Introduction

Electricity is a fundamental form of energy occurring naturally (as in lightning) or produced artificially, and results from the motion of electrically charged particles of matter. These charges are either positive, or negative. Positively charged particles, such as protons, repel one another and the negatively charged particles, such as electrons, also repel one another. Negative and positive particles, however, attract each other. This behavior may be summarized as follows: Like charges repel, and unlike charges attract.

Electricity is a property of matter that results from the presence or movement of electric charge. Together with magnetism, it constitutes the fundamental interaction known as electromagnetism. Electricity is responsible for many well-known physical phenomena such as lightning, electric fields and electric currents, and is put to use in industrial applications such as electronics and electric power.

Static Electricity

Electric charge is a fundamental conserved property of some subatomic particles, which determines their electromagnetic interactions. Electrically charged matter is influenced by, and produces, electromagnetic fields. The interaction between charge and field is the source of the electromagnetic force, which is one of the four fundamental forces.

Electric charge which builds up on an insulator and is thus unable to flow is termed static electricity. Like-charged objects repel and opposite-charged objects attract one another. Static electricity is a class of phenomena involving the imbalanced charge present on an object, typically referring to charges with voltages of sufficient magnitude to produce visible attraction, repulsion, and sparks. Static electricity can be seen at work when hair is combed on a cold, dry day. As the comb is pulled through the hair, strands of hair stand out stiffly. Some kind of force seems to pull the hair upward toward the comb.

Rubbing action creates charged objects because it tears electrons loose from some kinds of atoms and transfers them to others. In the case of plastic rubbed with wool, electrons are taken from the wool and pile up on the plastic, giving the plastic a net negative charge and leaving the wool charged positively. When glass is rubbed with silk, the glass loses electrons and the silk gains, producing glass that is charged positively and silk that is charged negatively.

With a Comb

Picking Up Paper Bits with a Comb

Tear some paper into small pieces and put the down on a table. Comb your hair. Move the comb close to the paper pieces. The pieces of paper should jump up to the comb!

Deflecting Water with a Comb

Turn on a water tap so that the water flows in a narrow stream. Comb your hair. Move the comb close to the water but don't let it touch. You should see the water stream move towards the comb!

With a Balloon

Sticking Balloons to the Wall

Blow up a balloon, and rub it on your hair. Touch the balloon to the wall or ceiling. It should stick there!

Electrons

An electron is a negatively charged elementary particle; it is a constituent of all atoms. The electrons in each atom surround the nucleus in groupings called shells; in a neutral atom the number of electrons is equal to the number of protons in the nucleus. This electron structure is responsible for the chemical properties of the atom; chemical interactions take place between the outer electrons of atoms.

Electrons have an electrical charge and when they move, they generate an electric current. Because the electrons of an atom determine the way in which it interacts with other atoms, they play a fundamental part in chemistry. They were discovered by J J Thomson in 1897 through studying cathode rays (now called electron beams) in electric and magnetic fields. A heated wire filament can be made to emit electrons, and if this is done in a vacuum their paths can be controlled by electric or magnetic fields. Such beams of electrons are used to operate television picture tubes and electron microscopes.

The electron is a light weight fundamental subatomic particle that carries a negative electric charge. The electron is a spin-1/2 lepton, does not participate in strong interactions and has no substructure. Together with atomic nuclei, electrons make up atoms; they are responsible for chemical bonding. The flow of electricity in solid conductors is primarily due to the movement of electrons.

Classification

The electron is in the class of subatomic particles called leptons, which are believed to be fundamental particles. As with all particles, electrons can also act as waves. This is called the wave-particle duality, also known by the term complementarity coined by Niels Bohr, and can be demonstrated using the double-slit experiment.

The antiparticle of an electron is the positron, which has positive rather than negative charge. The discoverer of the positron, Carl D. Anderson, proposed calling standard electrons negatrons, and using electron as a generic term to describe both the positively and negatively charged variants. This usage is occasionally encountered today.

