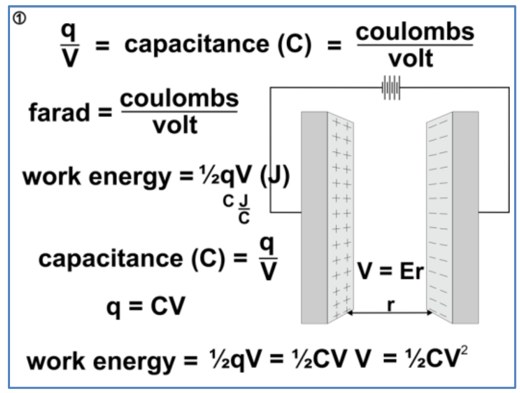
Also notice that since power equals current times voltage, and voltage equals I times R, power equals I^2 R.

Likewise, since I = $\frac{V}{R}$, power also = $\frac{V^2}{R}$.

The bottom row of the chart, q *x* V, is helpful when thinking about capacitors. Here's how.

Introduction to Electricity 3

When electrical charges accumulate on a capacitor, they create a voltage between the capacitor plates equal to the electric field times the distance between the plates



The coulombs of electrical charge needed to create a voltage is symbolized by the fraction $\frac{q}{V}$, coulombs per volt. $\frac{q}{V}$ is capacitance.

When a fraction is divided, the denominator becomes 1. So capacitance measures the coulombs of electrical charge needed to raise the voltage across a capacitor to 1 volt.

The units for capacitance are farads (F). Farads are coulombs per volt.

It takes work to move electrical charges onto the capacitor plates. From the chart on the previous slide, the work of moving an electrical charge up a voltage gradient is q *x* V.

When charging a capacitor, however, it only takes half the work to fully charge up a capacitor because you only have charge one of the plates. The charges on the other plate will automatically flow off that plate.

For this reason, the joules of work needed to move electrical charges onto the capacitor plates to reach a certain voltage is only ½ the coulombs of electrical charges moved times the voltage: ½ qV. The units for ½ qV are joules, because voltage is joules per coulomb, and coulombs times joules per coulomb equals joules.

Since capacitance is $\frac{q}{V}$, or coulombs per volt, the coulombs on a capacitor is its capacitance times its voltage. So ½ q times voltage is also ½ the farads of capacitance times the voltage squared (½ CV^2).

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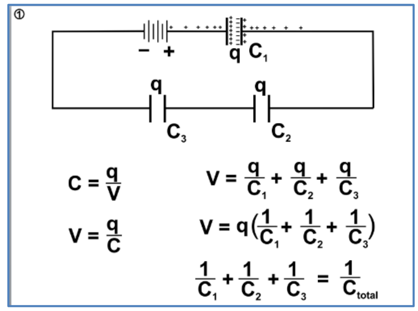
In a circuit, the electrical charges leaving the battery and flowing onto one plate of a capacitor are matched by the same number of electrical charges leaving the other plate. This is repeated for every capacitor in a series, so every capacitor in a series has the same number of electrical charges, q, on its plates as every other capacitor in the series.



Capacitance measures the coulombs of electrical charge needed to raise the voltage across a capacitor to 1 volt, coulombs per volt, which makes the voltage on a capacitor equal to the coulombs divided by the capacitance, $\frac{q}{C}$.

Because the voltage of a capacitor is $\frac{q}{C}$, and q is the same for every capacitor in a series, the voltage drop across each capacitor in a series is determined solely by the capacitance of each capacitor. The voltage drop across each capacitor, when added together, has to equal the voltage of the battery.

The total voltage across all the capacitors is the sum of the voltage drop across each capacitor.

As we did with resistors in parallel, the total combined capacitance of all the capacitors is arrived at by first adding together 1 over each individual capacitance, and reducing that fraction to 1 over some number. That number in the denominator is the total capacitance.

Capacitors in parallel are added together like resistors in a series.

Introduction to Electricity 5

Magnetic poles generate magnetic fields, much like masses generate gravitational fields. The three magnetic poles are a permanent magnet, a moving electrical charge, q, and an electrical current.

