Basic Physics of Earthing

by

Gaétan Chevalier, Ph.D.

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Introduction

Many people notice that they feel better when they walk barefoot on the earth such as when picnicking or walking on the beach. Recent research has shown that the feeling of well-being that comes from walking barefoot on the earth is associated with important physiological benefits. The earth is a natural source of electrons and subtle electric fields which are essential for proper functioning of our immune system, our endocrine system, our circulatory system, and for balancing our biorhythms and maintaining proper function of other physiological processes. Of major importance is the fact that modern medical research has documented a correlation and/or a causative role for chronic inflammation in the pathogenesis or promotion of all of the chronic diseases, including the diseases of aging and the aging process itself. Research has shown that inflammation is a condition that can be reduced or prevented by grounding our bodies to the Earth.[1] It has also been suggested that the modern epidemic of chronic and stress-related diseases began when the soles of shoes started to be made with rubber and plastics. Shoes made of leather conducts electrons (when moist), while soles made of rubber and plastics do not.[2]

In the present document, I lay down in simple terms the basic scientific notions needed to understand how Earthing can give so many benefits. These scientific notions come from physics, geophysics, biophysics, biology, molecular biology, physiology, biochemistry, and bioelectromagnetics. I begin by summarizing the basic laws of physics and electricity relevant to our purpose. Then we will show how these laws impose certain conditions to the physiology and the biology of the human body. With a little knowledge of these phenomena, it is easy to create a much healthier environment without major expenses and without having to undergo a major change in lifestyle.

1- Basics Notions of Physics and Electricity

1.1- Atoms and Molecules

All objects in the world, whether solid, liquid, or gas, living or not, are made of atoms. All atoms contain negatively charged electrons and positively charged protons. The protons are located inside a nucleus at the core of the atom while electrons circulate around that core (see **Figure 1**). Protons and electrons have exactly the same electric charge but it is of opposite sign. Since charges of the same sign repel each other and charge of opposite sign attract each other, electrons gravitate around the nucleus because of the electric attraction between opposite charges. The central nucleus of atoms also contains neutrons (no electric charge) except for the hydrogen atom, the only atom that does not have even one neutron. A neutral atom has the same number of protons and electrons showing no net electric charge overall. A molecule is composed of two or more atoms and is also neutral unless one or many electrons have been removed from it. When an atom or a molecule misses one or more electrons, it is called an ion and the process of removing electrons is called ionization. The electrons form clouds, called orbitals, around the positively charged nucleus of an atom. It is the number of protons that determine what chemical element an atom is. For example the nucleus of hydrogen (symbol H) has only one proton and no neutron while the nucleus of oxygen (symbol O) has 8 protons and usually 8 neutrons in its nucleus (there are oxygen atoms with 9 and 10 neutrons, these are called isotopes, but they are rare in nature). The periodic table of chemical elements classifies all elements according to the number of protons and their chemical affinity (see **Figure 2**). The letters in each box represents the official abbreviation of the name of the element while the number above that abbreviation represents the number of protons in the nucleus. For example Li stands for lithium and it has 3 protons while Na stands for sodium (from the Latin natrium) and it has 11 protons. Elements in the same column have similar chemical properties (except for the very heavy elements, those with more than 100 protons, whose chemical properties are presently unknown).

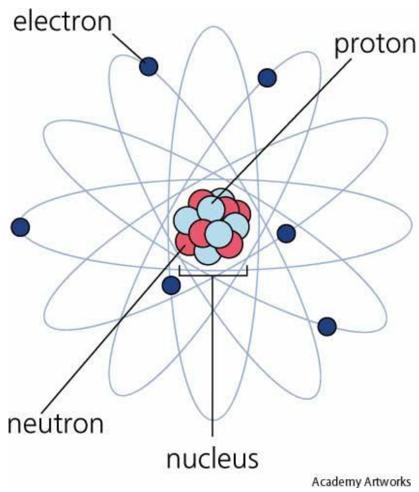

Figure 1: Simplified example of an atom. In reality the electrons do not follow a definite path around the atom but form a cloud that looks more like a bubble as shown in Figure 3.

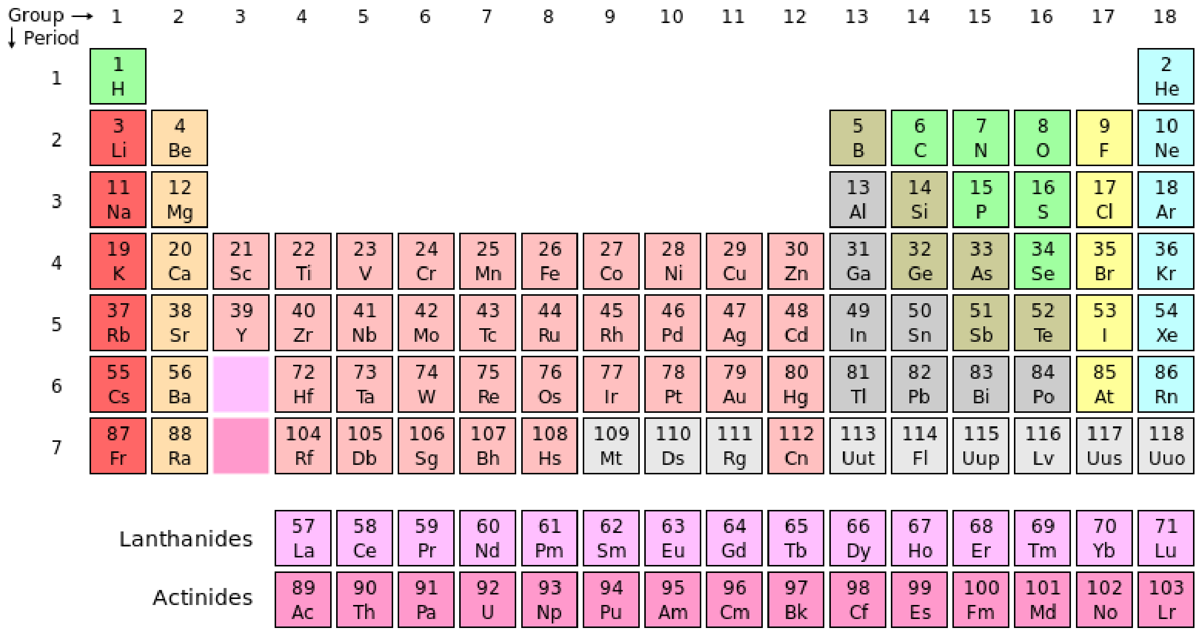

Figure 2: The periodic table of chemical elements. In each box the letters represent an abbreviation of the name of the element and the number above it is the number of protons in the nucleus of that element.

Molecules are built by combining various atoms. The simplest molecule has 2 atoms of the same element. For example, the oxygen we breathe is composed of molecules made of 2 oxygen atoms (**Figure 3**). The same situation exists for the nitrogen in the air, it is composed of 2 atoms of nitrogen combined in a similar way. Another simple molecule is sodium chloride (table salt) witch has one sodium (Na) atom and one chlorine (Cl) atom. However, when many Na and Cl atoms are placed together at room temperature, they naturally form a solid crystal (**Figure 4**). The larger chlorine atoms are arranged in a cubic array with a chlorine atom at each corner of a cube and another chlorine atom at the center of each of the six faces of the cube (this is called face-centered cubic arrangement or, in short, fcc), whereas the smaller sodium atoms fill all the mid-points between the chlorine atoms, forming an octahedral structure between the chlorine atoms as shown in the lower right side of **Figure 4**. This same basic structure is found in many other compounds and is commonly known as the halite or rock-salt crystal structure. It can be represented as a face-centered cubic (fcc) lattice with a two-atom basis or as two interpenetrating face centered cubic lattices, one lattice made from chlorine atoms, the other from sodium atoms.

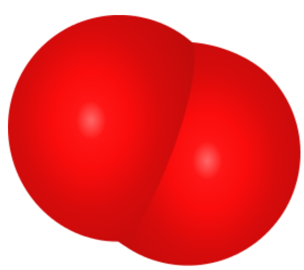

Figure 3: Example of a simple molecule: oxygen (2 atoms). The red balls show the position of the external electrons which form a bubble because their orbital movement is not well defined, as per quantum physics.

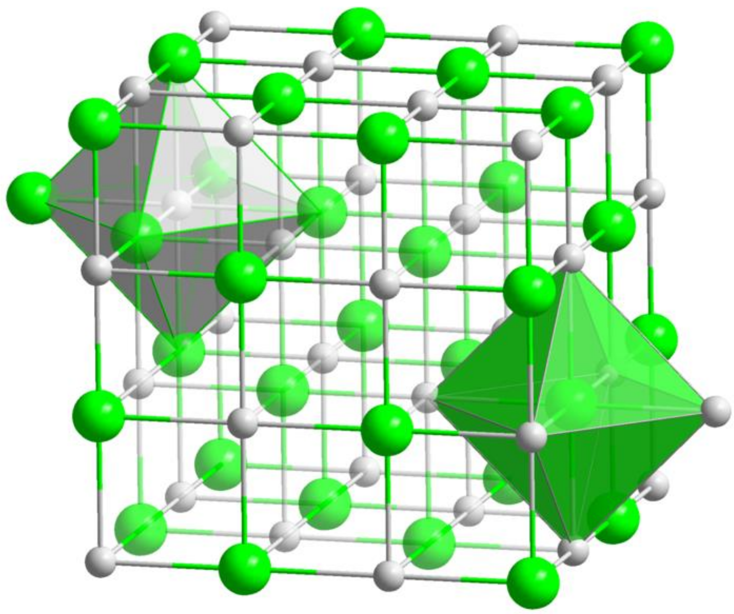

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Figure 4: Crystalline structure of table salt (NaCl). Cl atoms are bigger and colored in green while Na atoms are smaller and grey in color. (From Wikipedia, Sodium Chloride)

1.2- Electric charge and the Electric Field

Like mass, electric charge is an intrinsic property of protons and electrons (but it is not a property of neutrons since they are neutral). Electric charge is the physical property that causes electrically charged matter to experience a force when close to other electrically charged matter. Only 2 types of electric charges have been discovered. They are called positive and negative, since they have opposite polarity. Experiments have revealed that the magnitude of the electric charge of the proton is exactly equal to the magnitude of the electric charge of the electron but of opposite sign (the proton carries a positive charge usually symbolized as $+e$, the electron carries a negative charge symbolized as $-e$, where $e = 1.602 \times 10^{-19}$C)[3].

It is quite common to produce a separation of positive and negative charges when two unlike materials are rubbed together. For example, when an ebonite (hard, black rubber) rod is rubbed against an animal fur, some of the electrons from the surface molecules of the fur are transferred to the rod (only electrons can move without destroying the structure of the fur). The ebonite becomes negatively charged, and the fur becomes positively charged, as shown in **Figure 5**.

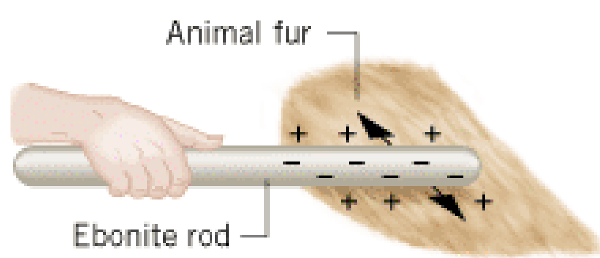


Figure 5: When an ebonite rod is rubbed against animal fur, electrons from atoms of the fur are transferred to the rod. This transfer gives the rod a negative charge (–) and leaves a positive charge (+) on the fur.

The process can be visualized as presented in **Figure 6**. When 2 materials with different affinities for electrons (some materials love electrons more than others and thus attract more electrons, these are said to be more electronegative) are put in contact and then separated, the material that loves electrons more (more electronegative) grabs some of the electrons of the less electronegative material, leaving a net positive charge on the less electronegative material and a net negative charge on the more electronegative material.

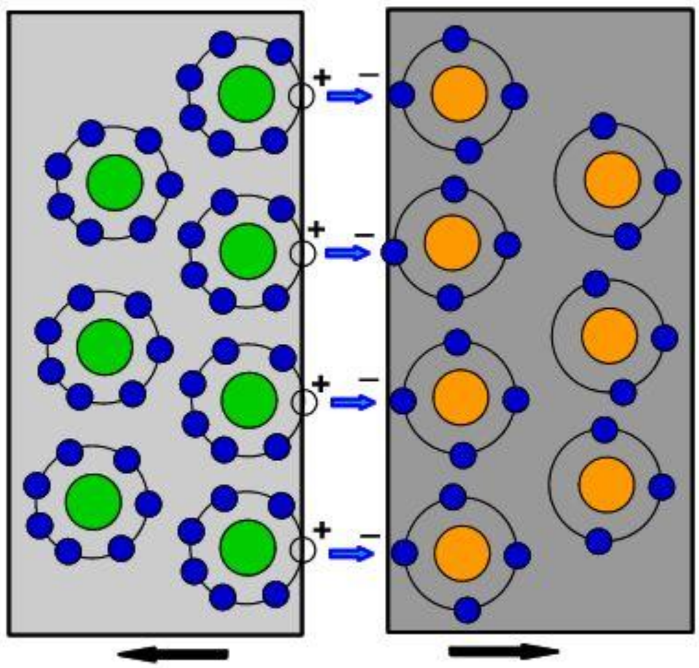


Figure 6: Electrons exchange happens when two materials are put in contact and then pulled apart. The material to the left is like the fur (it looses electrons and become positively charged) while the material to the right is like the ebonite (and becomes negatively charged). Note that the charge gained by the material to the right is exactly equal to the charge lost by the material to the left.

Box

The **triboelectric effect** also called **triboelectric charging** is defined as the generation of electrostatic charges when two materials make contact or are rubbed against each other, then separated.

Similarly, if a glass rod is rubbed with a silk cloth, some of the electrons are removed from the atoms of the glass and deposited on the silk, leaving the silk negatively charged and the glass positively charged. There are many familiar examples of charge separation, as when you walk across a nylon rug or run a comb through dry hair. In each case, objects become "electrified" as surfaces rub against one another. This is called "static electricity". Static electricity is an accumulation of electric charges on objects. **Figure 7** shows an example of a child who accumulated static electricity by sliding in a plastic tube. Her body lost electrons to the plastic tube and became positively charged. Her hair also became positively charged, causing the individual hairs to repel each other while being attracted to the negatively charged surface of the slide.

Figure 7: A child accumulated positive electricity after sliding through a plastic tube. Electrons from her clothes and body were snatched by the plastic tube which became negatively charged in the process.

As **Figure 7** demonstrates, static electricity can built up on our bodies when we are not grounded. Normally the human body and the objects around us have exactly the same number of electrons and protons and are therefore electrically neutral. Static electricity arises when electric charge builds up on an object. We are aware of static electricity when we experience the occasional surprise of a static electric shock (**Figure 8**). Static electricity can be produced by electric equipment such as photocopiers, hair dryers, fans and so on, and by friction between different materials, such as synthetic furnishings, carpets and clothing, as already explained.

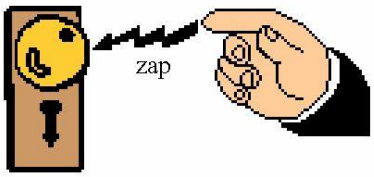


Figure 8: Electric charge can build up on our body while walking on a carpet in a dry day. When our hand gets close to a door knob the electricity is discharged by creating a spark between our fingers and the door knob.

When the relative humidity is low, walking across a carpet can develop up to 35,000 volts of static electricity on your body (more on voltage will be explained in sections 1.3 and 1.5). Picking up a plastic bag can charge your body up to 20,000 volts. An urethane foam-padded chair can develop 18,000 volts and a vinyl floor can produce 12,000 volts.[4] When your body becomes electrically charged in this way, you can experience a shock when you reach for a grounded object such as a door knob or light switch. Even though the voltages produced by static electricity can be very high, much higher than the 120 volts of our home electrical power outlet, we are not killed by them because the number of electrons that are discharged during a static electric shock are very few, meaning the current is very small (more will be explain on current in section 1.5). These electric shocks, technically called *electrostatic discharges*, are static electricity in action. While mass production and wide distribution of plastics started only in the

1950’s, they are now in our clothing, shoes, bedding, and carpets—almost everything we touch. These materials and fabrics can easily generate static electricity when robbed against other materials and fabrics.

Box

When electricity becomes dangerous
As shown by the examples in the text, it is not the voltage that is dangerous but the current. For example, walking across a carpet can develop up to 35,000 volts of static electricity on your body and yet, when you touch a door knob you get only an unpleasant shock. However, a discharge of 10,000 volts passing a current of about 0.1 ampere (the unit of current that represent 1 coulomb of charge per second) through your chest would kill you by stopping the heart from beating. It is not the voltage that is causing the damage, it is the current. The voltage can vary depending on the skin resistance. For example, dry skin has a pretty high resistance (100,000 ohms or more) and 120 volts AC passing between your hands would not kill you, much higher voltage would be necessary for that. However, if your skin is wet, its resistance will decrease enough (it can be as low as 300 ohms) that a voltage as low as 30 volts AC can produce a current of 0.1 ampere and kill you if it pass through your chest.[5] These notions of voltage, current and resistance will be explained in more details later in the text (section 1.5- Electric Systems).

Conductive surfaces or objects that are grounded to the earth cannot build up static electricity (conductive materials will be explained in section 1.4). Since the body is a conductor, grounding the human body rapidly discharges static electricity. The semiconductor devices used in electronic circuits are very sensitive to static electricity, and the people who work to build these circuits need to wear grounding straps or shoes before they go to work to prevent buildup of static electricity that can cause damage to the circuits when discharging.

Remember that when an ebonite rod is rubbed with an animal fur, the rubbing process serves only to separate electrons and protons already present in the materials. No electrons or protons are created or destroyed. When an electron is transferred to the rod, the rod acquires one negative charge and the fur is left with one positive charge because protons never move since they are part of the structure of the material. Since the charge of the electron and proton are identical in magnitude and opposite in sign, the algebraic sum of the charges is zero, and the transfer does not change the net charge of the fur/rod system. If each material contains an equal number of protons and electrons to begin with, the net charge of the system is zero initially and remains zero at all times during the rubbing process (nothing is created and nothing is destroyed, electrons only change places from one material to another).

The notion of electric charge plays an important role in many situations other than rubbing two surfaces together. It is involved, for instance in the electronic circuits that make our cell phones, computers and appliances work, in the electricity delivered to houses and companies, in chemical reactions and thunderstorms. In fact, electricity plays a role in almost every physical process. A great number of experiments have verified that in any situation, the *law of conservation of electric charge* is obeyed. Specifically, this law states that: “during any process, the net electric charge of an isolated system remains the same (is conserved).” An isolated system is a closed system, a system that does not exchange energy or particles with the rest of the universe. For example one can consider the ebonite rod and the fur to be a system, i.e. we can neglect any other interactions with the universe. In that case, the law of conservation of electric charge applies. Of course it is an idealization that does not exist in reality but under certain circumstances a real system can be a good approximation of an isolated system. For example, one can consider the system comprising the ebonite rod rubbing against the fur to be relatively well isolated from other systems of the world if one takes the precaution to not touch the ebonite or the fur with other materials.