Electrons - behavior

When electrons and positrons collide, they annihilate each other and produce pairs of high energy photons or other particles. On the other hand, high-energy photons may transform into an electron and a positron by a process called pair production, but only in the presence of a nearby charged particle, such as a nucleus.

The electron is currently described as a fundamental or elementary particle. It has no known substructure. Hence, for convenience, it is usually defined or assumed to be a point-like mathematical point charge, with no spatial extension. However, when a test particle is forced to approach an electron, we measure changes in its properties (charge and mass).

This effect is common to all elementary particles: Current theory suggests that this effect is due to the influence of vacuum fluctuations in its local space, so that the properties measured from a significant distance are considered to be the sum of the bare properties and the vacuum effects (see renormalization).

The classical electron radius is 2.8179 Ã— 10â^'15 m. This is the radius that is inferred from the electron's electric charge, by using the classical theory of electrodynamics alone, ignoring quantum mechanics. Classical electrodynamics (Maxwell's electrodynamics) is the older concept that is widely used for practical applications of electricity, electrical engineering, semiconductor physics, and electromagnetics; quantum electrodynamics, on the other hand, is useful for applications involving modern particle physics and some aspects of optical, laser and quantum physics.

Based on current theory, the speed of an electron can approach, but never reach, c (the speed of light in a vacuum). This limitation is attributed to Einstein's theory of special relativity which defines the speed of light as a constant within all inertial frames.

However, when relativistic electrons are injected into a dielectric medium, such as water, where the local speed of light is significantly less than c, the electrons will (temporarily) be traveling faster than light in the medium. As they interact with the medium, they generate a faint bluish light called Cherenkov radiation.

Electrons - Properties

Electrons have an electric charge of â^'1.6021765 Ã— 10â^'19 coulomb, a mass of 9.11 Ã— 10â^'31 kg based on charge/mass measurements and a relativistic rest mass of about 0.511 MeV/cÂ^2. The mass of the electron is approximately 1/1836 of the mass of the proton. The common electron symbol is eâ^'.[1] Electron mean lifetime is >4.6x1026 years, see Particle decay.

According to quantum mechanics, electrons can be represented by wavefunctions, from which a calculated probabilistic electron density can be determined. The orbital of each electron in an atom can be described by a wavefunction. Based on the Heisenberg uncertainty principle, the exact momentum and position of the actual electron cannot be simultaneously determined. This is a limitation which, in this instance, simply states that the more accurately we know a particle's position, the less accurately we can know its momentum, and vice versa.

The electron has spin Â½ and is a fermion (it follows Fermi-Dirac statistics). In addition to its intrinsic angular momentum, an electron has an intrinsic magnetic moment along its spin axis.

Electrons in an atom are bound to that atom; electrons moving freely in vacuum, space or certain media are free electrons that can be focused into an electron beam. When free electrons move, there is a net flow of charge, this flow is called an electric current. The drift velocity of electrons in metal wires is on the order of mm/hour. However, the speed at which a current at one point in a wire causes a current in other parts of the wire, the velocity of propagation, is typically 75% of light speed.

In some superconductors, pairs of electrons move as Cooper pairs in which their motion is coupled to nearby matter via lattice vibrations called phonons. The distance of separation between Cooper pairs is roughly 100 nm. (Rohlf, J.W.)

A body has an electric charge when that body has more or fewer electrons than are required to balance the positive charge of the nuclei. When there is an excess of electrons, the object is said to be negatively charged. When there are fewer electrons than protons, the object is said to be positively charged. When the number of electrons and the number of protons are equal, their charges cancel each other and the object is said to be electrically neutral.

Electric Current

Electric current consists of charge particles - usually electrons - moving through a conductor. Between collections of positive and negative charges there exists a potential difference called 'voltage'. If a conducting path exists between two charged groups, charges will flow from one to the other, constituting an electric current, and usually consists of a flow of electrons from the more negatively charged body to the more positively charged one. Metals and other materials that allow the flow of electric charge through them are known as conductors. Materials that resist the passage of an electric current are known as insulators.