①	pole strength ×	permeability =	magnetic flux ÷	magnetic flux surface area =	magnetic field strength
	PS	μ	Φ	A	B
	amp-meters	$\frac{\text{newtons}}{\text{amp}^2}$	$\frac{\text{newton-meters}}{\text{amp}}$ Webers	m^2	$\frac{\text{newtons}}{\text{amp-meter}}$ $\frac{\text{Webers}}{m^2}$ Teslas
permanent magnet	given	μ_o	Φ	$4\pi r^2$	$\frac{\mu_o PS_{given}}{4\pi r^2}$
moving electrical charge	qV	μ_o	Φ	$4\pi r^2$	$\frac{\mu_o qV}{4\pi r^2}$
electric current	Il	μ_o	Φ	$2\pi rl$	$\frac{\mu_o I}{2\pi r}$

magnetic field strength$_1$ x pole strength$_2$ = magnetic force

B_1 — $given_2$, qV_2, Il_2

Here is a chart summarizing the magnetic field strength around the three types of magnetic poles. The units for pole strength are amp-meters. Here's how amp-meters is arrived at for each magnetic pole.

The pole strength for a permanent magnet is given, already having been stamped on the magnet at the factory in amp-meters.

The pole strength for a moving electrical charge is q in coulombs times v, the velocity of the electrical charge in meters per second. Coulombs per second becomes amps, and qv becomes amp-meters.

The pole strength for a current is simply the current, I in amps, times the length of the wire in meters, l, giving units in amp-meters.

Permeability refers to the medium surrounding the magnetic pole. Its units are in newtons per amps squared. The Greek letter mu (μ) stands for permeability. μ_0 is the permeability of empty space.

The total number of magnetic field vectors emanating from a magnetic pole is its flux, represented by the Greek letter phi (Φ). Φ is calculated by multiplying the magnetic pole strength times the permeability of the surrounding medium.

The strength of the magnetic field surrounding a magnetic pole is the number of magnetic flux vectors passing through a unit of surface area surrounding the magnetic flux.

The surface area of a magnetic field around a permanent magnetic pole and a moving electrical charge is a sphere: $4\pi r^2$. The surface area of the magnetic field around a current is the surface area of a cylinder: $2\pi rl$.

The magnetic field strength for a permanent magnet, moving electrical charge, and an electrical current are calculated by dividing the magnetic flux by the surface area around the magnetic flux.

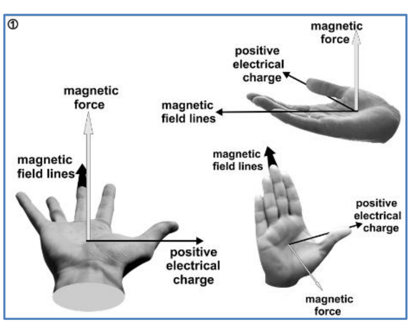
The units for magnetic field strength are newtons per amp-meter, also known as Teslas.

Magnetic field strength is not the same thing as a magnetic force. A magnetic force does not occur until the magnetic pole of a magnetic source is brought into the magnetic field of another magnetic source. The same goes for gravitational fields around a mass: no force is produced until another mass enters the gravitational field. A magnetic field and a gravitational field provide acceleration for a mass or a magnetic pole entering the field of acceleration. Only then is a force created.

The magnitude of the magnetic force that develops when a magnetic pole enters a magnetic field is the product of the magnetic field strength, B, times the pole strength of the approaching magnetic pole.

Introduction to Electricity 6

The right hand rule determines the direction of the magnetic field for positively charged moving electrical charges and positive electrical current. With the right thumb pointed in the direction of movement of the positively charged particle or current, and the fingers pointed in the direction of magnetic field lines through which the positive electrical charge or current is moving, the palm points in the direction of the magnetic force.