It was stated earlier that electric charge is the physical property of protons and electrons that causes them to experience a force when close to other electrical charges. It is called an *action-at-a-distance* because a force is experienced without any physical contact. Here is what this means. It is easy to demonstrate that two electrically charged objects exert a force on one another. Consider **Figure 9(a)**, which shows two small balls with opposite charges attached to a ceiling by strings made of a non-conducting material. The balls attract each other. On the other hand, balls with the same type of charge, either both positive or both negative, repel each other, as parts **(b)** and **(c)** of **Figure 9** show.

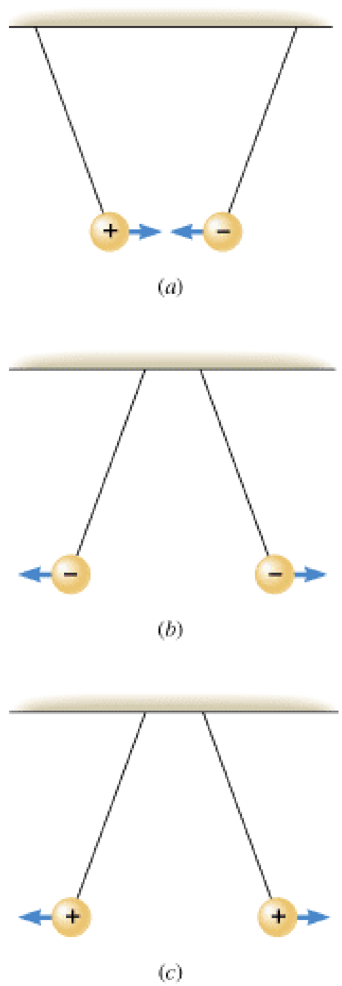


Figure 9: **(a)** A positive charge (+) and a negative charge (–) attract each other. **(b)** Two negative charges repel each other. **(c)** Two positive charges repel each other.

Now, it is easy to see why electrons like to swarm around a positively charged nucleus, they are attracted to it. Like any other force, the electric force (also called the electrostatic force when talking about electrically charged objects) can alter the motion of an object that is electrically charged (positively or negatively). It can do so by contributing to the net external force that acts on the object. For example if you rub a plastic CD (anything made of plastic will do) against your hairs, this will cause the CD to be electrically charged. You can then use it to lift up small pieces of paper sitting on a table. In this case, the vertically upward attractive electrostatic force is caused by the negatively charged CD repelling the negative charges in the pieces of paper, making the side of each piece of paper facing the CD positively charged. This situation generates an attractive force that is greater than the downward gravitational force and the pieces of paper seem to levitate above the table to stick to the CD (**Figure 10**).

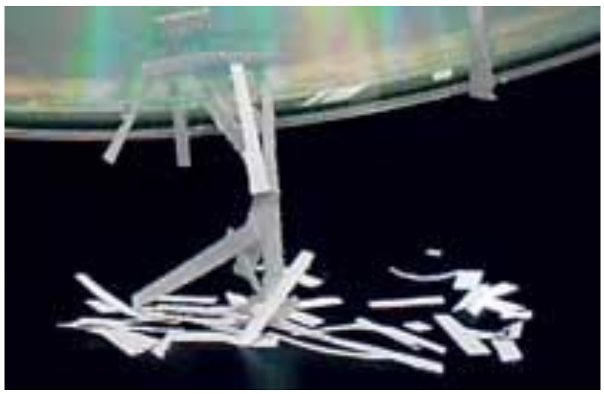


Figure 10: Paper shavings attracted by a charged CD.

We can generalize the action-at-a-distance resulting in attraction and/or repulsion between electric charges by using the concept of *lines of forces*. **Figure 11(a)** shows a gold sphere charged with a positive electric charge $+q$ ($+q$ is a multiple of $+e$, the charge of a proton which is the smallest electric charge possible). A point-like test charge placed at points 1 through 8 would experience a repulsive force (because test charges are always positive). This is represented by the red arrows pointing away from the gold sphere (a force always has both a strength and a direction, it is a vector and thus it is represented by a line with an arrow pointing in the direction of the force). Also note that the lines of force are directed radially outward from the gold sphere, this means that the test charge is pushed out in a line that passes through both the gold sphere and the test charge. **Figure 11(b)** shows a representation of these lines of force at many locations around the gold sphere. The electrostatic force (let's call it F_E) that a test charge experiences depends on the amount of charge in the gold sphere ($+q$) and the amount of charge in the test charge (let's call it $+p$). In fact the electrostatic force F_E depends on the product of $+q$ and $+p$, i.e. $q \times p$. The greater the value of $+q$ or $+p$, the greater the electrostatic force. This is true not only at the 8 points shown in **Figure 11(a)** but all around the gold sphere as shown in **Figure 11(b)**.

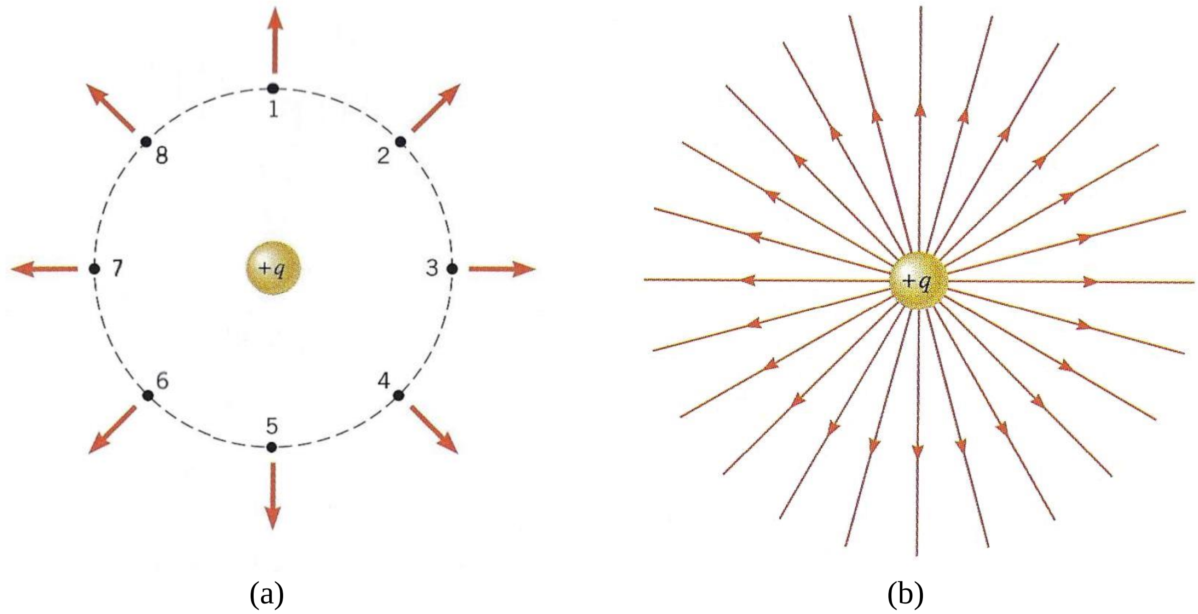


Figure 11: **(a)** At any of the eight marked spots around a positive charge +*q* (gold sphere), a positive test charge (black dot) would experience a repulsive force directed radially outward as the red arrows show. **(b)** The lines of force are directed radially outward from a positive point charge +*q*. The density of the lines is proportional to the strength of the electrostatic force F_E.

The electrostatic force experienced by a test charge also depends on the distance between the test charge and the gold sphere. If we put the test charge at twice the distance from the gold sphere shown in **Figure 11(a)** the electrostatic force decreases by a factor of $4 = 2^2$; if we put it at 3 times the distance, the force will decrease by a factor of $9 = 3^2$ (the force is said to be inversely proportional to the square of the distance or that it follows an inverse square law). The strength of the electrostatic force is represented in **Figure 11(b)** by the density of the lines which decrease with distance from the gold sphere in such a way as to represent that inverse square law. If the distance between the gold sphere and the test charge is represented by the letter *r*, then the electrostatic force $F_E = q \times p/r^2$ (a constant that depends on the system of units used is omitted for simplicity of understanding).

The concept of *electric field* is derived directly from the concept of lines of force. In the case of lines of force, the electrostatic force depends on the charge +*q* of the gold sphere and the charge +*p* of the positive test charge. The greater either one of these 2 charges, the greater the electrostatic force since this force depends on the product $q \times p$. It would be desirable to find a physical property that capture the essence of the electrostatic force around the gold sphere and that is independent of any test charge. The advantage of that property would be that it would apply to any configuration of test charges. This is exactly what the concept of *electric field* was invented to do (the strength of the electric field is usually represented by the letter E, the direction by an arrow). The electric field E is defined as the electrostatic force F_E experienced by a test charge divided by the value of that test charge, which is taken to have the value of +*p* in **Figure 11**, i.e. $E = F_E /p = q/r^2$. Now it can be seen that the equation describing the electric field does not contain the value of the test charge +*p* but only the value of the charge of the gold sphere (+*q*) and the distance *r* between the gold sphere and a particular point around it. The electric field E has the same direction as the electrostatic force F_E (so the electric field is also a vector, having both a strength and a direction). When a positive test charge is brought near the gold sphere, the test charge experiences a repulsive force. A negative test charge would experience an attractive force (the electrostatic force as the opposite direction when the charge is negative). Dividing the electrostatic force F_E by the value of the test charge effectively eliminates the test charge from the equation of the electric field. Since the direction of the electric field is the same as that of the electrostatic force, **Figure 11(b)** can also be viewed as representing the electric field around a positive test charge +*q*.

In a similar way, for a gold sphere with a negative charge -*q*, the direction of the electric field is inverted i.e. the force experienced by a positive test charge becomes radially attractive and the arrows now point in the direction of the gold sphere, as shown in **Figure 12**. If you take a positive nucleus and have electrons around it, these electrons would also experience an attractive force because unlike charges attract each other (**Figure 9**). According to the classical theory of electrostatics, the electrons should fall toward the nucleus and they should not stop until in contact with the positive nucleus. However, at the beginning of the 20th century, physicists realize that this was not the case i.e. electrons do not fall on the nucleus but circle around it in precise orbits. The challenge for these physicists was to understand why the orbiting electrons do not fall on the nucleus. This puzzle was ultimately solved by quantum physics (but it required a profound revision of many of the most basic concepts of physics).

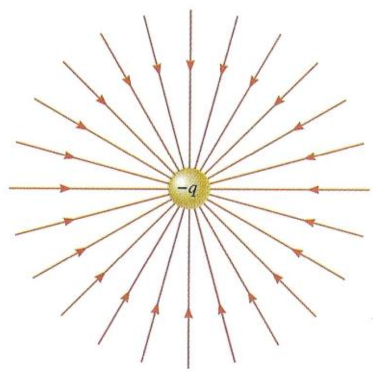


Figure 12: The lines of force are directed radially inward from a negative point charge +*q*. This configuration of lines can represent the direction of the electrostatic force or the electric field.

It is interesting to see what happens to the electric field when two charges of the opposite sign are placed next to each other. Compare the result with what happens when two charged of the same sign are placed next to each other (**Figure 13**). The two charges with the opposite sign attract each other and you can see the electric field lines of one charge "blend" perfectly with the electric field lines of the charge with the opposite polarity. When charges of the same sign are next to each other the electric field lines don't seem to "get along" i.e. they to do blend together and the two charges repel each other.

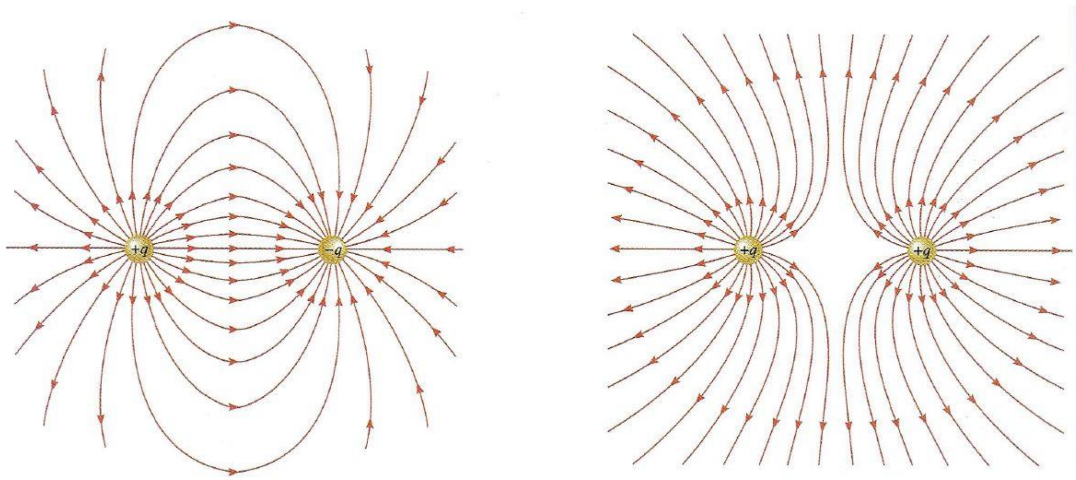


Figure 13: Electric field lines when two charges of opposite sign are near each other (left) and when two charges with the same sign are placed next to each other.

1.3- Potential energy and the Electric Potential

We now come to a very important concept since physicists and engineers refer to it most often when talking about electricity: the *electric potential*. For example when we say that the voltage in a home is 120 volts, we are referring to the electric potential. To help understand the concept of electric potential, we will go back to the more easily understandable notion of gravity. Electric fields are similar to gravitational fields in that both involve forces that act over a distance without physical contact (action-at-a-distance). So to understand the electric potential we can use the gravitational potential as an analogy.

Before we get to the concept of gravitational potential, we need to introduce the concept of *work* (usually represented by the letter W). Contrary to force, work is not a vector i.e. it has no direction, it is simply a quantity. Work is a familiar concept but in physics it has a very specific meaning. In physics, work is done whenever a force is applied to an object and causes the object to move in the direction of the force. The amount of work is equal to the strength of the force multiplied by the distance traveled in the direction of the force (assuming a constant force, if the force is not constant the idea is the same but more complex mathematics are needed). For example it takes work to lift a weight from the ground or to push a car that is stalled. Looking at the stalled car example (**Figure 14**), when a force F pushes on a car and makes the car moves a distance *d*, the work done is equal to the force multiplied by the distance (or $W = F \times d$)..

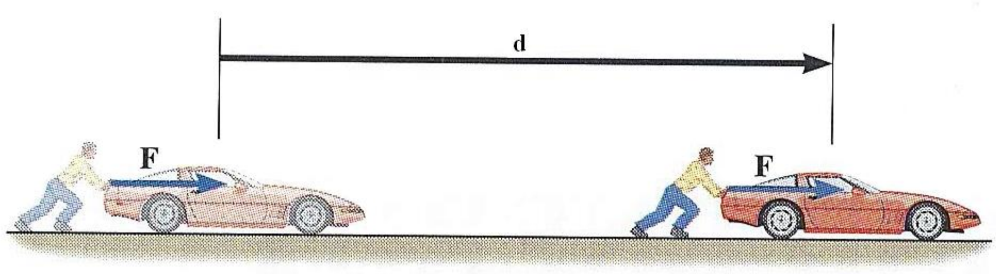


Figure 14: Work is done when a force F pushes on a stalled car and produces a displacement d in the direction of the force.

Similarly, when a basketball is taken from ground level to an initial height h_i (**Figure 15**, left) the work done to bring the basketball there is equal to the force applied to lift the ball multiplied by the vertical distance h_i. In this case, the force is applied to overcome the gravitational force that is pulling the basketball downward. Now, to let the basketball fall to its final height h_f, all we have to do is let it go (let's assume there is a table at h_f that stops the basketball from falling to the ground). In this case, the force F_g doing the work is gravity and the work done by gravity is $W_g = F_g \times d$. In this case the distance d is de distance between h_i and h_f i.e. $d = h_i - h_f$ (d is the difference between the initial height minus the final height).

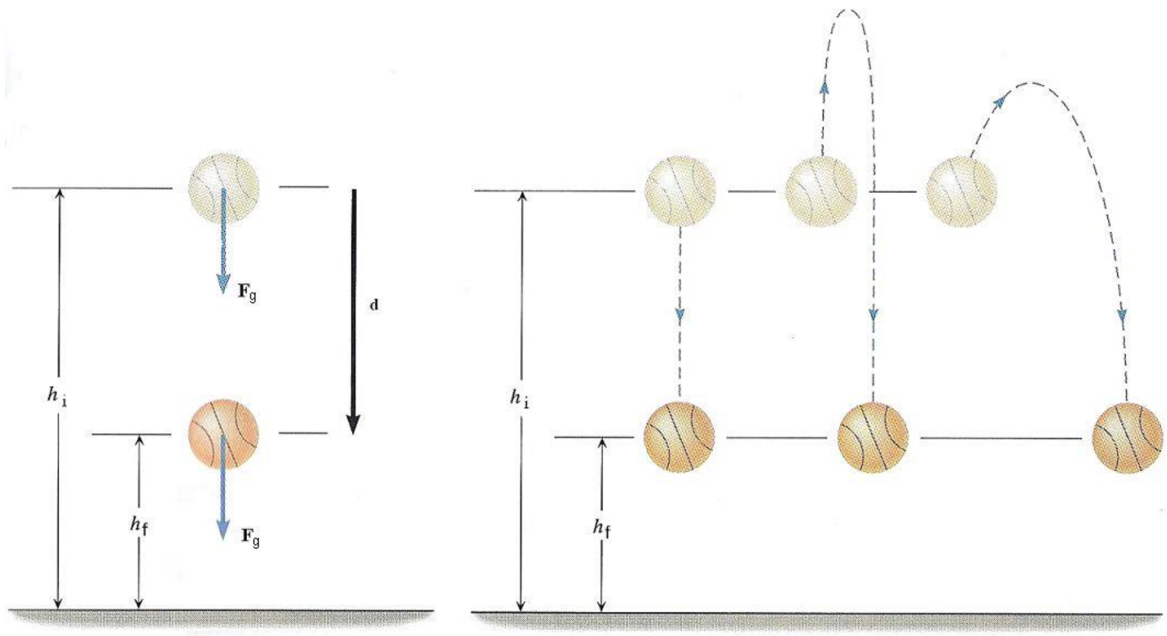


Figure 15: Left) When a basketball at an initial height h_i is let go to a final height h_f, work is done by gravity and it is equal to the gravitational force F_g multiplied by the displacement d. Right) the work done by gravity does not depend on the trajectory taken by the basketball, it only depends on the initial and final positions.

An interesting feature of the concept of work is that the work done by the gravitational force depends only on the initial and the final position of the basketball in the direction of the force (which is vertical). For example, the right side of **Figure 15** shows 3 cases that are equivalent in term of work done by the gravitational force: in the first case the basketball is simply dropped; in the second case the basketball is pushed up and come down to its final position h_f; in the third case the basketball is pushed up and sideways and then come down to its final position h_f. Even though the final horizontal position is different in the last case, the work done by the gravitational force is the same because only the displacement in the direction of the gravitational force is important because the other observed effects would be produced by other forces, not the gravitational force. In each of these 3 cases, because the initial and final positions are the same vertically, the work done by gravity on the basketball is the same. This is because the gravitational force is purely vertical and the definition of work states that only the displacement in the direction of the force matters (this is an example where it is important to remember that a force is a vector, otherwise the calculation of the work done may be wrong). In the case where the basketball is pushed up first, another force has to do this work in order to produce this result. So the work done to push the ball up is not due to gravitation. Similarly, when the ball is pushed sideways, another force is doing that work, it is not the gravitational force. You start to see why the definition of work stipulates that only the component of the displacement in the direction of the force counts. From this example, it is apparent that work is only a number (also called a scalar), it does not have a direction.