A direct current (DC) is a constant flow between two points having a different electrical potential and the charge flow is one way, as from a battery. Or it may be alternating current (AC), as from a mains supply. Here, the charge flows alternately backwards then forwards in a circuit many times every second.

By convention, a positive current is defined as that which flows from a higher potential to a lesser one, driven by the potential difference. An electrical circuit is a network that has a closed loop, giving a return path for the current. A network is a connection of two or more simple circuit elements, and may not necessarily be a circuit.

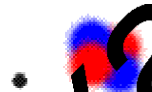
Make a Battery

You need 2 different metals, e.g. copper & steel, or a penny and a nail. Stick them carefully into a citric fruit such as a lemon (not your hand!). Attach a wire to each piece of metal (crocodile clips work best) and place the other ends onto your tongue. You should feel a tingle from the electricity.

The current isn't enough to power a small light bulb, but you could try putting more metal pairs into the same, or other, pieces of citric fruit, and connecting the wires in parallel.

Net Electrical Charge

Electrons around an atom Matters are made of atoms. An atom is basically composed of three different components -- electrons, protons, and neutrons. An electron can be removed easily from an atom. Normally, an atom is electrically neutral, which means that there are equal numbers of protons and electrons. Positive charge of protons is balanced by negative charge of electrons. It



has no net electrical charge.

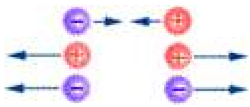
When atoms gain or lose electrons, they are called "ions."

* A positive ion is a cation that misses electron(s).

* A negative ion is an anion that gains extra electron(s).

repel and attract What is charge? Objects that exert electric forces are said to have charge. Charge is the source of electrical force. There are two kinds of electrical charges, positive and negative. Same charges (+ and +, or - and -) repel and opposite charges (+ and -) attract each other.
The law of conservation of charge says that charge is neither created nor destroyed.

Conductors and Insulators



Substances can be classified into three types -- insulators, conductors, and semiconductors. Insulators are materials which allow very little electrical charges and heat energy to flow. Plastics, glass, dry air and wood are examples of insulators.

Conductors are materials which electrical charges and heat energy can be transmitted very easily. Almost all metals such as gold, silver, copper, iron, and lead are good conductors. Semiconductors are materials which allow the electrical charges to flow better than insulators, but less than conductors. Examples are silicon and germanium.

Charged Objects

When two objects are rubbed together, some electrons from one object move to another object. For example, when a plastic bar is rubbed with fur, electrons will move from the fur to the plastic stick. Therefore, plastic bar will be negatively charged and the fur will be positively charged.

a. Methods of Charging

Charging by Induction

When you bring a negatively charged object close to another object, electrons in the second object will be repelled from the first object. Therefore, that end will have a negative charge. This process is called charging by induction.

When a negatively charged object touches a neutral body, electrons will spread on both objects and make both objects negatively charged. This process is called charging by conduction. The other case, positively charged object touching the neutral body, is just the same in principle.

Unit of Electrical Charge: The Coulomb " C "

The symbol for electric charge is written q, -q or Q. The unit of electric charge is coulomb "C". The charge of one electron is equal to the charge of one proton, which is 1.6 * 10-19C. This number is given a symbol "e".

Coulomb's Law

The magnitude of force that a particle exerts on another particle is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

Direction of the force between particles

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

where:

F is the force between the two particles,
q1 is the net charge on particle A,
q2 is the net charge on particle B,
d is the distance between the particles,
k is a proportionality constant which is 9.0 * 109 Nm2/C2.

The direction of the force is on the line from one particle to the other.

Gravitational Field vs. Electric Field

The concept of electric field was introduced by Michael Faraday. The electrical field force acts between two charges, in the same way that the gravitational field force acts between two masses. We know about accelaration of the earth, i.e., the gravity (g = 9.8 m/s2), but where does this number come from?