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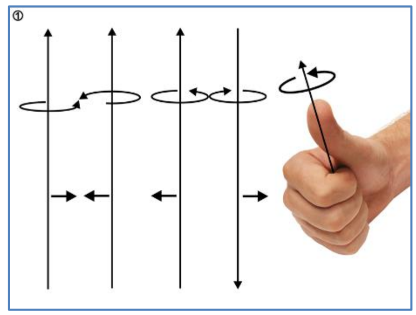
Another use of the right hand rule is to point your thumb in the direction of movement of the electrical current, and curl your fingers. Your fingers represent the magnetic field lines around the electrical current.



Here are two parallel wires, each carrying a current. When the two currents are traveling in the same direction, the magnetic field lines between the wires point in the opposite direction and cancel each other out. The resulting magnetic force between the wires is weakened, allowing the stronger outside forces to push the two wires together.

When the currents are flowing in the opposite direction, the magnetic field lines reinforce each other and overcome the magnetic field lines outside the two wires. The two wires are thus forced apart.

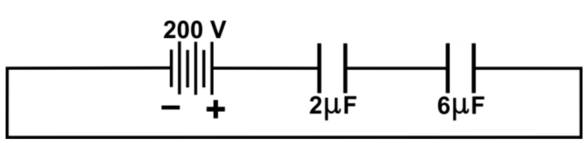
1. What is the resistance of a 100 watt light bulb in a 120 volt house circuit?

(A) 120 ohms
(B) 144 ohms
(C) 240 ohms
(D) 288 ohms
(E) 360 ohms

2. A capacitor with a capacitance of 2 farads is charged with 2 coulombs of electrical charge. How much energy in joules is stored in the capacitor?

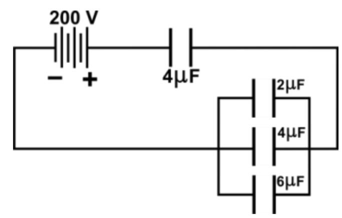
(A) 1 joule
(B) 2 joules
(C) 3 joules
(D) 4 joules
(E) 5 joules

3. Here is a 200 volt battery connected to two capacitors in series. One capacitor has a capacitance of 2 microfarads and the other with a capacitance of 6 microfarads. What is their combined capacitance, and what is the voltage drop across the 6 microfarad capacitor?



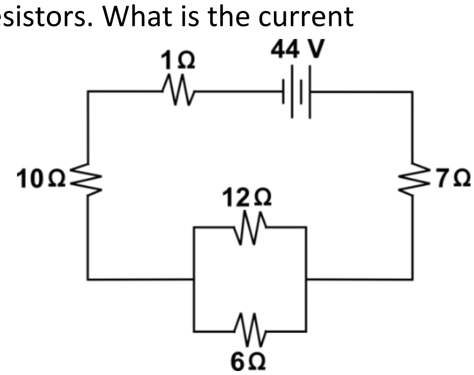
(A) 20 V
(B) 40 V
(C) 50 V
(D) 100 V
(E) 150 V

4. Here is a 200 volt battery connected to four capacitors, three in parallel with capacitances of 2, 4, and 6 microfarads. The fourth capacitor has a capacitance of 4 microfarads. How much charge is on the 2 microfarad capacitor and what is the voltage drop across the 4 microfarad series capacitor?



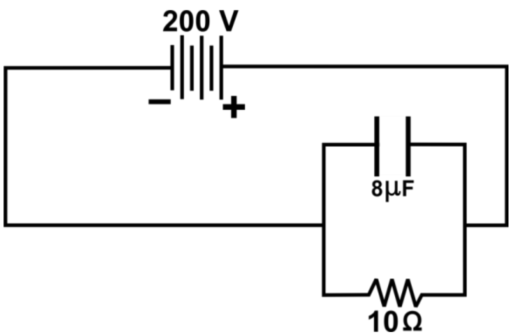
	2 μF Parallel Capacitor	4 μF Series Capacitor
(A)	200 μC	50 V
(B)	200 μC	100 V
(C)	100 μC	100 V
(D)	100 μC	50 V
(E)	300 μC	100 V

5. A 44 volt battery is attached to the following set of resistors. What is the current through, and the voltage drop across, the 6 ohm resistor?