Two more concepts that are also very important and have very specific meaning in physics are; *energy* and *power*. These two concepts are scalars (no direction involved, only quantity). *Energy* is defined as the capacity to do work. Its unity or “currency” is called the *joule*. You must have energy to do work otherwise no work can be done. Energy can be compared to how much money you have while work is how much money you spend. To do 10 joules of work, you must spend 10 joules of energy (work has also the unit of *joule*, it is an expenditure of energy). If you have not spent the energy and you still have it with you, it is called *potential energy*. The word potential here means that it is there, you have it, but it has not been used or spent yet. It has not done work. You can spend energy in many ways, one way is to accelerate an object by applying a force to make it move faster. The energy is then transformed into giving the object a certain velocity. We can say that you have transformed the potential energy into *kinetic energy* (the word kinetic means “in movement”). When a pitcher throws a baseball toward the batter, you know that the baseball has energy because it makes a noise when it hit the bat (to make the noise, work is done to transform kinetic energy into sound). The baseball has enough kinetic energy to even injure the batter if it hits him. The kinetic energy is transferred to the baseball during the time the pitcher takes the baseball from rest and applies a force to accelerate it to its final velocity (the kinetic energy acquired by the baseball is the product of the force the pitcher applied to the ball multiplied by the distance over which it was applied). At the moment the pitcher let the ball go, it reaches its maximum velocity and it also has maximum kinetic energy. The kinetic energy (represented here by the letter K) contained in the ball is dependent on the mass of the ball multiplied by its maximum velocity squared ($K=½mv^2$, m represents the mass and v the velocity; the factor ½ comes from mathematical considerations that are beyond the level of this text). The dependence of the kinetic energy on the velocity squared is important to understand because it has dreadful implications while driving your car. For example if you hit a car at 30 miles per hour, the energy in the impact is 4 times bigger than at 15 miles (not 2 times) because of the dependence of the kinetic energy to the square power of the velocity. So be very careful while driving at 60 miles per hour, the impact can be devastating!

Power is the rate at which you spent energy. Its unit is the *watt*. One watt is equal to spending one joule of energy per second. If you spent 10 joules per second during one second then you spent 10 watts. If you do the same during 10 seconds you spent 100 watts. When we say a light bulb is a 100 watt bulb, it means that the light bulb spent 100 joules of electric energy per second to produce light and some heat too. When you are billed by the utilities, they look at the meter which tells them how many watts you spent over a certain period of time (one week or one month). If you multiply the number of watts by the time it was spent, you get the energy that was used and that is what you get billed for.

When the gravitational force does work to move an object from a high location to a lower location above ground, the object's total amount of energy is conserved. Here is what this means. Take again the example of the basketball (**Figure 15**). Let’s say one let go of the ball from its highest position, which is h_i. During the course of the falling motion, the potential energy decreases because it depends on the height of the ball above the ground, the higher the ball is brought above the ground the more potential energy it has i.e. the energy that was spent to bring the ball at h_i is “stored” in the ball; this potential energy decreases when the ball is dropped. However, the kinetic energy increases (the velocity of the dropped ball increases as it falls). Experiments have repeatedly shown that, if one neglects the friction force of the air, the sum of the potential energy and the kinetic energy remains constant. The total energy of the basketball/ground system is conserved. Because of that property, gravity is called a conservative force, meaning the total energy (which is the sum of the kinetic energy and potential energy) is conserved or constant, it does not change over time (neglecting friction forces). This is true for any isolated system. However, the friction of the ball with the air makes the falling basketball to lose energy to air and so the basketball/ground system is not strictly an isolated system and the total energy is not conserved but it would be if you remove the air. Also the quantity of energy lost to the air is small so that in first approximation we can say that the basketball/ground system is almost an isolated system. The electric force is also a conservative force and that is why the comparison between the gravitational force and the electric force can be made.

Even if a force is not conservative (such as friction force), basic laws of physics stipulate that energy is never lost, it is only transformed. This is what conservation of energy means i.e. that energy is never created or destroyed, it only changes form. Einstein extended the conservation of energy principle to include transformation of energy into mass and vice-versa (mass is excluded from the energy conservation principle in classical or Newtonian physics). In his famous equation $E = mc^2$ (here E is energy in *joules*, m is mass in *kilograms* and c is the speed of light = 300,000 *kilometers* per second), Einstein gives the formula to calculate how much energy is stored in mass. If you do the calculation, you will find that even a very small mass has enormous energy stored in it and that is why atomic energy is so powerful (and why the atom bomb is so devastating).

We saw that both the gravitational force and the electric force are conservative forces and that is the reason why we can use the gravitational force to help understand the electric force. Here is how the comparison is done: 1) the gravitational field is replaced by the electric field; 2) mass is replaced by electric charge (i.e. just as the gravitational field acts only on mass and not on electric charge, the electric field acts only on electric charges and not on mass). There is one major difference: while mass comes in one type only (all masses always attract each other), electric charge comes in 2 types: positive and negative which renders repulsion possible on top of attraction. Also the electric force is many times stronger than the gravitational force. That is why static electricity can overcome gravity (see **Figure 10**).

Now we are ready to look at the *electric potential* (usually the letter V is used to denote that quantity). The reason we need the electric potential is similar to the reason why we needed the electric field. Just as in the case of the electric field, it is useful to have a quantity that does not depend on a test charge. Since electric work (W_E) depends on the electric force (F_E) which includes the value of a test charge, electric work is dependent upon the value of the test charge as well (i.e. $W_E = F_E \times r$ with $F_E = q \times p/r^2$). In similarity with the electric field, we can eliminate the test charge by dividing the electric potential energy by the value of the test charge, just like we obtained the electric field by dividing the electric force by the value of the test charge (i.e. $V = W_E/p = F_E \times r/p = q/r$). This electric potential is now a universal quantity since it does not depend on the value of a test charge (+*p*), just like the electric field is a universal quantity because it does not depend on a test charge either.

The electric potential is a notion derived from the electric potential energy. The electric potential energy can be understood better by analogy to the gravitational potential energy. In **Figure 15**, gravitational potential energy was given to the basketball by lifting it up to the maximum height h_i. The work that was done to bring the basketball to h_i was transformed into gravitational potential energy. This gravitational potential energy could be transformed into kinetic energy by dropping the ball. The kinetic energy can be used to generate other forms of energy. For example, when the basketball hit the ground it makes a noise. The energy that produced the noise comes from a part of the kinetic energy that was transformed into sound when the ball started vibrating immediately after hitting the ground. The electric potential energy can be understood using similar logic.

We can draw a comparison between the electric potential energy and the gravitational potential energy keeping in mind the 2 substitutions already mentioned i.e. replacing the gravitational field by the electric field and replacing mass by electric charge. To make the analogy complete, we replace the basketball of **Figure 15** by a test charge and the ground by our gold sphere (imagine it is very big, the size of our planet which is also a ball, this will make the electric field lines almost perpendicular to the surface of the sphere). Let's assume the gold sphere is negatively charged so that the electrostatic force is an attractive force just like it is the case for the gravitational force (interestingly, the surface of the Earth is negatively charged see our article The Earth's Electric Surface Potential, so you can actually used the Earth instead of a large gold sphere in this example). In this case the electric potential energy can be defined the same way the gravitational potential energy was defined; by bringing a test charge from contact with the gold sphere to a certain distance from it, we are doing work and this work is transformed into electric potential energy. Just as the gravitational potential energy stored in a mass depends on the value of that mass and the distance above the ground, the electric potential energy stored in a test charge depends on the value of that test charge and its distance from the gold sphere.

An example can help understand the concept of electric potential better. Let's assume our gold sphere is charged positively as in **Figure 16**. Concentrate on the test charge placed at point #1 in **Figure 11(a)**. Let's say that this test charge has an electric charge +*p* and that it is at a distance *r* from the gold sphere (**Figure 16**). The electric potential energy (let's called it U) depends on the product of the 2 charges ($q \times p$), just like in the case of the electric force F_E. However, the electric potential energy decreases linearly with distance (i.e. it depends on 1/*r* so $U=q \times p/r$), while the electric force depends on the inverse of the square of the distance ($F_E = q \times p/r^2$). Also, you may have noticed that the equation for U is the same equation as that for the electric work W_E; the difference between the two is that U is energy stored in the test charge while W_E is energy spent when the test charge is in motion.

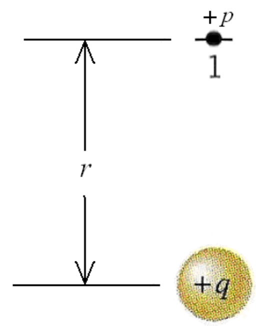


Figure 16: A positive test charge +p is placed at spot 1 at a distance r of a positive charge +*q* (gold sphere).

Eliminating the dependence on the test charge creates a new parameter called the *electric potential* (V). This is a desirable parameter since we do not want to be tied up with a test charge that is arbitrary (i.e. we do not always know what test charge we will use around the gold sphere). Also, having a property that is independent from the test charge make that property "universal" in the sense that it can be applied to any types or configurations of test charges. To get rid of the test charge, we just need to divide the electric potential energy U by the value of the test charge +*p*, just like we divided the electric force F_E by the value of the test charge to get the universal quantity that is the electric field E. The quantity we get from this process is called the *electric potential* (V) and it depends only on the charge of the gold sphere and the inverse of the distance from it (i.e. $V = W_E/p = q/r$). The unit of the electric potential is the *joule/coulomb* (this comes from $V = W_E/p$ where W_E is in *joules* and *p* is in *coulombs*) or, more commonly, the *volt*.

From the definition of the electric potential energy U and the electric potential V, it is clear the further away from the gold sphere we take the test charge, the smaller the value of U or V because they are dependent on the inverse of the distance. At a distance $r = \infty$ (infinite distance), U and V would be zero, i.e. there would be no electric potential accumulated and consequently no voltage. So it is logical to attribute the value of zero potential to a distance that is infinite. **Figure 17** shows the equipotential lines around a positive charge as the dashed gold lines forming circles perpendicular to the electric field lines. In reality the positive charge is a three dimensional object in three dimensional space and so the equipotential lines seen on **Figure 17** (dashed gold lines) are a series of concentric spheres around the positive charge when seen in three dimensions.

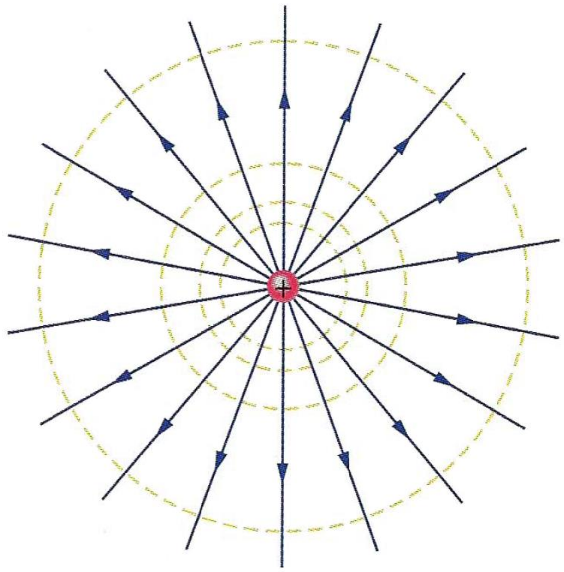


Figure 17: Electric field lines (blue lines) and equipotential lines (dashed gold lines) around a positive charge. Note that the equipotential lines are perpendicular to the electric field lines. The density of the gold lines represents the value of the electric potential i.e. the closer the gold lines to each other, the higher the value of the electric potential. As the distance from the positive charge increases, the density of the gold lines decreases until at an infinite distance the separation between gold lines becomes infinite (the electric potential is zero).

Also noticed how the equipotential lines are perpendicular to the electric field lines. This will always be the case no matter the configuration of the electric field. For example, if the electric field lines are parallel, as in **Figure 18**, the equipotential lines are planes perpendicular to the lines of electric field.

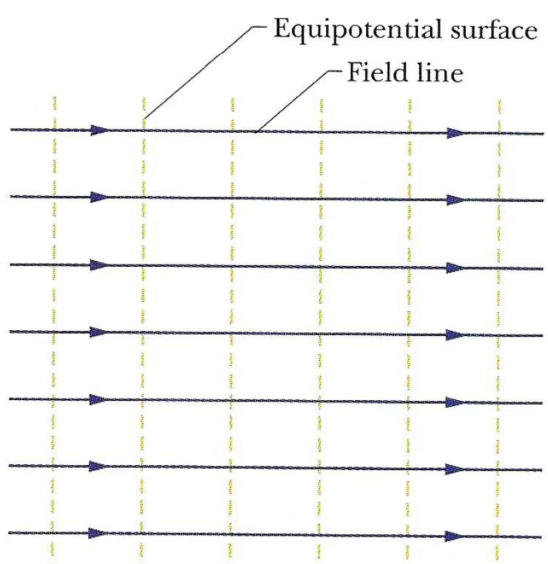


Figure 18: Parallel electric field lines (blue lines) and equipotential lines (gold lines). Note again that the equipotential lines are perpendicular to the electric field lines. This is a cross-section of a 3 dimensional object where each gold line form a plane in 3-D space.

This kind of electric field as represented in **Figure 18** can be approximately produced by two copper plates at different electric potential (**Figure 19**). A difference in electric potential is generated when charges of opposite sign are part of a closed system. Notice that there is a distortion at the edge of the plates in **Figure 19**. To be prefect, the analogy would require plates of infinite size, that is why we can only approximate the electric field and potential represented in **Figure 18** in the real world.

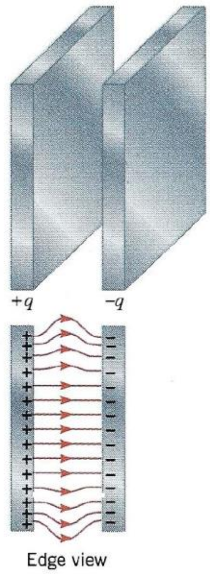


Figure 19: Parallel plates with opposite charges (+q and –q) distribute evenly at their faces facing each other. The electric field lines are parallel in the middle of the plates with a distortion at the edges.

When there is an electric potential difference (i.e. from a high electric potential to a low electric potential, which is always the case, there is no such thing in reality as one electric potential) there will always be an electric field produced by it and perpendicular to it. The reverse is true too, when there is an electric field there is an electric potential difference producing it. Always they are perpendicular to each other (this can be demonstrated mathematically but this is beyond the scope of this paper). In other words, they are always found together and perpendicular to each other. **Figure 20** shows another example from a person who has been electrically charged positively. The electric field lines come out of her head, pushing the positively charged hairs to move up her head. As required, the equipotential lines are perpendicular to the electric field lines.

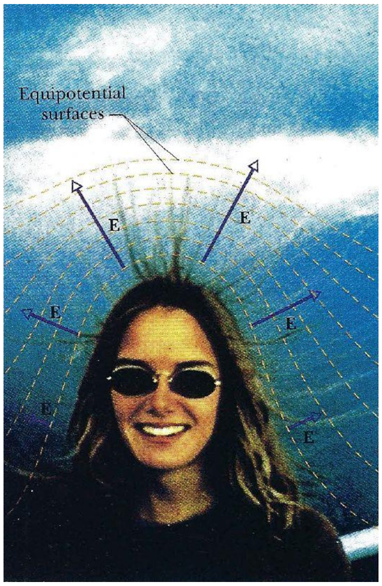


Figure 20: Person who has been electrically charged positively. The electric field lines are represented by arrows coming out of her head and the equipotential lines are the golden lines running perpendicular to the arrows representing the electric field.

There is a problem though if the electric charge is distributed over a large surface instead of being a point charge as in our example of the large gold sphere (**Figure 16**) or the parallel electric field lines (**Figure 18**). The problem is that the electric potential never goes to zero even at infinity for an infinitely large surface. For example, if you make the plates in **Figure 19** infinitely large and you bring the right plate (the negatively charged plate) at infinity (theoretically, of course, that cannot be done practically), the electric field lines will be parallel and there will always be an electric potential perpendicular to these plates that will not vanish even at infinity. Another problem is that in the practical world it is not convenient to use an infinite distance to define the electric potential of all instruments on the Earth! So what scientists decided to do is to assign a value of zero to the electric potential of the surface of the Earth (because it generally has the most negative electric potential around; for details, see our article The Earth's Electric Surface Potential) and use that as the reference point to calculate the electric potential of all electric equipment and processes on the Earth. In truth, we are only interested in differences in electric potential (as already mentioned one value of electric potential is meaningless unless it is referenced to another electric potential chosen as the reference potential). We want to know if the electric potential of an object above the ground is at a higher or lower potential than the Earth or another object. That is what matter because electric chocks comes from differences in electric potential, not from the pure value of the electric potential. You maybe in a high rise building at 10,000 volts, but if all objects around you are at the same electric potential, nothing happen. However, if you touch a pipe that is grounded, you will experience an electric shock. So this agreement of setting the surface of the Earth at zero volt makes perfect sense for all practical purposes.

1.4- Conductors, Insulators and Semiconductors

Materials such as metals are *electric conductors*. They contain free or mobile electrons that can carry electric energy from place to place inside the conductor. When we flip on a light switch, we are allowing the electric energy carried by the electrons to move through the conductive wires to a light bulb, which converts the electric energy into light energy (another form that work can take, i.e. work is necessary to transform electric energy into light). The human body is a conductor because it contains a large number of ions dissolved in water (when dissolved in water ions are called electrolytes). Blood and other body fluids are therefore good conductors.

Other materials, called *insulators*, have very few free or mobile electrons. Electrons are all bound locally to the molecules of the insulating material. Glass, plastic, wood and rubber are good insulators. Rubber and plastics are often used to cover electric wires to keep the conductors from touching each other and to keep you from touching the conductors, which could otherwise give you an electric shock.

Some other materials are not as good as conductors to carry electricity but not as bad as insulators. These are called *semiconductors*. You probably already heard that term because these materials are used in the electronic industry to make electronic chips. The reason is that it was discovered that the electric conduction of these materials can be controlled at will with the appropriate setup. So was born the transistor. These transistors can be used for the same purpose as the old electronic lamps but they can be made so much smaller that you can literally have millions of transistors taking the place of only one lamp. The discovery of this property of semiconductors is at the heart of the development of our modern electronic equipment (TV, cell phone, computers, etc.).

1.5- Electric Systems

All electric systems have 3 measurable properties that are important to understand for the following discussion of the health effects of Earthing. These properties are *voltage*, *current* and *resistance*. Electric systems work by sending electric energy through a wire made of a conducting material with the goal of producing some work such as lighting up a bulb or make a motor rotate, etc. These 3 properties will help us understand how this works.