It comes from Newton's law of universal gravitation. It states that every matter which has a mass attracts other matters with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between the centers of gravity of the two matters.

$$F = G\frac{m_e m_o}{d^2}$$

where:

$G = 6.67 \times 10^{-11}\, N \cdot m^2/kg^2$ (constant),

me = mass of the earth (kg),

mo = mass of an object (kg), and

d = distance between the earth and the object (m).

We already studied about gravitational force of an object on earth, which is F = m*g, where "m" is mass of the object and "g" is the gravity of the earth. Then, we can say that $m_o \cdot g = G \cdot m_e \cdot m_o / d^2$. Therefore, gravity (g) of the earth is $G \cdot m_e / d^2$, where "me" is the mass of the earth and "d" is its radius (we are talking about gravitational force on the surface of the earth.).

$$g = \frac{\left(6.67 \times 10^{-11} m^3 / kg \cdot s^2\right) \times 5.98 \times 10^{24} kg}{\left(6.38 \times 10^6 m\right)^2} = 9.80 m/s^2$$

The electric field (E) is derived in the same way from the equation $F = K\frac{Q \cdot q}{d^2}$

where:

$K = 9.0 \times 10^9 N \cdot m^2 / C^2$ (constant),
Q = electric force of one object (C),
q = electric force of the other object (C), and
d = distance between the two objects (m).

However, electric field E is a little bit different from gravitational field g. Gravitational force depends on mass, whereas electric force does not depend on mass. Instead, electric force depends on charges on both objects.

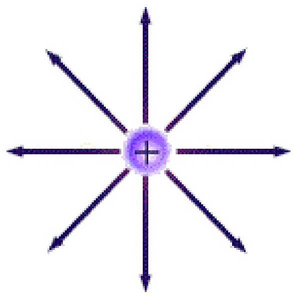
By rearranging the formula, we get:

Electric field (E) for Q: $E = K \cdot Q / d^2$

Electric field for q: $E = K \cdot q / d^2$

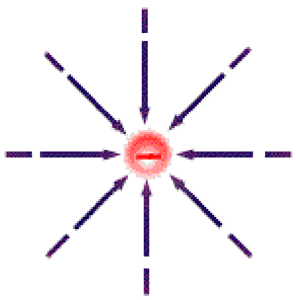
Electric Field Line

Electric field lines can be drawn using field lines. They are also called force lines.



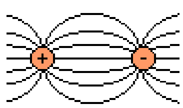
(Positive charge electric field)

The field lines are originated from the positive charge.



(Negative charge electric field)

The field lines end up at the negative charge.



A positive charge exerts out and a negative charge exerts in equally to all directions; it is symmetric. Field lines are drawn to show the direction and strength of field. The closer the lines are, the stronger the force acts on an object. If the lines are further each other, the strength of force acting on a object is weaker.

Gravitational Potential vs. Electric Potential

Any matter lifted from the surface of the earth has a potential energy. This gravitational potential energy is given by the formula PE=mgh, and the potential energy can be altered by changing its height. The electrical potential energy also can be changed by changing distance between two charges.

Gravitational potential energy equals to product of the mass of an object, gravitational field force, and its height from the earth.

$PE_G = mgh$

where:

m is the mass of the ball (kg),
g is the gravitational field force (g = 9.8 m/s2), and
h is the distance between the ball and the earth (m).

Electric potential energy equals to the electric potential energy divided by charge. PE = qEd
where:
q is the charge of an object (C),
E is electric field produced by Q (N/C), and
d is the distance between the two charges.

Electric potential is called Voltage, which can be derived from above equation.

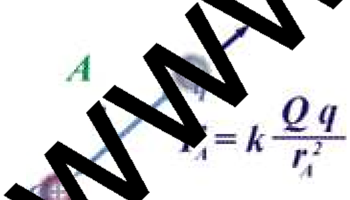
$$Ed = \frac{PE}{q} = V\,(Voltage)$$

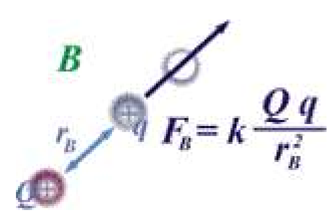
Voltage is also related to force.
V = Ed = (F/q)*d = Fd/q= W/q

(W = Fd -- force times displacement in the direction of force is work (J))

A high voltage means that each individual charge is experiencing a large force. A low voltage means that each individual charge is experiencing a small force.