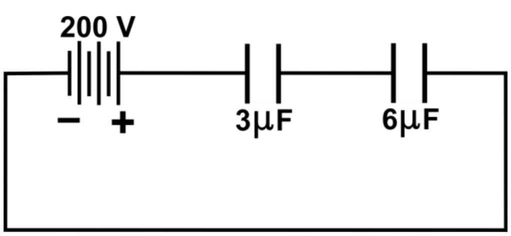
(A) $\frac{2}{3}$, 8 volts
(B) $\frac{3}{4}$, 6 volts
(C) $\frac{4}{3}$, 8 volts
(D) $\frac{3}{4}$, 8 volts
(E) $\frac{2}{3}$, 6 volts

6. What is the electrical charge in coulombs on this 8 μF capacitor?



(A) 9.6×10^{-4} coulombs
(B) 4.0×10^{-3} coulombs
(C) 1.6×10^{-3} coulombs
(D) 1.5×10^{-3} coulombs
(E) 9.6×10^{-2} coulombs

7. A 3 microfarad and a 6 microfarad capacitor in series are connected to a 200 volt battery. How many joules of energy are stored in the two capacitors?

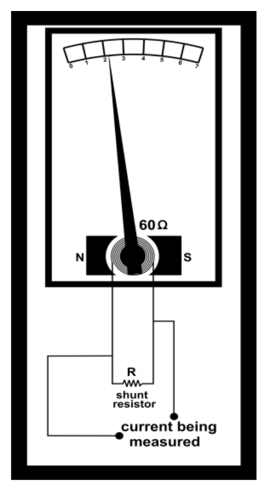


(A) 0.01 J
(B) 0.04 J
(C) 0.06 J
(D) 0.09 J
(E) 0.12 J

8. An ammeter measures current by using a tiny fraction of the current being measured to generate a magnetic field in a coil of wire around the base of a delicate needle. The needle rotates when the magnetic field generated in the coil interacts with a permanent magnet surrounding the base of the needle.

To prevent excess current from rotating the needle beyond its maximal range, the ammeter has to divert the vast majority of the incoming current away from the rotating needle. This is done by inserting a low resistance shunt resistor in parallel with the rotating needle.

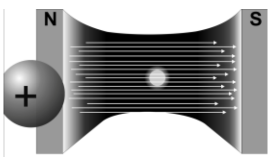
If, for example, the needle needs only 0.00015 amps to fully deflect the needle, and the needle apparatus has a resistance of 60 ohms, how large a shunt resistor is needed to allow a 2 amp current to fully deflect the needle?



(A) 0.0045 ohms
(B) 0.0065 ohms
(C) 0.0085 ohms
(D) 0.0105 ohms
(E) 0.0115 ohms

9. This positive electrical charge of 2 coulombs is traveling horizontally at a speed of 10 meters per second toward the hole at the back of a permanent magnet with a magnetic field strength of 2 webers per square meter.

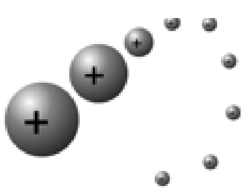
According to the right hand rule, the moving electrical charge will bend downward as it passes through the magnetic field. What is the force exerted on the electrical charge?



(A) 5 newtons
(B) 10 newtons
(C) 15 newtons
(D) 20 newtons
(E) 40 newtons

10. The magnetic force exerted on the moving electrical charge in question 9 is perpendicular to its path. A perpendicular force causes an object moving in a straight line to begin moving in a circle.

If the electrical charge weighs 1.0×10^{-5} kg, what is its radius of curvature?



(A) 1.0×10^{-6} m
(B) 1.5×10^{-6} m
(C) 2.0×10^{-6} m
(D) 1.0×10^{-5} m
(E) 2.5×10^{-5} m

11. To prevent the moving electrical charge from curving downward, we could insert a set of capacitor plates in the magnetic field. The question is how much voltage we would need to apply to keep the electron moving in a straight line. The capacitor plates are 5×10^{-4} meters apart.

(A) 0.001 V
(B) 0.01 V
(C) 0.1 V
(D) 1.0 V
E(A) 10.V