1.5.1- Direct current (DC) electricity

First let’s look at the simplest form of an electric system: Direct current (DC). DC electricity is produced by electrons flowing in a wire. A hydraulic analogy may be helpful here. In this analogy, the flow of electrons can be compared to the flow of water through a pipe (**Figure 21**). The voltage corresponds to the pressure in the water pipe. The pressure can be created by a vertical column of water, as from a water tank on a hill pushing water down through a pipe by gravity, or by a mechanical pump pumping water in a pipe. The left side of **Figure 21** with high pressure corresponds to high voltage. The flow of water corresponds to the current of electrons in the wire and the restriction in the pipe corresponds to the electrical resistance. When water gets to the region of smaller diameter in the pipe, it experiences a higher level of friction with the walls of this smaller diameter pipe which slows down the flow of water through the pipe resulting in a decreased pressure after the restriction, where the pipe returns to its original size. This is similar to what happens to the electrons going through an electrical resistance. That resistance increases friction between the flowing electrons and the material of which the resistance is made of. This results in a decrease in electrons’ energy and thus the electric potential goes down (the electric potential is defined as the energy per electric charge so if the energy goes down so does the electric potential). When the water pressure is low, there is less energy pushing on the water to move it than when the pressure is high; likewise when the voltage is low there is less electric energy pushing the electrons in the wire than when the voltage is high (i.e. they are moving more slowly). When the voltage is high, it can be difficult to stop the flow of electric energy, and when the voltage between two objects is extremely high, sparks will jump from one object to another to discharge or neutralize the difference in electric charge (or electric potential which is caused by the separation of these electric charges) between the two objects (as shown in **Figure 8**).

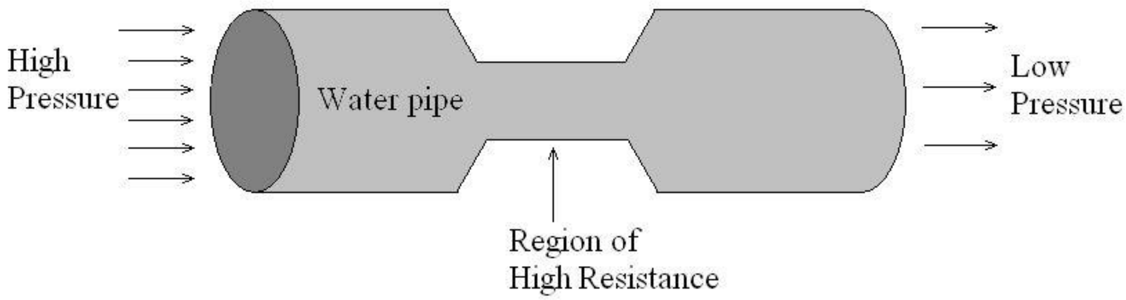


Figure 21: Water pipe analogy. Pressure mimics voltage, water flow mimics electrons flow (current) and the restriction in the pipe works like a resistance.

In real life, DC voltage is usually produced by electric cells and batteries. **Figure 22** shows a number different types and sizes of cells and batteries that are commonly used for battery-powered equipment such as flashlights, camcorders and cordless phones. All these batteries produce direct current (DC) voltage which is the source of the DC current. Remember that a difference in electric potential always produces an electric field (section 1.3, **Figures 17-20**). This is also true in the case of DC electricity i.e. there is an electric field going from high electric potential to low electric potential and, in reality, it is this electric field inside the wire that moves the electrons and in doing so produces the electric current.

Figure 22: Various cells and batteries (top-left to bottom-right): two AA, one D, one handheld ham radio battery, two 9-volt (PP3), two AAA, one C, one camcorder battery, one cordless phone battery (credit: Wikipedia, http://en.wikipedia.org/wiki/Battery_%28electricity%29).

In an electric circuit, resistance is generally produced and controlled using resistors with specific resistance values (i.e. it is known by how much such a resistance will impede the flow of electrons). A resistor is a passive two-terminal (ie. it has two wires, one on each side of it) electrical component that implements electrical resistance as a circuit element. **Figure 23** shows an example of a common type of resistor.

Figure 23: A typical axial-lead resistor. The colors code the value of the electric resistance offered by this resistor (credit: Wikipedia; http://en.wikipedia.org/wiki/Resistor).

It has been demonstrated a long time ago that the current (I) through a resistance (R) increases in direct proportion to the voltage (V) existing across the two terminals of the resistance and that it is inversely proportional to the resistance (i.e. the current decreases linearly with the resistance). This relationship is called "Ohm's law" and the equation describing it is:

$$I = V/R$$

where I is the current flowing through the resistance (or resistor) in units of amperes, V is the electric potential difference measured across the resistance in units of volts, and R is the resistance of the resistor in units of *ohms* which is more commonly used than *volt/ampere* (from R = V/I). As you can see, the current increases when the voltage increases and it decreases when the resistance increases.

As an example of *direct current (DC)* electricity, consider a small penlight with a 1.5 volt DC battery in it (**Figure 24**). Remember that DC voltage is analogous to the pressure in the water pipe (**Figure 21**) and causes the electrons to flow (analogous to water flow in a pipe) through the light bulb (analogous to the restriction producing friction and resistance in the water pipe). The light bulb contains a tungsten filament with a high resistance that causes the current to heat up the filament enough to produce light (in the case of an incandescent light bulb, the work done by the electric current on the resistance transforms the electric energy into heat first and then light if the temperature goes high enough). In the case of direct current (DC), the electric energy is carried by the electrons which move through the wire (this is not true with AC current, as it is explained in section 1.5.3 below). A chemical reaction within the battery provides the energy that creates the voltage which pushes the electrons through the circuit. As the battery is used or ages, the chemical reaction looses energy and the voltage decreases, resulting in dimming of the light emitted by the light bulb until, eventually, there is not enough electric energy to produce light.

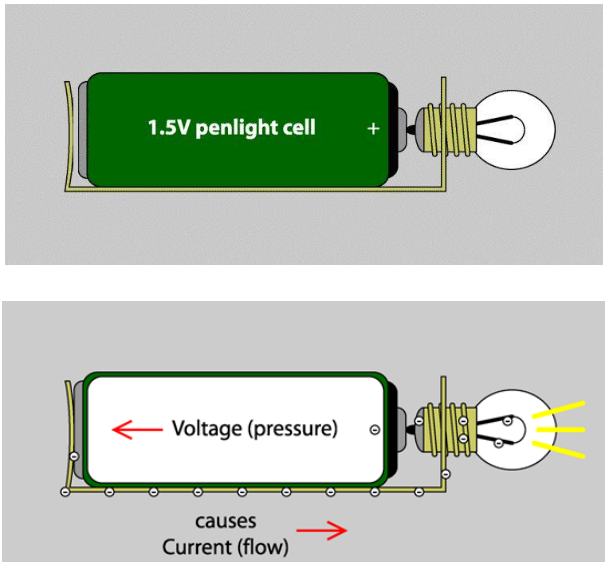


Figure 24: Top: The penlight is turned off (the circuit is not closed, there is a gap between the left metal electrode and the left terminal of the battery) and so there are no electron flowing through the light bulb and consequently there is no light. Bottom: the circuit is closed and electrons are flowing from the negative terminal to the positive terminal of the battery passing through the tungsten wire in the light bulb and in doing so the current produces light.

For DC, the *electric current* is the rate at which the electrons move through the circuit and it is measured in *electrons per second* or, more often, in *amperes*.[3] The analogy for the flow of water in a pipe would be gallons per minute. Surprisingly, the actual speed of electrons moving in a wire is very slow. For a copper wire of 1 mm in diameter carrying a steady current of 3 amps, the drift velocity of the electrons is only 0.28 mm/sec—about a quarter of a mm per second![6] You will see that the situation is very different for AC electricity (section 1.5.3).

Resistance is the third property of DC electric circuits to consider. In the case of the small penlight, the filament in the light bulb provides almost all of the resistance to current flow. While the actual physics is a bit more complicated than this, one could say that the friction between the moving electrons and the thin tungsten filament in the light bulb creates heat and light (it can be said that the work that is done to move the electrons through the tungsten filament is transformed into heat and light by the process of being forced through the resistance caused by the tungsten filament). Remember that the water analogy to resistance is a narrow pipe that slows the flow of water through it (**Figure 21**). In this case the resistance offered by the tungsten filament is so high that it heats up the filament to the point where it starts emitting light. To emit light an object must be heated to at least 1,700 ^{o}F (degrees Fahrenheit; which is equal to 850 ^{o}K; ^{o}K means degrees Kelvin which is used by scientists because the absolute cold temperature, the coldest temperature possible in the universe, is zero in this temperature measuring system). A tungsten filament usually operates between 4,040 ^{o}F (2,500 ^{o}K) and 4,760 ^{o}F (2,900 ^{o}K). Still the light from an incandescent light bulb looks yellowish. To have beautiful white light like the sun, we would need a material that can sustain a temperature of 10,340 ^{o}F (6,000 ^{o}K). No material can sustain such a temperature without melting or evaporating. Tungsten has the highest known melting temperature (6,164 ^{o}F or 3,680 ^{o}K) and the lowest rate of evaporation (vapor pressure) of the pure metals. Carbon can withstand higher temperatures without melting, but evaporates too rapidly. Compounds and alloys (usually metal carbides and nitrides) with higher melting temperatures and lower evaporation rates exist, but these are brittle and tend to disassociate at these very high temperatures.[7]

Figure 25 shows how electricians represent a DC circuit such as that found in the penlight shown above (**Figure 24**). The symbol for the battery is shown on the left of **Figure 25** (also called the source), and the light bulb's resistance is referred to as a load and is represented by a wavy line which is the symbol used for resistance. The electron flow is from the negative terminal of the battery, through the load, and back to the battery.

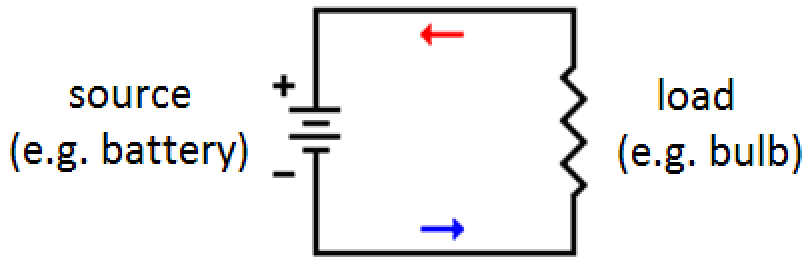


Figure 25: Diagram representing schematically the penlight circuit of the preceding Figure. The arrows show the direction of electron flow (the current flows in the opposite direction by definition).

The current flows in the opposite direction because way back, before anybody knew what electricity was made of, Benjamin Franklin defined the current flow as the motion of positive charges into a wire (this is based on his famous kite experiments where he postulated that a positive "fluid" was moving inside the wire holding the kite). Today, we know that it is the electrons (negative charges) that produce the current in wires. Reversing the sign of the moving charges is equivalent to changing the direction of the current flow to the opposite direction (think about this!). Notice that in a DC system, the electrons flow in one direction through the wire and through the bulb and back to the battery again. We will see that this is very different from the situation with alternating current (AC) electricity. Also notice that when the penlight is turned off (by opening the circuit; this could be best done by the use of a switch) the electrons are not moving in the wire and the load.

1.5-2- The Magnetic Field

Before talking about alternative current (AC) systems, it is necessary to talk about the magnetic field. When electrons move through a wire, another phenomenon occurs: a magnetic field is created around the wire carrying the current (**Figure 26**). Researchers discovered that the magnetic field produced by moving electrons in a wire always form closed loops that circle around the wire with the plane of the magnetic loop perpendicular to the direction of the circulating current. This phenomenon has been observed for a long time (the physical law encoding this discovery is the Biot-Savart law that was formulated in 1820) and it has been included in the famous Maxwell equations (the equations describing electromagnetic waves) which were published in 1861.[8] So this phenomenon has been known for quite a long time.

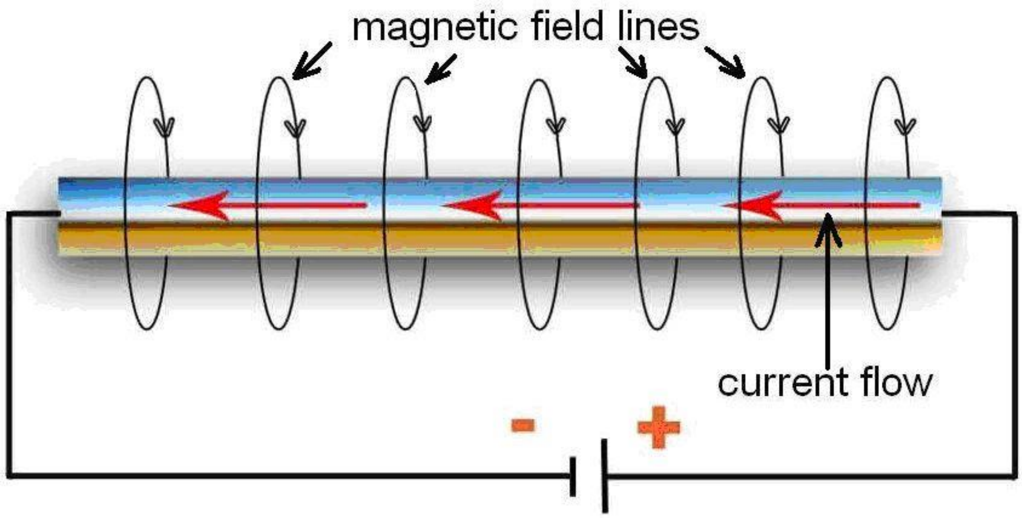


Figure 26: The DC current flow produced by a battery generates a magnetic field looping around the wire with the plane of the loops perpendicular to the wire. Note that the direction of the current is opposite to the flow of electrons because electrons have a negative charge (the current is defined as the flow of positive charges -> the flow of negative charges is in the opposite direction to the current).

Remember from section 1.2 (**Figures 11** and **12**) that an electron always creates an electric field around it. The direction of the electric field around the electron is always radial and pointing toward the electron (because it is a negative charge; it is pointing away from the charge for a positive charge). A wire carrying a current has a huge number of circulating electrons in it and it can be demonstrated mathematically that the resulting electric field is radiating perpendicular to the wire and pointing toward it. **Figure 27** presents the complete picture which is that electric and magnetic fields both exist around a DC current. Magnetic field lines are produced by the movement of electrons in the wire i,e, an electric charge in motion always produces a magnetic field looping in a perpendicular direction to the motion of the electric charge. However, no magnetic field is created when electrons are at rest; the theory of magnetic fields states that the strength of the magnetic field increases with the number of charges in motion and with the speed at which they move. An electric field also exists because electrons are negative charges and electric charges always have an electric field around them as already explained (section 1.2). Note also that the magnetic field and the electric field are perpendicular to each other. This is true at every location around the wire. We will see later that this is always the case even in AC electric systems and in electromagnetic waves.

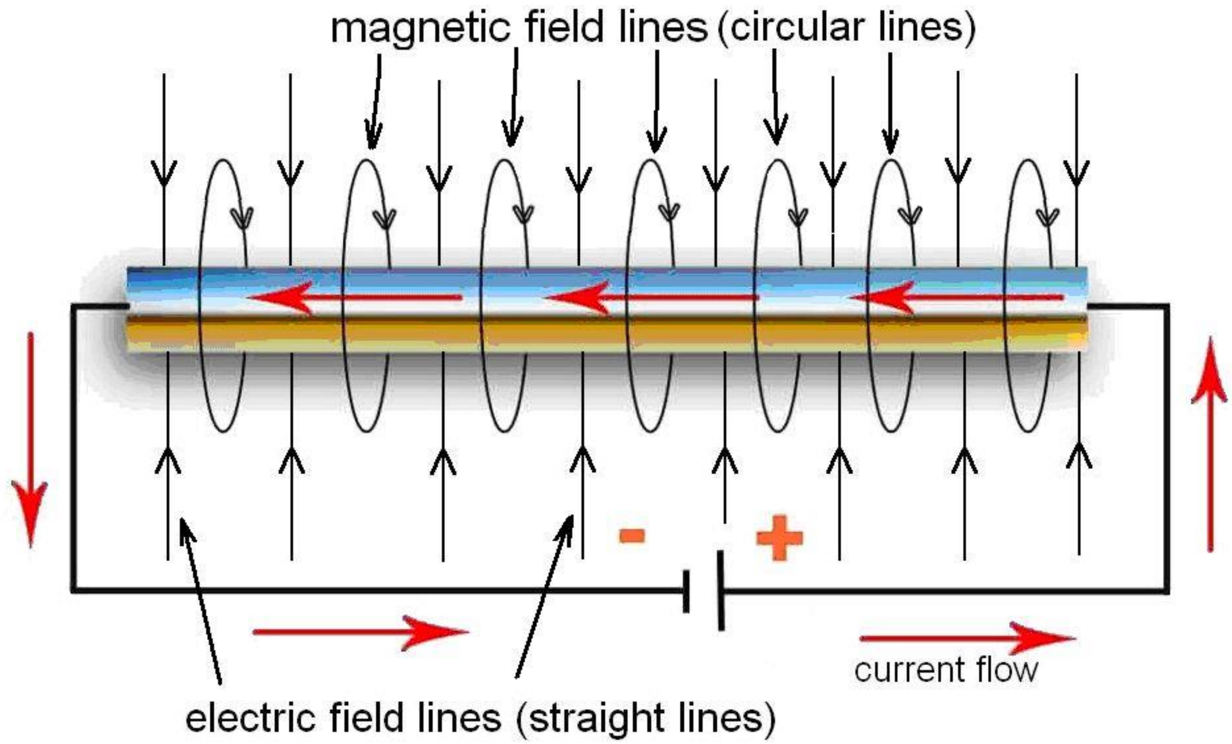


Figure 27: The complete picture: the DC current flow produced by a battery generates a magnetic field and an electric field around the wire. Note that the magnetic field lines form closed loops while the electric field lines are straight and end on the electrons moving in the wire (at all places around the wire, the electric and magnetic field are perpendicular to each other).

As another example of magnetic field, consider a magnet. It is easy to see the magnetic field lines around a magnet using iron fillings as shown in **Figure 28-A**, top image. A pictorial representation of an ideal cylindrical magnet and its magnetic field is presented in **Figure 28-A**, bottom image. Notice how the magnetic field of the magnet looks like the magnetic field of a current circulating in a loop (**Figure 28-B**, top image). The resemblance is even greater when considering several loops next to each other (**Figure 28-B**, bottom image). The single current loop is similar to an electron rotating around the nucleus of an atom; both produce a magnetic field as depicted in **Figure 28-B**, top image. When several electrons rotate in a similar direction around many atoms, just like many loops that are aligned, the magnetic field is reinforced and this produces a strong magnet (**Figure 28-B**, bottom image). Materials that exhibit a magnetic field have unpaired electrons (i.e. "paired" electrons are electrons coupled in a particular way on the same atomic orbital; this coupling produces a cancellation of each other magnetic field; this is a quantum effect and detailed explanations about this are beyond the scope of this paper) spinning around their respective atoms in the same direction, in a similar way as current loops that are aligned in **Figure 28-B**, bottom image. These materials are called "ferromagnetic" and include iron, cobalt, nickel and their alloys. However, most materials do not have unpaired electrons spinning in alignment and, when they do, because there are trillions of electrons spinning around trillions of atoms in even the smallest sample big enough to be seen, their magnetic fields cancel each other perfectly and we do not experience that they have a magnetic field. Examples of such non-ferromagnetic materials include wood, plastic, rubber, aluminum, copper, and all insulating materials.