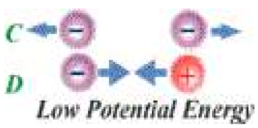
Gravitational Potential vs. Electric Potential





"q" on A has smaller force than "q" on B. If the distance of B is one half of that of A, the force acting on B is twice as large as A because the force is inversely proportional to the square of the distance between two charges.

A has high potential energy because these particles want to separate from each other.
B has high potential energy because these particles want to come together. It is the same priciple as the gravity.



C has lower potential energy compared to A because the electric field force is inversely proportional to the square of its distance.
D has lower potential energy compare to B for the same reason.

When same charges are put close together, we say we have a high voltage because it has a high potential energy.
Larger the distance is, the smaller the force and voltage are.

If the spheres are brought close together, the charge will try to get as far away from each other as possible. As a result, the voltage becomes equal on both sphere.

Charge will always move until the force acting on it is reduced to a minimum or until the voltage becomes the same.

Flow of Charge: The Current

The flow of charge is called the current and it is the rate at which electric charges pass though a conductor. The charged particle can be either positive or negative. In order for a charge to flow, it needs a push (a force) and it is supplied by voltage, or potential difference. The charge flows from high potential energy to low potential energy.

Suppose A has a potential of 12 V and B has a potential of 2 V. There is a potential difference. A has higher potential energy than B, and it means there is voltage. The potential difference is

VA - VB = 12 - 2 = 10 V.

If there is a potential difference between two regions and if we join them together, the charge will flow. The charge will always move until the force acting on it is reduced to a minimum or until the voltage becomes the same.

Suppose C and D has a potential of 7 V. There is no potential difference between two plates. The potential difference is VA - VB = 7 - 7 = 0 V. Therefore, it has no voltage and it means no flow of charge.

What will happen if something pushes the charge from the bottom plate to the upper plate E in the diagram? This will generate a potential difference, and hence, there will be continuous flow of charge. This is how a battery works; it takes "+" charge from bottom and push it to top. The system like E, a closed loop of current, is called an electric circuit.

The current [I] measures the amount of charge that passes a given point every second. The unit for current is Ampere [A]. 1 A means that 1 C of charge passes every second. 1 C/s = 1 A

Electric Resistance and Ohm's Law.

Resistance is a feature of a material that determines the flow of electric charge. The unit of resistance is ohm. The resistance varies in different materials. For example, gold, silver, and copper have low resistance, which means that current can flow easily through these materials. Glass, plastics, and wood have very high resistance, which means that current can not pass throught these materials easily.

A German scientist Georg Simon Ohm experimented with circuits and found out the relationships between current, voltage, and resistance. It became known as Ohm's law and can be written in an equation V=IR, where V is voltage, I is current, and R is resistance.

Practice problem.
What is the current of a circuit that has 3 V and 0.5 ohm of resistance?

Answer:

You first have to modify the equation V = IR to I = V / R. Then you just have to input the numbers into this equation.

I = 3 / 0.5 = 6 A [ampere].

Resistance of a piece of wire (or any other conductor) is proportional to the length of the material, and is inversely proportional to its thickness or sectional area.

R = k * (L / A)

where:

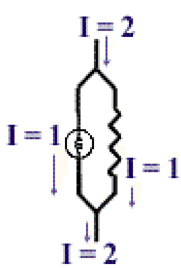
k is resistivity constant that depends on the types of material,
L is the length (m), and
A is the area (m2). A potentiometer uses this characteristic. It can change its resistance by controlling its length. This aperture is used in T.V. volume, light controller, and everything else dealing with changing its electricity gradually.
The gray bar inside is connected to the black wire of its around, and it rotates (see above). Let's say an electrical line is connected to the left and the middle. If the gray bar is at the left, then the circuit will have small resistance because the length of the black wire outside is shorter. When the gray bar trun to the right, then it will have larger resistance.

Voltage Law and Current Law
Voltage Law

"In any circuit, the sum of decrease in voltage equals the sum of its increase."

For example, imagine a circuit with a battery and a bulb. If the battery generates 3 V, then the bulb must consume 3 V, because the sum of decrease in voltage (-3 V consumed by the bulb) must be equal to the sum of increase in voltage (+3 V generated by the battery).

Current Law

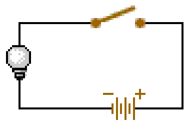


"At any junction point in an electric circuit, the total electric current into the junction is equal to the total electric current out."

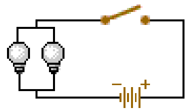
A junction is a point where wires are splits into two or more. In the left diagram, incoming current (2 A) is being split into half at a junction point (1 A), and then is combined back to the original current (2 A).

In other words, current coming in is equal to the current going out.

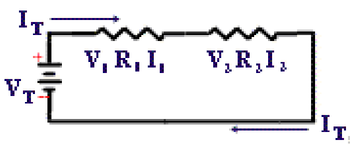
There are basically three types of circuit -- series, parallel, and series and parallel circuit.
Series Circuit:



Parallel Circuit:



Series Circuit



The total voltage is the sum of the voltage on each component.

eq 1: V0 = V1+ V2 + V3 +...+ Vn

(In this case, VT = V1+ V2)

The total resistance is equal to the sum of the resistance on each component.

eq 2: R0 = R1 + R2 + R3 +...+ Rn

(In this case, RT = R1 + R2)

The total current is equal in every component.

eq 3: I0 = I1 = I2= I3= I4 =...= In

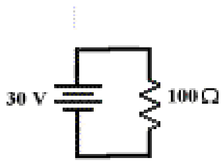
(In this case, IT = I1 = I2)

We have a series circuit like this. What is the total voltage, resistance and current?

First, we have to find out the total voltage using equation 1 above, and then resistance using equation 2, and finally you can find out the current using equation 3.

Total voltage is 9 + 1 + 16 + 4 = 30 V

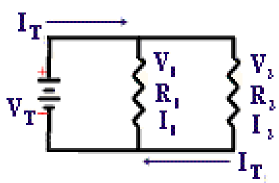
Total resistance is 30 + 10 + 40 + 20 = 100 ohm



Using ohm's law, I = V / R, then we can find out the total current.

I = 30 / 100 = 0.3 A

Parallel Circuit



The total voltage is equal in every component.

eq 4: V0 = V1= V2= V3 =...= Vn
(In this case, VT = V1= V2)

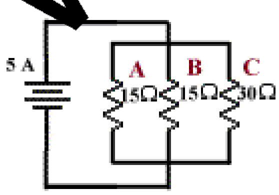
The resistance is equal to the sum of resistance on each component divided by the product of resistance of each component.

eq 5: 1/R0 = 1/R1 + 1/R2 +...+ 1/Rn
(In this case, 1/RT = 1/R1 + 1/R2)

The total current is equal to the sum of current in each component.

eq 6: I0= I1 + I2 + I3 + I4 +...+ In
(In this case, IT = I1 + I2)

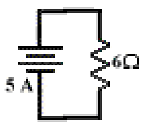
Example



If you have a parallel circuit like this, what is the total resistance and voltage? And voltage and current on A, B, and C?

In order to find out the total voltage, we have to find out the total resistance. Using equation 5, we can find out the total resistance.

1/R = 1/15 + 1/15 + 1/30 = 5/30, R = 6 ohm



Then using ohm's law,V = I R, we can find out the total voltage.

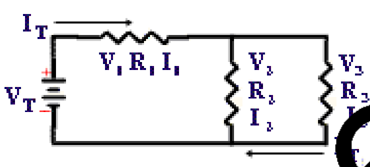
V = 5 * 6 = 30 V

Using equation 4, we now know the voltage on A, B, and C, which is 30 V each. Using ohm's law again, we can find out the current on A, B, and C.