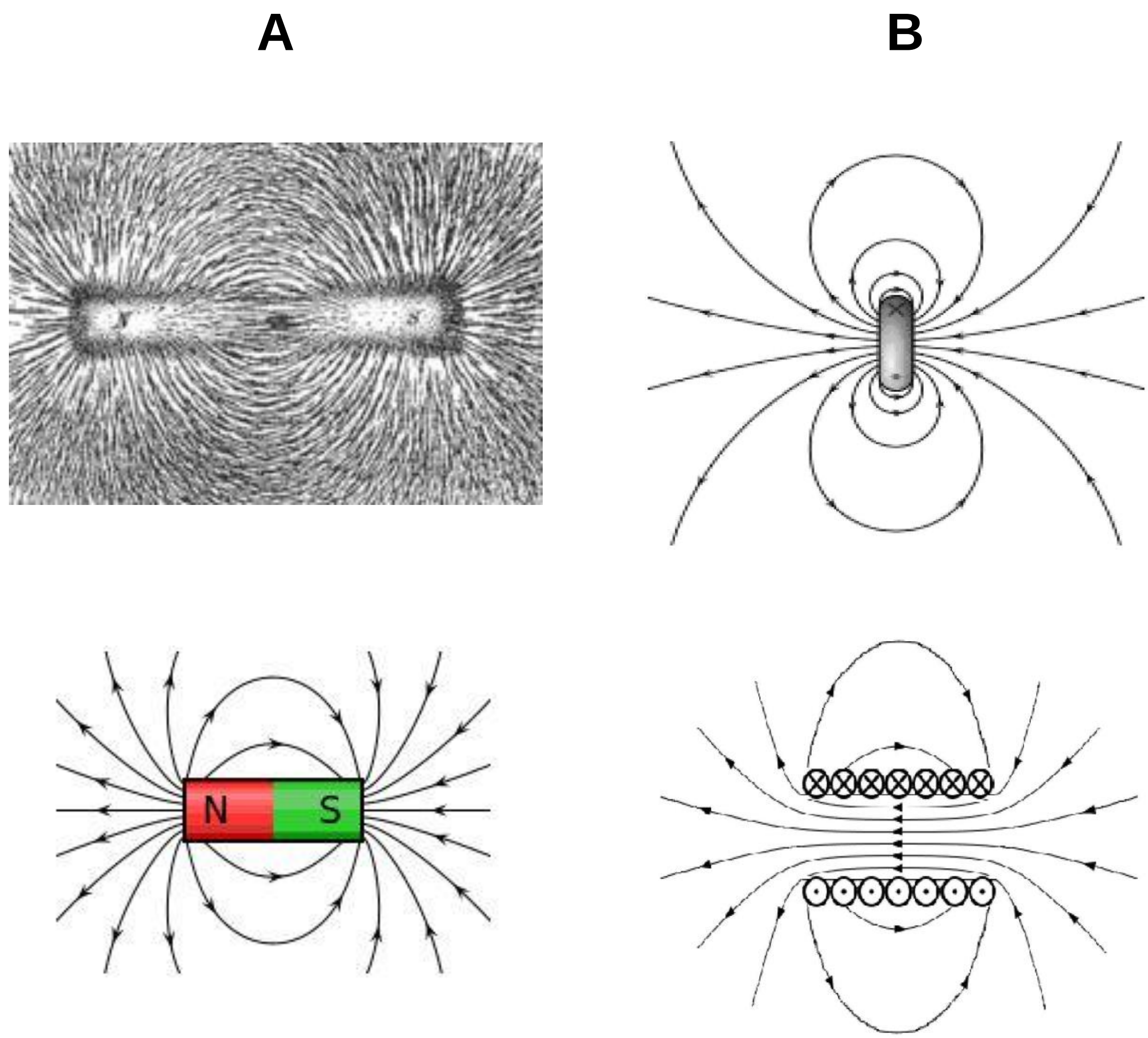


Figure 28. **A Top:** Magnetic field lines are made visible by the alignment of iron filings sprinkled on a piece of paper placed above a bar magnet. **A Bottom**: Magnetic field lines drawn around a cylindrical magnet (magnetic fields lines go out of the north pole (N) and come in through the south pole (S)). **B Top**: Magnetic field lines around a single current loop seen head on. **B Bottom**: Magnetic field lines around several current loops perfectly aligned forming a solenoid (a dot means the current goes out of the page, an x means the current goes into the page).

If an electric charge is at rest in a magnetic field, the magnetic field will have no effect on the charge, the charge will not start to move because of the presence of the magnetic field. This is contrary to the electric field that always causes charges to move, even when they are at rest. When the charge is in motion, a magnetic field will make it move differently than an electric field would. The electric field always makes charges move in a direction that is parallel (or anti-parallel for negative charge) to its direction. A magnetic field will make a charge in movement rotate around an imaginary point in a direction that is perpendicular to the direction of its initial movement resulting in a helical movement (**Figure 29**). The direction of the rotation (clockwise or anti-clockwise) and its size (large loops or small loops) depend on the strength and direction of the magnetic field, the type of charge (positive or negative), the amount of electric charge in motion and the direction of its movement. This is all coded in a formula developed in the nineteen century but to understand that formula advanced mathematics are needed that are beyond the scope of this paper.

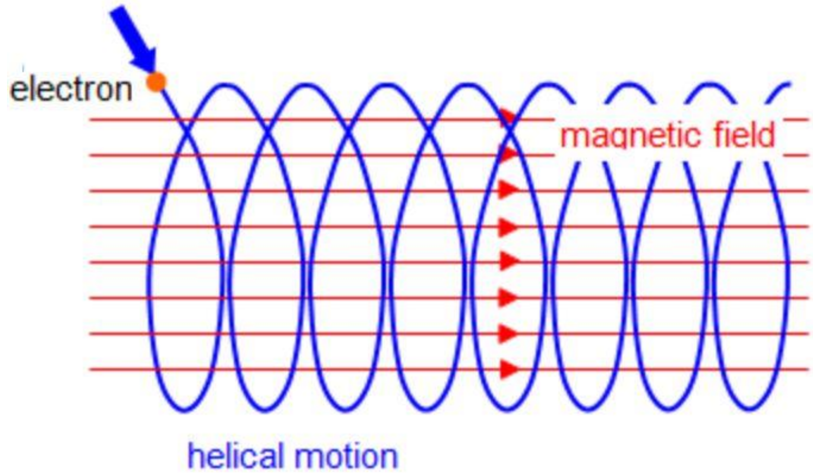


Figure 29. The blue arrow shows the initial direction of the electron (orange ball) moving at constant velocity. Upon entering the region of the magnetic field, the electron starts to spiral in the direction of the magnetic field lines. The effect of the magnetic field is to make the electron rotate around an imaginary point in the middle of the spiral instead of going straight.

In summary, electric fields are generated by electric charges (protons and electrons) even when the charges are not in motion. Magnetic fields exist only when charges are in motion (meaning when there is an electric current flowing). The table below highlights the differences between the electric field and the magnetic field.

Electric fields	**Magnetic fields**
1. Electric fields arise from electric charges. 2. Their strength is measured in Volts per meter (V/m) 3. An electric field can be present even when a device is switched off and there is no current. 4. Most building materials shield electric fields to some extent.	1. Magnetic fields arise from currents (i.e. electric charges in motion). 2. Their strength is measured in amperes per meter (A/m). A related measure is often used instead: the magnetic flux density in microtesla (µT), millitesla (mT), gauss (G) or miligauss (mG). 3. Magnetic fields exist as soon as a device is switched on and current flows. 4. Magnetic fields are not attenuated by most materials (only by ferromagnetic materials such as iron, nickel and cobalt).

If you have followed this discussion closely you may have realized that a charge in motion produces a variable electric field at one fixed point in space (because the charge is moving, the electric field at one fixed point in space must be changing in strength and direction because the charge is moving toward or away from this fixed point in space). Also you now know that a charge in motion produces a magnetic field. Combining these two statements you might have deducted that a variable electric field must produce a magnetic field. If you did, you would have been correct.

In the first half of the nineteenth century, Michael Faraday discovered that the opposite is also true; a varying magnetic field produces an electric field (Faraday's law, 1831). That both varying fields produce each other is why an electromagnetic field (EMF) can propagate in space. The varying electric field produces a varying magnetic field, which produces a varying electric field, which produces a varying magnetic field, and this process repeats and goes on almost indefinitely in space and time. Motors work in a similar way: the current (electric charges in motion) in the wires inside the motor generates a magnetic field which produces a force on the magnets inside the rotor; the configuration of magnetic field and the positions of the magnets inside the rotor are designed to make the rotor rotate for as long as there is a current in the wires. If you reverse the process and rotate the rotor mechanically, you will produce a current in the wires inside the motor and this current can go on the wires outside the motor and, for example, light up a light bulb and that is how generators work! Since changing electric and magnetic fields are needed for this process to occur, motors and generators works only in alternating current (AC) mode. There is a way to make motors work with DC but you still need to create some sort of AC current flow in the wires inside the motor.

1.5.3- Alternating current (AC) electricity

Alternating current (AC) is the type of electricity that is delivered to homes and businesses by the utilities. Normal household electricity is usually produced by a generator and is distributed throughout a community via wires that are overhead or buried under the ground.

Figure 30 shows how electricians diagram an alternating current circuit. The electric generator is presented as the source on the left and the resistance is shown as the load on the right, using a wavy line just as was the case with DC electricity. However, the symbol for the source of voltage (the generator) is a sine wave in a circle, representing the cyclic nature of alternating currents.

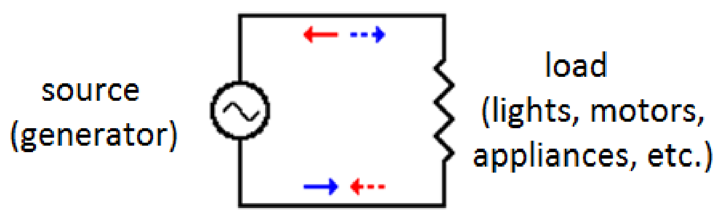


Figure 30: Diagram representing an AC circuit.

In contrast to direct current (DC), where electrons move out of the battery from the negative pole and enter back the positive pole of the battery, in an AC circuit the electrons in the wire move back and forth around the same location, they do not have a net drift velocity. This is depicted in **Figure 30** by the red and blue arrows in opposite directions. It is a rarely appreciated fact (even a misunderstood fact) that the electrons do not actually flow through the wire and the load in an AC circuit. What flows is the *energy* of the electrons. When the circuit is open (the switch is in the off position), there is no energy used (that is in theory, in practice the wire has some resistance and therefore there is a small loss of energy). When the switch is turned on, the electric energy starts to flow from the generator to the load, kind of hopping from one electron to the next as an energetic movement in the wire while the electrons do not actually move along any appreciable distance. So for a typical AC current in a typical lamp cord, the electrons don't actually "flow." Instead they vibrate back and forth by a distance of about a hundred-thousandth of an inch. This means that the electrons in your household wiring are probably the same ones that were there when your house was built many years ago. In contrast to DC, electrons do not leave the AC source and they do not return to the source after they delivered their energy to the load (some websites purporting to explain how electricity works have made this mistake). Yet, the energy flows almost at the speed of light; a conceptual explanation on how this is possible can be found as the bead-straw effect in the Earthing book.

Now you can consider one of the advantages of an AC circuit over a DC circuit. Since electrons do not change position appreciably in an AC circuit, the same electrons that were there when the wiring was installed in your home are the same electrons still providing you with electricity to this day. However, with DC circuits, since electrons actually flow, there is the possibility that the wire can be depleted of electrons. It was found experimentally that this happens over extended period of use of DC systems. This makes the wires brittle and easily breakable.

There is also the fact that motors need AC currents to work. If we were to go back to using a DC electric power system, we would need to convert AC electricity into DC electricity locally (that is doable but at a cost) as the loss of energy along long DC lines would make electricity very expensive. Also, every equipment using an electric motor in the house would need to have additional electric circuits to transform the DC back again to AC. Not very practical and certainly costly!

Figure 31 shows AC electrons wiggling in a wire from right to left (the 3 red dots on the left of **Figure 31**) and then from left to right (the 3 red dots on the right of **Figure 31**). The rate of the switching from one direction to the other and back to its original direction (completing one cycle) is 60 times per second in North America (this is referred to as 60 Hz) and 50 times per second in Europe (they use 50 Hz). The sine wave (waving blue line below the lightbulbs in **Figure 31**) represents the rhythmic variations in the strength and direction of the electric field inside the wire (the electric field produced by the electrons does not change). The electric field inside the wire is produced by the electric generator (which generates an electric potential difference that produces the electric field inside the wires) and it is this electric field that makes the electrons wiggle back and forth in the wire (i.e. this electric field creates the AC current by forcing the electrons to move back and forth in the wire). Starting at zero electric field (blue line coinciding with the horizontal grey line to the left side of that grey line), the electric field goes up to some positive value (i.e. the electrons in the wire start moving to the left as represented by the black line below the 3 left dots), then the electric field reaches a maximum value (at the same time the electrons reach their maximum speed to the left) and then the electric field starts to decrease (and so does the speed of the electrons to the left), crossing the zero point (in the middle of the grey line, the electrons are at rest) and then the electric field starts going into the opposite direction (making the electrons move to the right as shown by the black arrow below the 3 dots on the right of **Figure 31**), the electric field then reach a maximum value there (making the electrons move to their maximum speed to the right) and then it comes back to zero (right end of the grey line, the electrons are again at rest). This process is repeated 60 times per second! This is how the electrons wiggle inside the wires in an AC electric system.

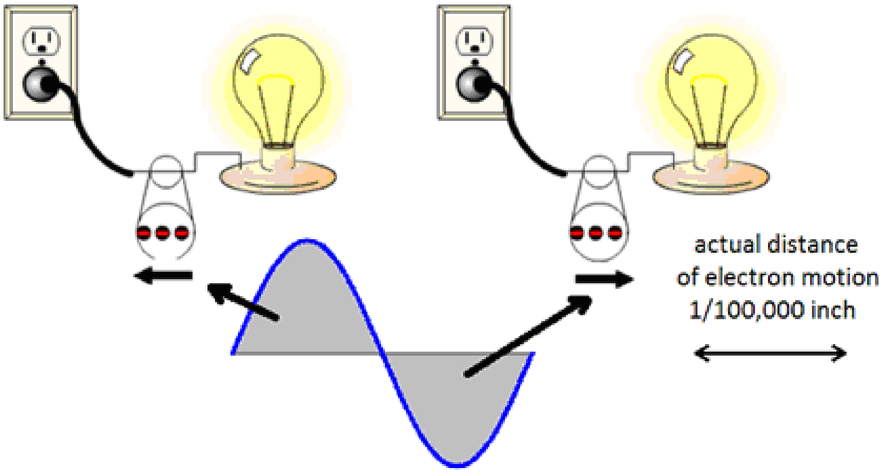


Figure 31: Representation of electrons movements in an AC circuit.

When you flip a switch to turn on the lights in a room, you close a circuit that allows the electrons to move back and forth in the light bulbs. This back and forth movement has energy and it is this energy from the electrons inside the light bulb that heats up the tungsten filament to produce light. As the energy is consumed by the process of heating up the light bulb, the electrons inside the tungsten filament lose energy but, since they are part of the same circuit as the rest of the electrons in the wire (all the way to the generator which can be far away) the nearby electrons transfer some of their energy to the electrons inside the tungsten filament and their newly renewed energy is consumed again in heating up the tungsten filament. This process goes on for as long as the switch is turned on and the electric energy from the generator is available. The amount of electric energy that had to be spent by the generator in order to provide energy to the light bulb so that it can continue to emit light can be calculated. It is from such a calculation for all the electric appliances you use in your house in a month that you are billed monthly by the utility company. An example of an electric generator is presented in **Figure 32**.

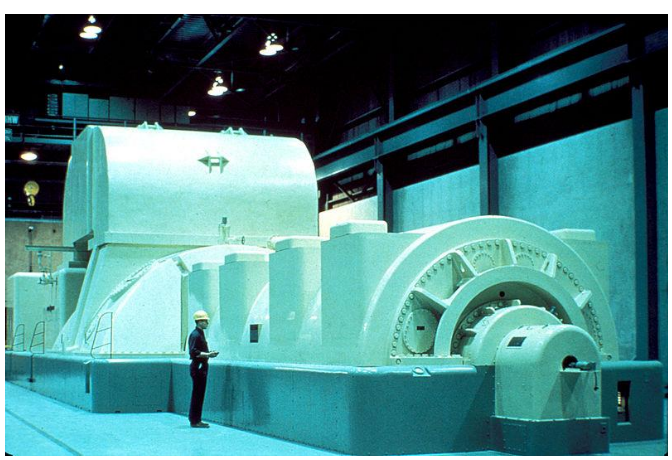


Figure 32: U.S. NRC image of a modern steam turbine generator (credit: Wikipedia, http://en.wikipedia.org/wiki/Electric_generator).

The electricity produced by these electric generators is AC because the generators themselves are like huge motors that are made to rotate by steam (such as the one shown in **Figure 32**) or water (hydroelectric power) or nuclear energy used to produce steam (nuclear power plan). As already mentioned, a generator is a motor that is used in reverse; that is an electric motor transforms AC electricity into a rotating movement while a generator transforms rotating movements into AC electricity. In the case of steam turbine generators, the steam comes from heating water into vapor which is at high pressure and it is this high pressure vapor that is used to make the turbines of the generator to rotate. One way to heat a lot of water into vapor for that purpose is to use a nuclear fission reactor (which is actually an atomic bomb exploding slowly under controlled conditions; sounds dangerous? It is, hence Chernobyl and Fukushima). Further, the electric power is delivered at 60 Hz because these gigantic turbine generators rotate 60 times per second!

1.6- Electromagnetic Fields

As already mentioned, the movement of electrons through a wire creates a magnetic field in the space around the wire (see **Figure 26** and **Figure 33** below). When the current flow is to the left, the magnetic field circulates around the wire in the direction shown (out of the page below the wire and back into the page above the wire). When the flow stops between cycles, the magnetic field collapses to zero, as shown in the middle. When the flow reverses and goes to the right, the magnetic flow circulates around the wire in the opposite direction (out of the page above the wire and back into the page below the wire).

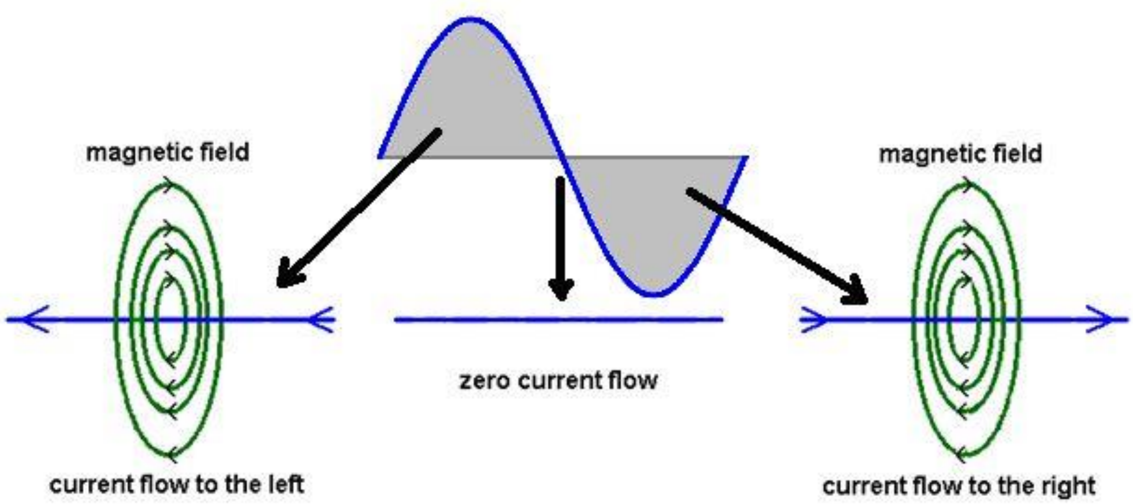


Figure 33: Representation of magnetic fields lines in an AC circuit.