IA = 30/15 = 2 A,
IB = 30/15 = 2 A,
IC = 30/30 = 1 A .

When you add up all the current (using equation 6), we get 5 A which is the total current.

Series - Parallel Circuit



Series-Parallel; many circuits are both series and parallel. The total voltage is the voltage of series plus the voltage of parallel.

eq. 7: VT = V1 + V2 = V1 + V3

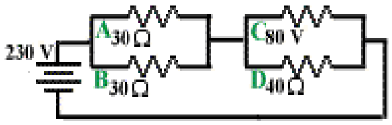
The total resistance is the resistance of series plus the resistance of parallel.

eq. 8: RT = R1 + [(R2R3) / (R2 + R3)]

The total current is equal to the current on series and to the sum of the current of parallel circuit.

eq. 9: IT = I1 = I2 + I3

Example



What is voltage on A, B, and D?

What is current on A, B, C, and D?

What is resistance on C?

What is total current and resistance?

First of all, we have to look at the diagram very carefully (The order of the questions also help us from where we have to start). Using equation 4, we know that the voltage on D is equal to C, which is 80 V. We also know A and B have the same voltage. Using the voltage law, we can find out the voltage on A and B, which is 230 - 80 = 150 V each.

Now we get all the voltages on each component. Using ohm's law, we can find out the current on A, B, C, and D. IA= 150/30 = 5 A; IB = 150/30 = 5 A; ID = 80/40 = 2 A; IC = 10-2 = 8 A. The sum of the current on A and B is equal to that of C and D (eq. 3). A+B = C+D.

The resistance of A+B is 15 ohm (eq. 2) The resistance on C is R = 80 [V] /8 [IC]= 10 ohm. Therefore, the resistance of C+D is 8 ohm.

Using equation [illegible], we can find out total resistance of this circuit.

R = 15+8 = 23 ohm; I = 230 [V] /23 [R] = 10 A

Joule's Law and Power

The heat energy produced by a resistor is

H = I2Rt

where:

H is heat energy in joule,

I is the current in A,

R is the resistance in ohm, and

t is time in second.

You can convert joule to calories by multiplying 0.24 on joule.

In a parallel circuit, the least resistance draws the most current and produces the most heat energy because larger current flows through that component. The rate of using or supplying energy is called power [P]. The power consumption of a resistor is

P = VI = I2R = V2/R

where:

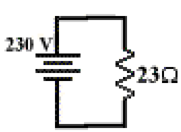
[P] is power in watts,

[V] is voltage through resistor in volts,

[I] is current through resistor in ampere, and

[R] is resistance in ohms.

Joule's Law and Power



Also,

Power [W] = work (energy) / time [t] (unit of work is joule [J] and time[t] is in second).

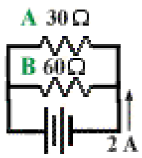
Therefore,

work or energy [joule] = power [W] * time [t].

The unit for energy is watt-second; watt-minute; and watt-hour.

1 watt-second = 1 joule

Example



What is the power consumption of the resistor A and B? (in watts; [W])

What the heat energy produced on A and B if it is used in 10 second? (in joules; [J])

First, we have to find out the total resistance, and then the total potential difference (voltage). Total resistance is R = 60/3 = 20 ohm.(eq.5) And total potential difference is V = 20 * 2 = 40 V.(V=I*R) Now, we can find current on A and B. IA = 40/30 = 4/3 A and IB = 40/60 = 2/3 A.

Power consumption PA = (V*I) = 40 * 4/3 = 160/3 (53.3) watts. PB = 40 * 2/3 = 80/3 (26.7) watts.

The heat energies are

HA = I2Rt = (4/3)2 * 30 * 10 = 1600/3 (533.3) J;

HB = (2/3)2 * 60 * 10 = 800/3 (266.7) J