The cyclic variations of the relative intensities of the electric and magnetic fields caused by the AC electrons' back and forth motion in a wire are depicted for one cycle in **Figure 34** below. When the electrons are not moving, the flow of electric energy is zero and the wire has a pure electric field around it directed radially from the wire (the red line starting on the top left of **Figure 34**). As the electrons begin to move, the electric field gradually decreases in strength as the magnetic field increases (the strength of the magnetic field is depicted by the blue line in **Figure 34**). It is like the electric field energy is gradually transformed into magnetic field energy (in fact the sum of the energy in the electric field + the magnetic field remains constant per the law of conservation of energy). When the electrons are moving the fastest the electric field is zero (first crossing of the gray line by the red line on the left) and the magnetic field is at its maximum strength. As the electrons' movement decreases, the magnetic field declines and the electric field increases in the opposite direction until it reaches a maximum in that direction (lowest point of the red line in **Figure 34**) and then starts to decreased again, crosses the zero electric field line again and reaches a maximum at which point the electrons come to rest again. This cycling back and forth from pure electric field to pure magnetic field results in the production of an electromagnetic field (EMF) radiating away from the wire.

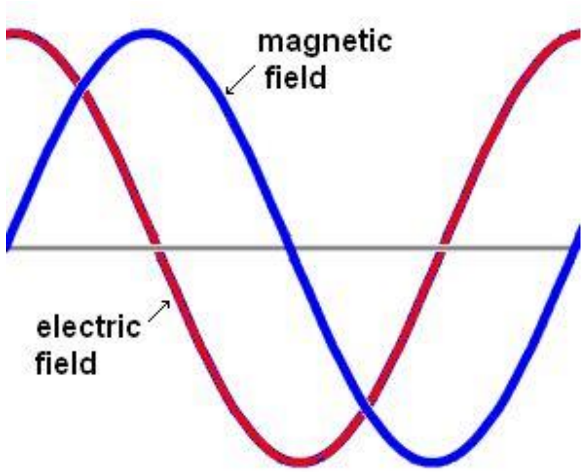


Figure 34: Representation of electric (red line) and magnetic (blue line) fields in an AC circuit during one cycle. The horizontal line represents time (time zero is to the left and the electrons are at rest, then they start to move in one direction then the other direction and they come back to rest at the extreme right)

In reality, the configuration of electric and magnetic fields around real wires are more complicated than represented in **Figure 34**. As an example, **Figure 35** presents a realistic depiction of the electric and magnetic fields (or electromagnetic field) emitted by an antenna due to the back and forth motion of electrons inside the antenna (the 2 small black wires in the middle of the picture form the antenna).

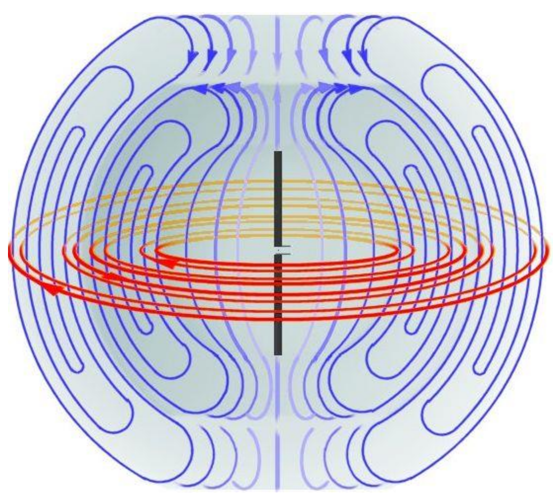


Figure 35: Depiction of the electric field (blue lines) and the magnetic field (red lines becoming yellow as they go around and back the antenna) emitted by an antenna (the 2 small black vertical lines in the middle of the picture). These fields are expanding away from the wire at the speed of light and are continually renewed as long as the antenna is provided with AC power.

When an appliance, such as a lamp, is turned on, the lamp's power cord radiates both electric and magnetic fields similar to ones shown in **Figure 35** which are emitted as electromagnetic fields (EMFs) traveling away from the power cord at the speed of light. These EMFs rapidly diminish in strength with distance away from the power cord. Even when the lamp is turned off, the lamp's power cord still radiates a little bit of EMFs because the electrons are still having a much smaller back and forth movement inside the power cord. The fact that the lamp's power cord as a small resistance causes a small loss of electric power even when the lamp is turned off. Unplugging the lamp's power cord from the power outlet will avoid this small loss of electric power and its emission of EMFs. This is the only way to ensure there will be no EMFs emitted from the lamp's power cord. However, because there are electric wires inside the walls of the house or building and they cannot be unplugged from the electric power source (unless you shot down the breakers of the house) these wires still emit a bit of EMFs even when there are no appliances connected to the power outlets.

This electromagnetic aspect of the wiring found in homes and buildings has a number of consequences. The first consequence is that these wires act as antennas that both emit and receive natural and man-made EMFs. **Figure 36** shows the way our electromagnetic environment transformed in one century (from 1900 to 2000) from a naturally quiet place to one that is literally packed with EMFs of many different frequencies. Recent technologies have added significantly more EMFs to our electromagnetic environment since the year 2,000: cell phone towers, Wi-Fi, wireless routers, satellite TV, GPS and cordless telephones, to name a few.

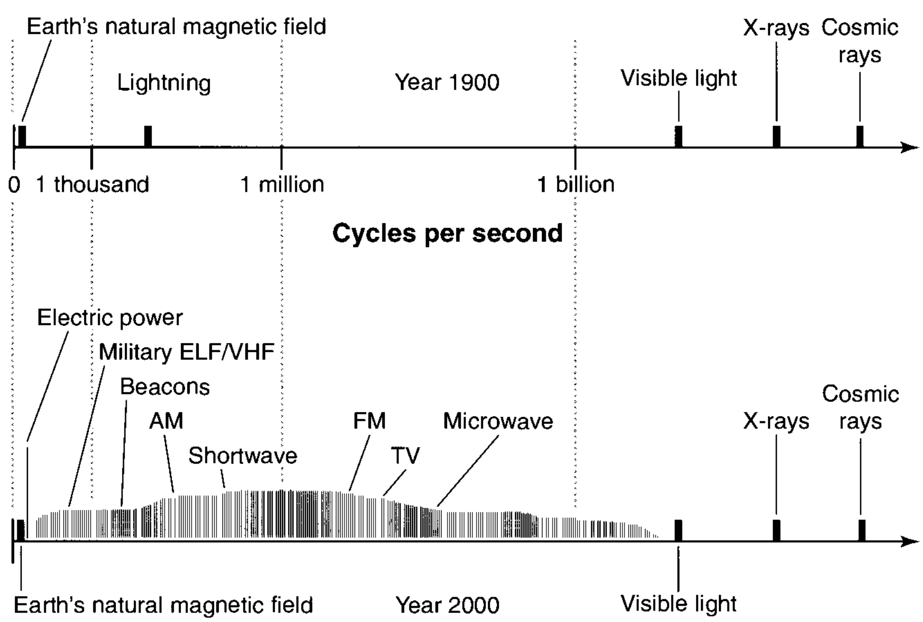


Figure 36: How our electromagnetic environment changed between 1900 and 2000.

Also variety of devices introduces spikes or transients that distort the 60 cycle electric field in the wiring, particularly when they are switched on or off. Some examples:

- ballasts used in fluorescent lighting

- high-efficiency lighting such as CFL (Compact-Fluorescent) lightbulbs
- computer hard drives
- electric heaters
- electric hair dryers
- refrigerators and air conditioners
- vacuum cleaners
- light dimmer switches

For example, when your neighbor's refrigerator or air conditioner switches on or off, an electric spike is created that travels through your neighbor's wires to your household electric system using the incoming electric wires from the utilities which are connecting both houses. Taken together, the various signals and distortions to the 60 Hz field create what some have referred to as "dirty electricity" which has been suspected of having a variety of health effects. Evidence exists (and mounting regularly) that some people are very sensitive to electromagnetic fields and can become sick from exposure to them. This is now termed electrosensitivity. Researchers in this are of research have shown that electrosensitive people have been exposed to strong EMFs for a long time or to other pollutants such as paints and/or other toxic chemicals; their adrenals and autonomic nervous system are overstressed. To mitigate some of these effects, a number of groups have advocated the use of filters between the power source and appliances to "clean" the dirty electricity (**Figure 37**).

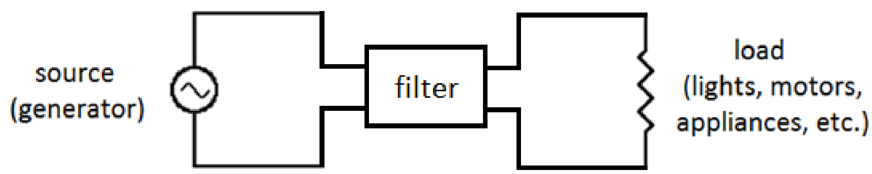


Figure 37: Example of a filter placed between the power source and the load in order to prevent spikes from reaching sensitive equipment.

Unfortunately, such filters are of questionable value since the "dirty" signals travel not only in the wires but also in the atmosphere as EMFs. These EMFs are a constant presence in the home environment and will be picked up again by the wires after they leave the filter. Health Canada tested such filters and found that they create considerable distortions of the load current, creating high frequency components well in excess of 10,000 Hz that are not normally present in the power line. Their conclusion is that the filters they tested added higher frequencies to the "dirty" signals already present in the electric power system.

1.7- Capacitance (this is a more advanced topic and can be skipped)

Capacitance is defined as the capacity to store an electric charge. Any object that can be electrically charged has a capacitance (even the human body). A device with a capacitance is called a capacitor. To form a capacitor, it is needed to have two conductors separated by a non-conducting medium (called the dielectric). The notion of self capacitance, i.e. the capacitance of one electrically charged object alone in space, is a concept that exists but is not much in use because of its lack of utility. Below is an example of how two conductors of any shape form a capacitor (**Figure 38**).

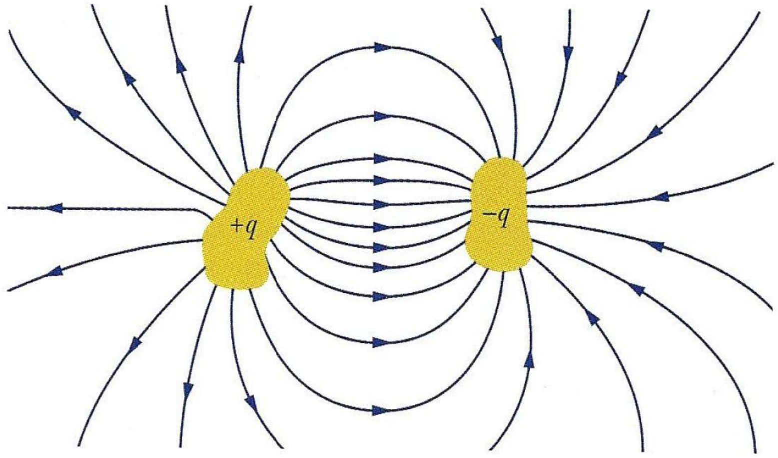


Figure 38: Two conductors, isolated from each other and from their surroundings by a non-conducting medium called a dielectric (here the dielectric is the air between the two conductors) form a capacitor. When the capacitor is charged, the two conductors, or "plates" as they are called, carry equal but opposite charges of magnitude q (one plate with a positive +q charge and the other with –q charge).

Another example of a capacitor is the human body in a room of a building. The body is one "plate" of the capacitor and the wires in the wall of the room form the other "plate" of the capacitor (even if the wires are not isolated since they are connected to the electric power system, they still act as the "other" plate; the important point is that at least one "plate" is isolated from the environment and can have its own independent electric charge). If the person is outside, the other plate is now the surface of the Earth but only if the person is not in direct contact with the surface of the Earth; for example if the person wears shoes with rubber or plastic soles. If the person is in direct skin contact with the surface of the Earth, the person becomes part of the Earth electrically i.e. the electric potential of the person equalizes with that of the Earth and consequently the body does not form the other "plate" of a capacitor with the Earth because of its electrical unity with the surface of the Earth. If another person, isolated from the Earth, come closed to the person in contact with the Earth, this ungrounded person forms one "plate" of the capacitor while the grounded person electrically united with the surface of the Earth form now the other "plate". The grounded person has become electrically "one" with the Earth.

A capacitor also stores potential energy. Just as potential energy can be stored in a spring by compressing it, or potential energy can be stored in a ball by bringing the ball above the ground (working against gravity as previously explained in section 1.3 Potential energy and the Electric Potential and **Figure 15**), a capacitor can store potential energy in the electric field existing between the "plates" when they are charged. All these forms of potential energy can be used to do work. In the case of the spring, if you let it go it can make a toy move, if you let the ball fall down it can push a lever and lift up some weight or make some noise when coming in contact with the floor. We will explore below what can be done with the electric potential energy stored in a capacitor.

The most common form of a capacitor used in electricity is the parallel-plate capacitor. An example has already been presented in **Figure 19**. It is simply composed of two parallel plates that are separated by a small distance from each other. You can see in **Figure 19** the configuration of the electric field lines going out from the positively charged plate (+q) and ending on the negatively charged plate (-q). Let's have a closer look at what happens inside a charged parallel-plate capacitor. **Figure 39** shows a capacitor with two parallel metallic plates separated by a distance "d". The dielectric is represented by the non-conducting material in red placed between the plates. Each plate has an area equal to A (could be in square centimeters or square inches but usually the plates are much smaller than these units of measure). Each capacitor plate carries a charge of same magnitude but opposite sign (-q and +q). Because of the charges, the electric potential of the positive plate exceeds that of the negative plate by an amount V, as **Figure 39** shows. Multiple experiments demonstrated that when the magnitude q of the electric charge is doubled, the electric potential is also doubled, so this indicates that q is proportional to V. The proportionality constant is the capacitance of the capacitor. Putting this into in equation we get:

$$q = CV$$

where C, the proportionality constant, is the capacitance. We can rewrite this equation as:

$$C=q/V.$$

Since the unit of charge is the *coulomb* and the unit of voltage is the *volt*, the unit of the capacitance is the *coulomb*/*volt*. This is called a *farad* (the symbol for the farad is F; it is named after the 19th century English inventor Michael Faraday 1791-1867).

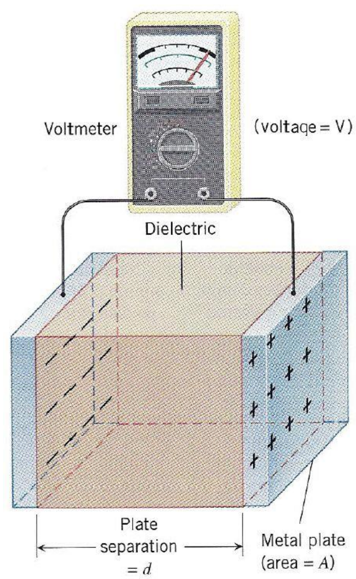


Figure 39: A parallel plate capacitor consists of two metal plates, one carrying a charge +q and the other a charge –q. The difference of potential between the plates is V (the electric potential of the positively charged plate exceeds the potential of the negative plate by an amount V) as indicated by the voltmeter. The region between the plates is filled with a dielectric (red space between the plates).

One farad is an enormous capacitance. Usually smaller amounts, such as a microfarad ($1\ \mu F = 10^{-6}$ F), the nanofarad ($1\ nF = 10^{-9}$ F), or a picofarad ($1\ pF = 10^{-12}$ F), are used in electric circuits. The capacitance reflects the ability of the capacitor to store charge in the sense that a larger value of the capacitance C allows more charge q to be put onto the plates for a given value of the electric potential difference V. There are many types of capacitors used in electric circuits (**Figure 40)**.

Figure 40: The left picture shows solid electrolyte, resin-dipped 10 µF 35V tantalum capacitors (the + sign indicates the positive terminal), the middle image shows 4 electrolytic capacitors of different voltages and capacitance, while the right picture shows miniature low-voltage capacitors above a ruler divided in centimeters.

In practice many electric circuits contain both resistors and capacitors**. Figure 41** illustrates an example of a resistor-capacitor or RC circuit. This is called a charging circuit because when the switch S is closed, the battery with voltage V will charge the capacitor C slowly to the same voltage V. However, it takes some time for the capacitor to be fully charged and the voltage across the capacitor V_c will go from 0 volt to the full voltage of the battery V in a characteristic time which is called the time constant.

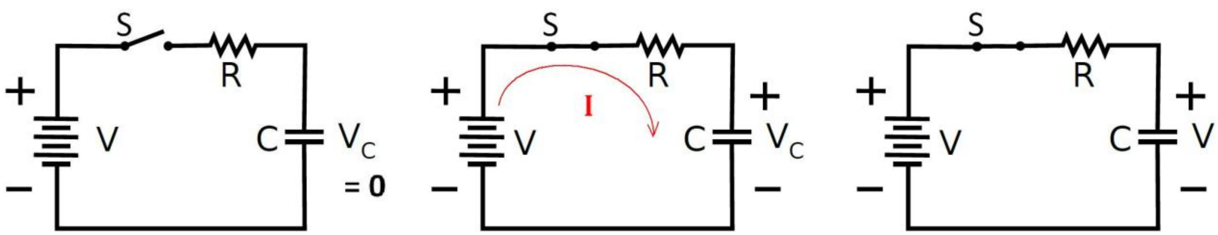


Figure 41: A simple RC circuit demonstrates charging of a capacitor. The left diagram shows that the switch S is open and so there can be no current flowing from the battery, with voltage V, to the capacitor C so the voltage (and charge) on the plates of the capacitor is 0 volt (and the charge is 0 coulomb). The middle diagram shows what happens just after the switch is closed. A current I starts to flow (showed by the red harrow) and the capacitor is charging. It is not completely charged yet so the capacitor voltage $V_c < V$. The right diagram shows a fully charged capacitor. The voltage between the capacitor plates is now the same as that of the battery, V, and there is no current flowing because the voltage on the capacitor prevents any current from bringing more charges on the capacitor plates.

Once the capacitor is charged, the charge stored in it can be used to do some work. **Figure 42** shows a modified circuit that allows a capacitor to be charged or discharged, depending on the position of the switch. When the switch is in position "a" the battery is charging the capacitor. This is equivalent to the circuit of **Figure 41**. When the switch is in position "b" the charged capacitor is discharging into the resistor R. In this case, the capacitor acts like a battery. It can light a penlight just as a battery can (see **Figures 24** and **25**).

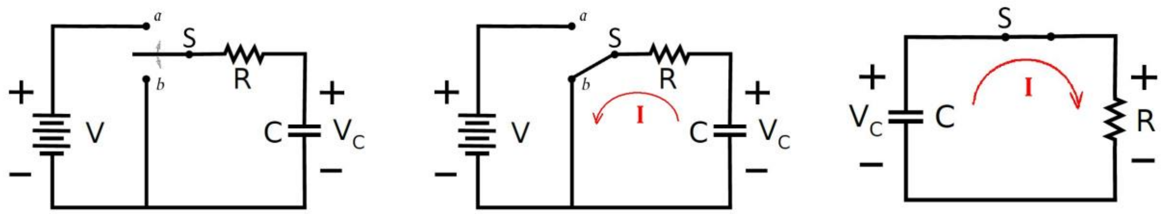


Figure 42: A simple RC circuit demonstrates charging and/or discharging of a capacitor. The left diagram shows a circuit that can charge or discharge a capacitor, depending on the position of the switch S. When the switch is in position "a" the battery is charging the capacitor. This is equivalent to the circuit shown in **Figure 41**. The middle diagram shows the switch in position "b". In that position, the capacitor is now discharging into the resistor R. This is the same circuit as the simplified circuit in the right diagram.

However, contrary to a battery that has the capability to generate some energy from chemical reactions and maintain a constant voltage for long periods, the capacitor charge is not replenished as it used. As the stored electric charge gradually flows through the resistor R, the current provided to the resistor decrease exponentially. If fact both the charging and discharging of a capacitor using a resistor R happens with a characteristic time called the time constant usually represented by τ (the Greek letter "tau"). This time constant as for value RC i.e. $\tau = RC$. This is illustrated in **Figure 43**.

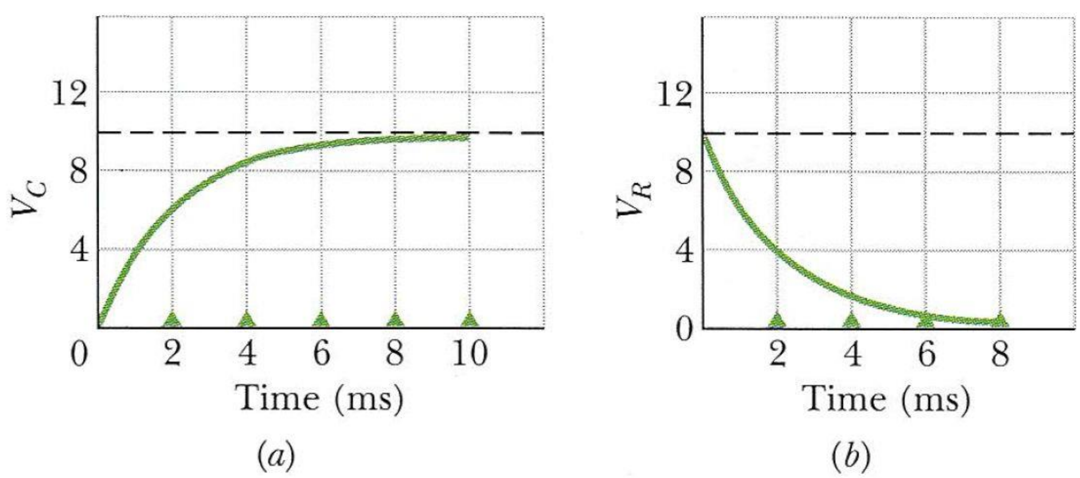


Figure 43: (a) A plot reflecting the buildup of charge on the capacitor C of **Figures 41** and **42**. Initially the voltage V_C of the capacitor is 0 and within about 10 milliseconds it is charged up almost to the voltage of the battery (10 volts; dotted line). (b) A plot reflecting the discharging of the voltage across the capacitor C into the resistor R as shown in **Figure 42**. Initially the voltage V_R across the resistor is the same as that of the fully charged capacitor C (10 volts) and decreases to almost 0 in 8 milliseconds. In reality the time constant of these two plots is the same as the same capacitor and resistor were used. For this illustration the voltage of the battery V = 10 volts; the resistor R = 2000 Ω; and the capacitance C = 1 µF. These numbers give a time constant $\tau = RC = 2$ milliseconds (ms).

The time constant τ represents the time it takes for a capacitor to charge to 63% of its full voltage. For example, after 2 milliseconds the capacitor of **Figure 43 (a)** is charged to 6.3 volts. In a discharging circuit, the time constant represents the time is takes for a resistor to discharge to 37% it is final voltage (which is zero). So after 2 milliseconds, the resistor of **Figure 43 (b)** has only 3.7 volts left.

In trying to understand better what a capacitor does, let's look at a hydraulic analogy. It is not a perfect analogy but it helps understand the basic physics behind the capacitor. **Figure 44** shows an example of a hydraulic capacitor. It is represented by a metallic sphere (it could have been made of any solid material and have any shape and still work) with a rubber membrane in the middle separating the two halves of the sphere completely. The water plays the role of the electric charge. No water can leak from one side of the sphere to the other; the membrane is sealed perfectly tight. This membrane corresponds to the space between the plates of an electric capacitor where the charges cannot go from one plate to the other because of the dielectric material between the plates that would not allow the charges to go through to the other plate. The size of the sphere corresponds to the size of the plates in an electric capacitor; the bigger the sphere (or the plates) the bigger the capacitance. If we remove the right stopper and force water to go in by increasing the pressure on that side, the membrane will bent toward the left side as shown in the figure. Simultaneously the same amount of water that was pushed in through the right side must go out on the left side, pushing out the left stopper. Energy is stored in the stretching of the membrane. This is equivalent to the energy stored in the electric field of an electric capacitor.

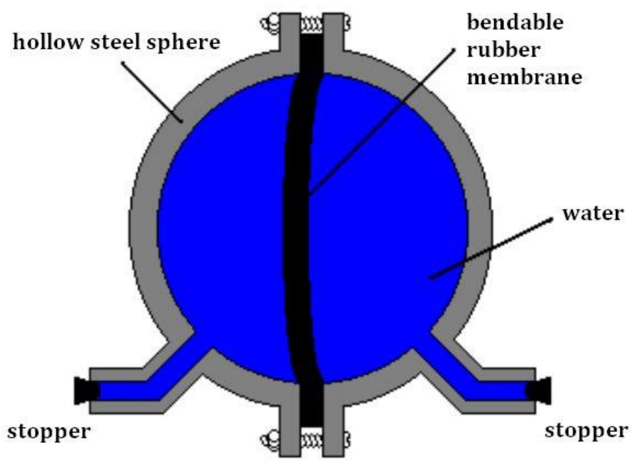


Figure 44: Hydraulic analogy of a capacitor.

Now, imagine that the hydraulic capacitor is initially empty of water and then we start pumping water into it from the right side. Initially, the water will go in easily, with minimum resistance. Then as the sphere is closed to be full, the resistance to get more water in increases and eventually no more water will be able to go in. This pattern of water filling the sphere is similar to the pattern of current bringing electric charges into the electric capacitor. Initially current goes in easily and the capacitor is charging up quickly. Then there is more opposition to more charges coming in as the voltage of the capacitor is getting close to the voltage of the battery. Eventually the current stops and the capacitor has the same voltage as the battery. This is represented in **Figure 43 (a)**. This same figure can also represents the filling of the sphere with water. As the back-pressure from the stretched membrane approaches the applied pressure, the water current becomes less and less until the current stops when the back-pressure of the membrane is the same as the applied pressure. The time constant to fill the sphere (similar to the time constant to fill an electric capacitor) depends on the product of the size of the sphere (capacitance) by the size of the pipe letting water into the sphere (resistance), just as is the case for the electric capacitor, justifying the validity of this hydraulic analogy.

There is a simple formula that has been developed to calculate the capacitance of a parallel plate capacitor. This formula is presented here as it leads to a better understanding of the factors influencing the capacitance of a capacitor. For a capacitor having each plate with a surface area *A* separated by a distance *d* as shown in **Figure 39**, the capacitance C is given by

$$C = \varepsilon_r \varepsilon_o \times A/d.$$

This means the larger the area *A* of the plates and the smaller the distance *d* between the plates, the larger the capacitance. It is easy to understand that the larger the plates the larger the capacitance based on the hydraulic model. In that model, the larger the sphere, the more water it can contain. Similarly, the larger the plates, the more charges it can store. The increase in capacitance with the smaller distance *d* between the plates is less obvious. However, this can be understood by the law of attraction between opposite electric charges. The closer the electric charges to each other the stronger the attraction between them. This is also the case for charges stored in a capacitor. The closer the plates, the closer the charges of opposite sign to each other and the more they attract each other. A stronger attraction means that more charges of the same sign can be packed together on one plate without the repulsion between like charges preventing them to become closer. That is why there is an increase in capacitance with a decrease in distance between the plates.

The factor $\varepsilon_r \varepsilon_o$ in the equation above take into account the properties of the dielectric that is put between the plates. The larger this factor, the better the dielectric is at maintaining charge separation between the plates and the higher the capacitance. This property of a dielectric can be understood by the concept of permittivity. All materials, even empty space (or vacuum), have a certain degree of permittivity. Permittivity is a measure of a material's ability to resist the formation of an electric field in that material. It describes how much electric field is created in that material per unit electric charge. The larger the permittivity the weaker the electric field produced by a charge in that material. The permittivity of the vacuum is represented by ε_o (called epsilon zero) and it has the fixed value of 8.85×10^{-12} F/m. the vacuum has the smallest permittivity meaning that vacuum has the smallest resistance to the formation of electric fields. This means that a charge creates the largest electric field in the vacuum. Other materials will decrease the strength of the electric field a charge produce in that material. The factor by which a material will decrease an electric field in it compared to the vacuum is called the relative permittivity and it is represented in the equation by ε_r (pronounce epsilon r). The table below shows the relative permittivities of common materials. Notice that while air has a permittivity barely above that of the vacuum, some materials can have very high relative permittivities. For example water has a relative permittivity of 80 at room temperature. This means that if you put water between the plates of a capacitor you would increase the capacitance by 80 compared to if air was in between. Some materials can have a relative permittivity 10,000 or more. You start to see the importance of using a dielectric with a high relative permittivity to build small capacitors with large capacitance.

Relative permittivities of some materials at room temperature under 1 kHz

Material	ε_r
Vacuum	1 (by definition)
Air	1.00058986 ± 0.00000050
PTFE/Teflon	2.1
Polyethylene/XLPE	2.25
Paper	3.85
Mica	3-6[2]
Sapphire	8.9–11.1 (anisotropic)
Concrete	4.5
Pyrex (Glass)	4.7 (3.7–10)
Rubber	7
Diamond	5.5–10
Salt	3–15
Graphite	10–15
Silicon	11.68
Ammonia	26, 22, 20, 17 (−80, −40, 0, 20 °C)
Methanol	30
Ethylene glycol	37
Glycerol	41.2, 47, 42.5 (0, 20, 25 °C)
Water	88, 80.1, 55.3, 34.5 (0, 20, 100, 200 °C)
Hydrofluoric acid	83.6 (0 °C)
Sulfuric acid	84–100 (20–25 °C)
Hydrogen peroxide	128 (–25 °C)
Hydrocyanic acid	158.0–2.3 (0–21 °C)
Titanium dioxide	86–173
Strontium titanate	310
Barium strontium titanate	500
Barium titanate	1200–10,000
Lead zirconate titanate	500–6000
Calcium copper titanate	>250,000

As already mentioned electric energy is stored in a capacitor. How much depends on the voltage V between the plates of the capacitor and the amount of charge Q stored in each plate. The energy stored in a capacitor is

$$W = ½CV^2 = ½VQ,$$

where W is the energy stored in the capacitor. The 2 equations are equivalents since Q = CV.

The behavior of a capacitor in an AC circuit is a very important subject but beyond the level of this paper. It includes such important subjects as tuning and resonance. The interested reader can find more information of this subject here: https://en.wikipedia.org/wiki/Capacitor.

1.8- Inductance (this is a more advanced topic and can be skipped)

The term "inductance" was coined by Oliver Heaviside in 1886. Inductance is the property of an electrical conductor to resist electric current changes by creating a voltage that opposes that current change in the conductor itself (self-inductance) or in any nearby conductors (mutual inductance). This phenomenon is called Lenz's law in honor of the Russian physicist Heinrich Lenz (of Baltic German ethnicity) who formulated this law in 1833. This effect is derived from two fundamental observations of physics: 1) a steady current creates a steady magnetic field (see section **1.5.2- The Magnetic field** and **Figure 26**); 2) a time-varying magnetic field induces a voltage in nearby conductors as described by Faraday's law of induction (see last paragraph of **1.5.2- The Magnetic field**). It is customary to use the symbol *L* for inductance, in honor of Heinrich Lenz.

The effect on an inductor in a simple circuit is pictured in **Figure 45.** Because there is a current flowing in the wire, there is a magnetic field around it (as shown in **Figure 26**). This magnetic field is particularly strong in the region of the coil or solenoid ("Inductor" in **Figure 45**) because the wire loops forming the solenoid are very close to each other and their magnetic fields add up to produce a strong magnetic field with magnetic field lines similar to those represented in **Figure 28 B Bottom**. This is where most of the inductance is located in a circuit as the inductance of a straight wire is negligible. If the current (*I*) shown in **Figure 45** increases, the magnetic field created by that current will increase. Faraday's law states that a change in magnetic field generates an electric field. That electric field creates a voltage that opposes the increase in current (Lenz's law). Shown to the left of the inductor is the voltage V_i that is induced in the wire (the positive and negative sides of are shown by the + and – signs, respectively). The locations of the positive and negative sides of V_i are in the right direction to oppose the increase in current. In the case of a decrease in current, V_i would be in the opposite direction (the + and – signs would be inverted) to try to maintain the current at the same level.

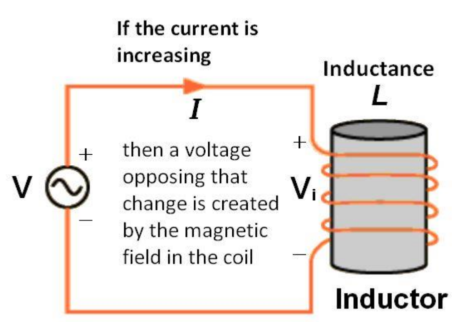


Figure 45: Illustration of the principle of operation of an inductor. The direction of the voltage V_i across the inductor is for an increase in current. This direction would be reversed for a decrease in current.

The equation expressing most exactly the relationship between the current I, the induced voltage V_i and the inductance L is:

$$V_i = - L\times(\Delta I/\Delta t).$$

In words, this equations states that the voltage induced across an inductor V_i is equal but in opposite direction (the minus sign is expressing Lenz's law) to the product of the inductor's inductance L by the rate of change of current through the inductor ($\Delta I/\Delta t$). In this equation $\Delta t = t_f - t_o$ is the time interval between the initial time at which the current was measured (represented by t_o) and the final time at which the current was measured again (represented by t_f) while $\Delta I = I_f - I_o$ is the difference between the final current I_f and the initial current I_o. The direction opposed by V_i is the direction of current change. For example, if the current circulates as shown by the arrow in **Figure 45**, an increase in current will make more current flow in that direction. The inductor will react to the current increase by generating a voltage that will try to diminish this current increase and that is why the direction of V_i is as shown in **Figure 45**. For a decrease in current the direction of V_i would be opposite i.e. V_i is trying to increase the current to prevent its decease.

In the SI unit system (SI is for "Système International d'unitées" or International System of units, the most prevalent unit system in the world but not in the United States, except in physics) the symbol for inductance is the henry with the unit symbol *H*, named in honor of Joseph Henry, an American scientist who discovered inductance independently of, but not before, Michael Faraday in England. Henry was the first Secretary of the Smithsonian Institution. To understand the unit of henry better we can re-write the equation above as (forgetting the minus sign which does no contribute to the unit analysis):

$$L = V_i/(\Delta I/\Delta t).$$

So if we now substitute their symbols for their units, we get

$$henry = volt/(ampere/second) = (volt\times second)/ampere.$$

In other words, a henry is a volt per ampere per second (i.e. the rate of increase or decrease in current per second). The important point to remember is that the greater the value of the inductance L, the bigger the voltage V_i induced across an inductor for the same change in current ($\Delta I/\Delta t$). Inductors have values that typically range from 1 μH ($10^{-6} H$) to 1 *H*. Some examples of inductors and chokes are presented in **Figure 46.**

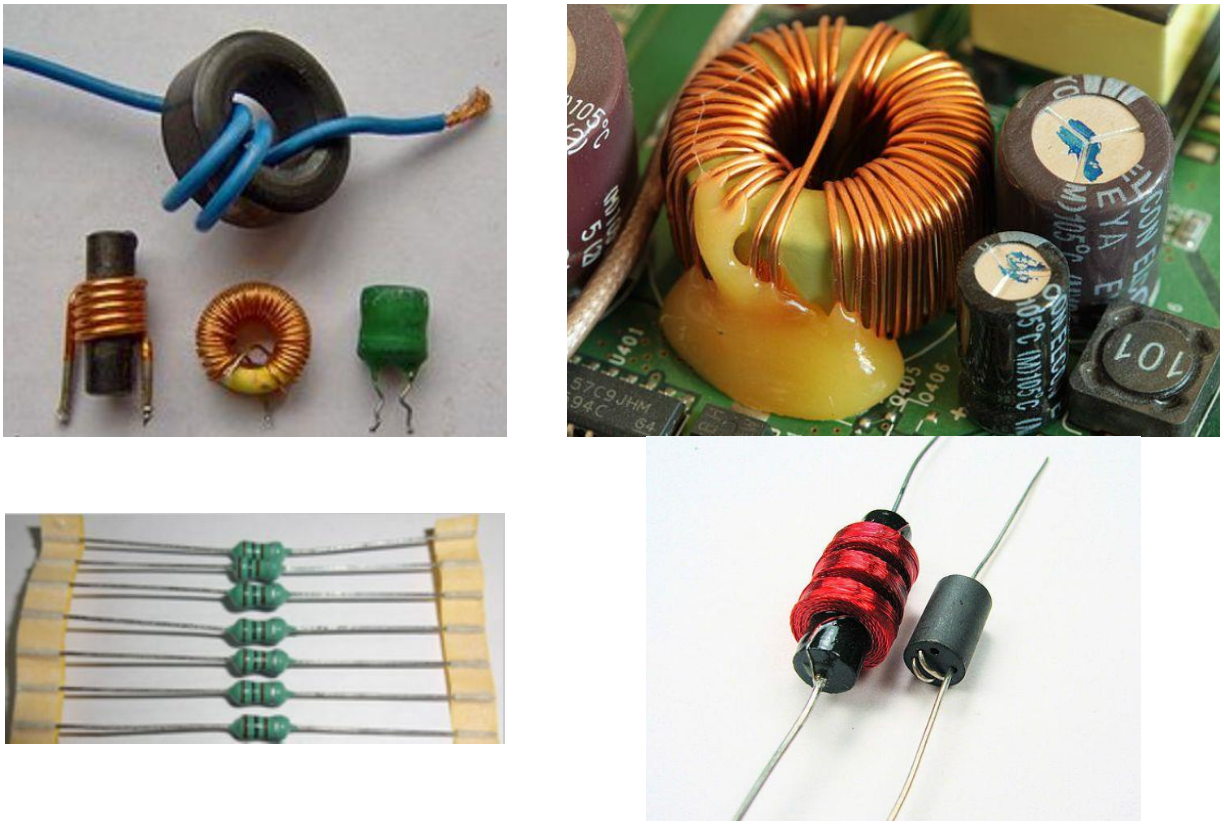


Figure 46: Top left: a selection of low value inductors. Top right: Toroidal inductor in the power supply of a wireless router. Bottom left: Axial lead inductors (100 µH). Bottom right: An MF or HF radio choke for tenths of an ampere (left) and a ferrite lead VHF choke for several amperes (right). Credit: Inductor, Wikipedia, https://en.wikipedia.org/wiki/Inductor

To help further in the understanding of what an inductor does, look at **Figure 47**. A wire coiled around a piece of iron (yellow), forming an inductor, is placed in parallel with a light bulb in a circuit with a battery and a switch. If you take the inductor out of the circuit, you end up with a flashlight similar to the one showed in **Figure 24**.

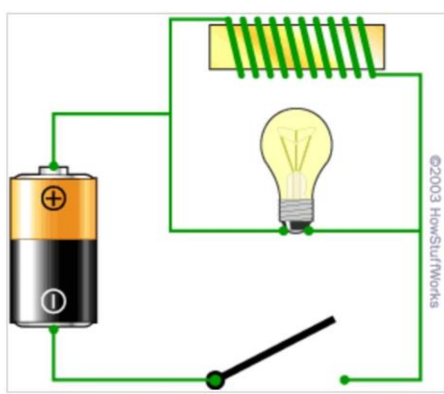


Figure 47: Electric circuit with a light bulb and inductor in parallel. Credit: How stuff work http://electronics.howstuffworks.com/inductor1.htm

In the circuit of **Figure 24** (which is the same as the one in **Figure 47** with the coil removed) when the switch is closed, the light bulb lights up. The lightbulb simply acts as a resistor. When you add the coil in parallel, something very different happens. The wire of the coil has very low resistance, so one would expect that when the switch is closed most of the current would go through the wire and the lightbulb would light up very dimly. Instead what happens at the closing of the switch is that the lightbulb become very bright and then gets dimmer. Then when the switch is open, the lightbulb becomes very bright again and then quickly goes out. The inductor is the cause of this unexpected behavior. Immediately after the switch is closed, the current in the wire increases. Because of Lenz's law, the inductor creates a voltage that opposes the increase in current, trying to inhibit it. This creates the equivalent of a higher resistance in the coil leading to more current going through the lightbulb, making it brighter. However, the current increase slows down and stops quickly, decreasing the resistance in the coil. This has for effect of increasing the current in the coil and decreasing the current in the lightbulb leading to the lightbulb to become dimmer. When the switch gets open, the current rapidly decreases leading to the production of an induced voltage opposing this decrease. This keeps the current flowing for a little time after the switch is open leading to the lightbulb to be lit for a little while after the switch is open. This phenomenon is due to the energy stored in the magnetic field of the coil. However, this energy dissipates very quickly and the lightbulb goes out quickly.

The difference between an inductor and a choke is in their function. A choke is specifically designed for blocking higher-frequency AC current in an electric circuit while allowing lower frequency or DC current to pass. The configuration is as represented in **Figure 48**. In this configuration an inductor functions as a low-pass filter, since the resistance of an inductor increases as the frequency of a signal increases. These chokes are used to protect computers from high frequency spikes on the power line or radio frequency interferences down the wire that could damage computers' sensitive electronic components.

Figure 48: Left: Placed in series with the circuit, the inductor blocks high frequency AC current allowing low frequency and DC currents to pass. Right: A ferrite "bead" choke, consisting of an encircling ferrite cylinder, removed electronic noise from a computer power cord while letting the 60 Hz pass through to power the computer, protecting its sensitive electronic components from high-frequency spikes. Credit: Inductor, Wikipedia, https://en.wikipedia.org/wiki/Inductor

Inductors are used extensively in analog circuits and in signal processing. They are used with capacitors and resistors to create filters for analog circuits and signal processing. Filters are used in most electronic circuits, although capacitors are used as often as possible rather than inductors since capacitors are smaller and cheaper than inductors. Inductors are used in contactless sensors to sense magnetic fields or the presence of magnetically permeable material from a distance. Inductive sensors are used at nearly every intersection with a traffic light to detect the amount of traffic and adjust the signal accordingly. They also form the core of magnetic induction motors. These motors turn electrical energy into mechanical energy. Like capacitors, inductors can be used for energy storage. However, they have a severe limitation on how long they can store energy since the energy is stored in a magnetic field which collapses quickly once power is removed. The main use of inductors as energy storage is in switch-mode power supplies, like the power supply in a PC.

The term air core coil describes an inductor that does not use a magnetic core made of a ferromagnetic material. The term refers to coils wound on plastic, ceramic, or other nonmagnetic forms, as well as those that have only air inside the windings. Air core coils have lower inductance than ferromagnetic core coils, but are often used at high frequencies because they are free from energy losses called core losses that occur in ferromagnetic cores, which increase with frequency. A side effect that can occur in air core coils in which the winding is not rigidly supported on a form is 'microphony': mechanical vibration of the windings can cause variations in the inductance.

The hydraulic analogy to an inductor is a paddle wheel in the flow of circulating water as shown in **Figure 49**. The mass of the wheel and the size of the blades restrict the water's ability to rapidly change its rate of flow (current) through the wheel due to the effects of inertia.

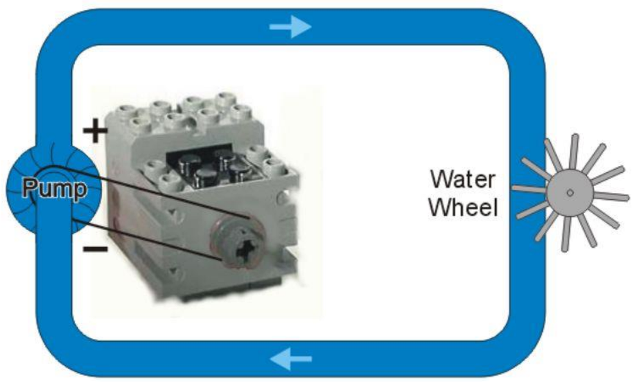
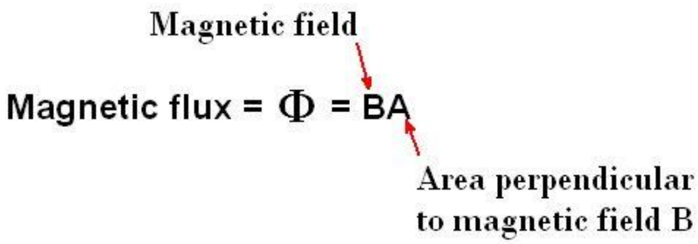


Figure 49: A paddle wheel in the flow of water current serves as a hydraulic analogy for an inductor. Credit: https://ece.uwaterloo.ca/~dwharder/Analogy/Inductors/

After some time, and because the pump (representing the battery) keeps water flowing constantly, the paddle wheel will rotate at the speed of the water and water will flow unimpeded through the pipe. The mass and surface area of the wheel and its blades are analogous to inductance, and friction between its axle and the axle bearings corresponds to the resistance that accompanies any non-superconducting inductor. When the current of water is increasing, the paddle wheel acts to slow down this increase and if the current of water is decreasing the inertia of the rotating paddle wheel will try to keep water flowing faster, in perfect analogy with what an inductor does in an electric circuit. Another hydraulic analogy for an inductor is a long pipe, perhaps coiled into a spiral for convenience. The inertia of the water flowing through the long pipe produces the inductance effects. The pressure difference (voltage) across the device must be present before current will start moving thus in inductors the voltage can be said to "lead" current.

A very important application of the inductor is the transformer. Now that we know a single coil can induce a voltage onto itself, let's look at what happens when two coils are near each other. But before we do that it is needed to define the notion of "magnetic flux" which plays a central part in the understanding of what happens when two coils are next to each other. Magnetic flux is the product of the magnetic field times the perpendicular area that it penetrates. In other words



The Greek letter Φ (phi) is customarily used to represents flux. Let's look at some examples to make clear the concept of flux. First the easy one: the magnetic field B has the same value anywhere on the surface and it goes through the surface at a 90^o angle (i.e. it is perpendicular). This is depicted in **Figure 50**. In this case Φ = BA.

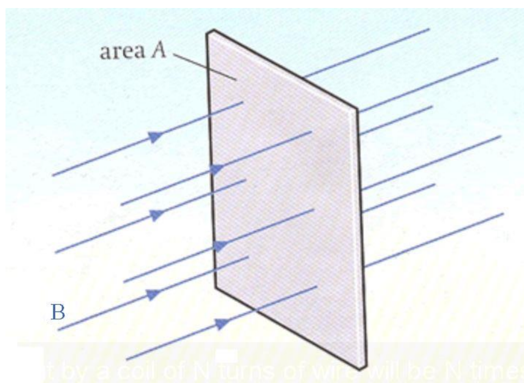


Figure 50: B is constant and perpendicular to the surface A

When there is an angle θ (the Greek letter theta is commonly used to represent an angle) between B and the surface it goes through, only the component of the magnetic field perpendicular to the surface contribute to the flux. This is represented in **Figure 51**.

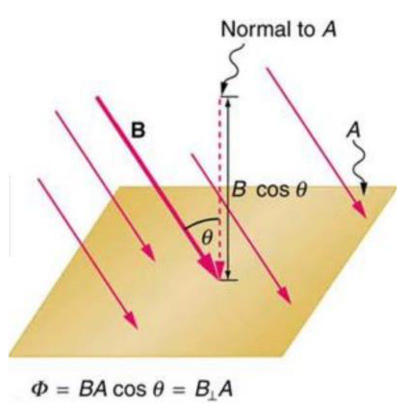


Figure 51: B is at an angle θ from the perpendicular direction (called "Normal to A" in the Figure). In that case only the component of B perpendicular to the surface contributes to the flux.

Why use only the perpendicular component of the magnetic field? Because the parallel component does not go through the surface and thus does not contribute to the flux going through the surface A. From a trigonometric standpoint, the projection of B in the direction perpendicular to the surface is $B_{\perp} = B\cos\theta$ and the flux is now $\Phi = B_{\perp}A$. If the direction and intensity of the flux varies all across the surface, it is still possible to compute the flux by dividing the surface in very small areas, so small that the magnitude and direction of B can be considered constant for that surface, and adding up the contribution of each small surface to the total flux. It is to be noted that the magnetic flux through a closed surface, such as a sphere or a cube, is always zero because all the magnetic field lines that came in through one side must come out on the other side of the closed surface.

With this knowledge of the magnetic flux we are now in a position to understand how one coil can influence another coil next to it to form a transformer. Consider the arrangement presented in **Figure 52**. A real transformer is hardly more complicated than the simple two-winding transformer shown in **Figure 52**. The "primary" winding (Coil #1) has power applied to it while the power coming out of the secondary winding (Coil #2) supplies some load (i.e. a lightbulb or another home appliance). The power can be applied to the secondary and power some appliance from the primary and this device will still work, in other word it is bidirectional. However, the final result will be different if your power source is coming in the secondary vs. if it is coming from the primary. We will see how this is so below.

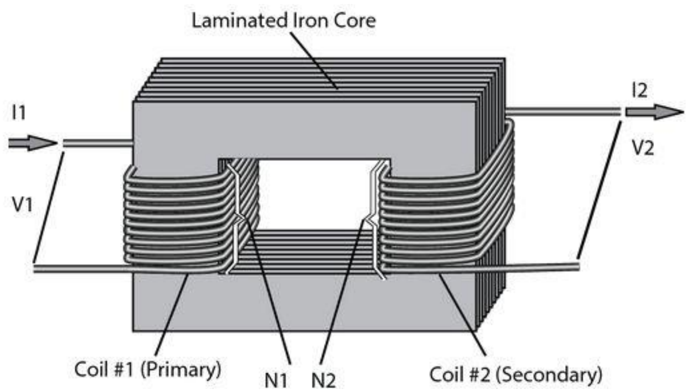


Figure 52: Basic features of a transformer. Credit: http://hydraulicspneumatics.com/other-components/hydraulic-electric-analogies-part-6-coils-cores-and-transformers-0

A transformer will only work when the flux is changing because there is no voltage induced when the flux is constant (Faraday's law). Applying AC voltage on the primary will ensure that the flux is constantly changing.

2- The Global Electric Circuit

Next, let's look at the source of the electrons that enter a grounded human body. **Figure 38** shows the "global electric circuit", a huge electric circuit that maintains the surface of the Earth negatively charged. As you lift off the surface of the planet and gain altitude, the electric potential increases by between 100 and 200 volts with every meter (3 feet and 3⅜ inches) gained in altitude, depending on the location your start from at the surface of the Earth. This is a well-established scientific fact. You might think, well why aren't we electrocuted from all that voltage in the air? You aren't because the air close to the surface of the ground doesn't have conductive qualities (it is in fact a good insulator) and that makes the electric current flowing through it very low, close to zero (but not exactly zero and that is important to understand otherwise there would be no global electric circuit).

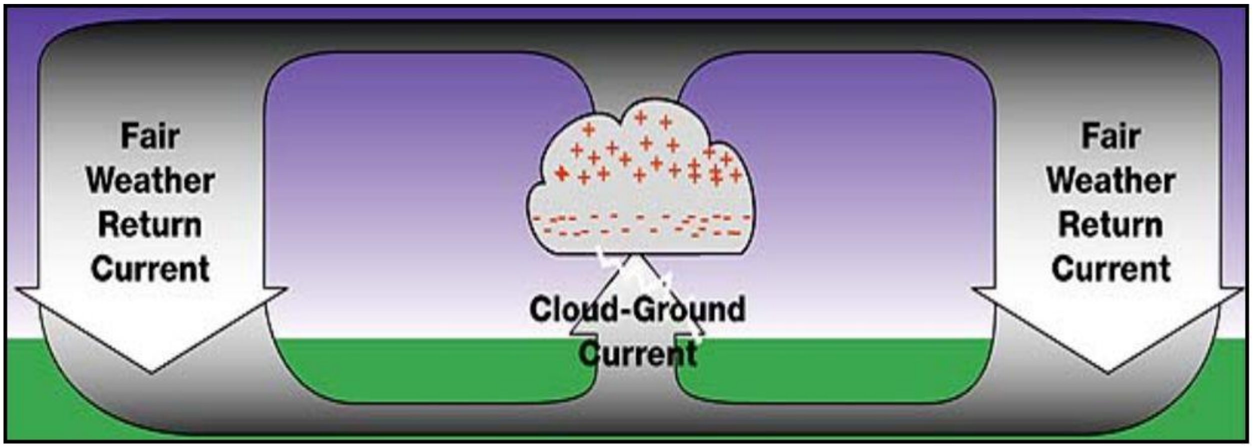


Figure 38. Global electric circuit. A current coming up from the ground at the location of lightning (which deposit electrons into the earth) returns to the ground elsewhere forming a close electric circuit. Source: NASA/MSFC (Dooling)

At several kilometers (miles) of altitude, the increase of the vertical atmospheric voltage begins to slow down. Then, at around 100 kilometers (62.5 miles), the increase stops. That's because the atmosphere has become a conductor. At this height, the sun rays are powerful enough to take electrons away from air molecules (even break up molecules) and in so doing, generate ions (charge particles). Thus scientists gave the name ionosphere to this region of the atmosphere.

In fair weather, when the sky is blue and there are little or no clouds, the electric potential difference between the ionosphere and the Earth's surface is 250,000 to 500,000 volts. Visualize this system as two conductors, one at zero volts (the ground) and the other at 250,000 to 500,000 volts at an altitude of about 100 kilometers (60 miles). Fair weather atmosphere below the ionosphere is not a good conductor (especially close to the ground) but it is not a perfect insulating medium either. There is a very small current of electrons escaping the ground at a rate of about 1 milliamperes per square kilometer (approximately equivalent to a power loss of 1 microwatt per square meter).

The global electric circuit is primarily maintained by the activities happening inside cumulonimbus clouds. These clouds have the property of separating the charged molecules of the ionosphere, pushing the negative charges (electrons) to the bottom of the cloud and the positive charges at the top of the cloud. The accumulation of electrons at the bottom of the cloud continues until the electric potential between the cloud and the ground reaches millions of volts, to the point that eventually the atmosphere breaks down and lightning strikes push a bunch of electrons into the ground. During an active thunderstorm, the collection of clouds in the storm generates an average current of about 1 amp down to the surface of the Earth. There are an estimated 1,000 to 2,000 thunderstorms happening globally at any one time and collectively these storms produce as many as 5,000 lightning strikes per minute. Thus, an electric current of 1,000 to 2,000 amps is continually transferring a negative charge to the surface of the Earth and an equal and opposite charge to the upper atmosphere. More recent research has shown that heavy rains also make a small contribution to the negative charges poured into the Earth's surface. If all thunderstorm activity and heavy rains would cease, it is estimated that it would take only about one hour for the difference in potential between the ground and the ionosphere to disappear, i.e. for the Earth to lose its electric charge completely.

In the ground, the negative charge takes the shape of a virtually limitless and continuously renewed reservoir of free electrons. These electrons vibrate according to stimuli from the sun, moon, and the processes going on in the atmosphere and inside the Earth itself. Their vibrations are quite low in frequency: from one vibration a year to about 30 vibrations per second. One of the most obvious cycles of electron vibration is the circadian rhythm. During the day, the sun gives much energy to the electrons at the surface of the Earth, making them vibrate faster. At night, this energy dissipates. The electrons vibrate slower. The solar effect on the Earth's electrons also creates currents into the Earth because the sun gives more energy to the electrons directly below, compared to distant electrons in other time zones, for example. These currents are referred to as "telluric currents." Together with local electron vibrations, they serve to synchronize the body's internal clocks and rhythms with the immediate environment and the Earth's cycles. For more information on the global electric circuit see our publication The Earth's Electrical Surface Potential A summary of present understanding.

3- Earthing and Health

Once those electrons enter the body what happens to the human body physiology and electrophysiology? Here is what was found in our and others research. Most of the information I will be quoting is from an article published in 2012 in the *Journal of Environmental and Public Health* (www.hindawi.com/journals/jeph/2012/291541/).

Some of the first benefits reported are *improved sleep* and *decrease in chronic pain*. In a blinded pilot study, Clint Ober recruited 60 subjects (22 males and 28 females) who suffered from self-described sleep disturbances and chronic muscle and joint pain for at least six months.[7] Subjects were randomly divided into two groups, one grounded and the other sham-grounded (the equipment is identical but does not ground these subjects) for the month-long study in which both groups slept on conductive carbon fiber mattress pads. Half the pads were grounded, while the other half were "sham" grounded—not connected to the Earth but looked connected. Most grounded subjects described symptomatic improvement while most in the control group did not. Some subjects reported significant relief from asthmatic and respiratory conditions, rheumatoid arthritis, PMS, sleep apnea, and hypertension while sleeping grounded. These results indicated that the effects of earthing go beyond reduction of pain and improvements in sleep.

Besides reduction in chronic pain and improved sleep, another study showed *reduction in stress* and *normalization of cortisol circadian rhythm*. A pilot study evaluated diurnal rhythms in cortisol (measured from subjects' saliva) and their correlation with sleep, pain, and stress (anxiety, depression, and irritability), as monitored by subjective reporting.[8] Twelve subjects with complaints of sleep dysfunction, pain, and stress were grounded to Earth during sleep in their own beds using a conductive mattress pad for 8 weeks. In order to obtain a baseline measurement of cortisol, subjects chewed Dacron salvettes for 2 minutes and then placed them in time-labeled sampling tubes that were stored in a refrigerator. Self-administered sample collections began at 8 AM and were repeated every 4 hours. After 6 weeks of being grounded, subjects repeated this 24-hour saliva test. The samples were processed using a standard radioimmunoassay. Subjective symptoms of sleep dysfunction, pain, and stress were reported daily throughout the 8-week test period. The majority of subjects with high- to out-of-range nighttime secretion levels experienced improvements by sleeping grounded. This is demonstrated by the restoration of normal day-night cortisol secretion profiles (**Figure 39**).

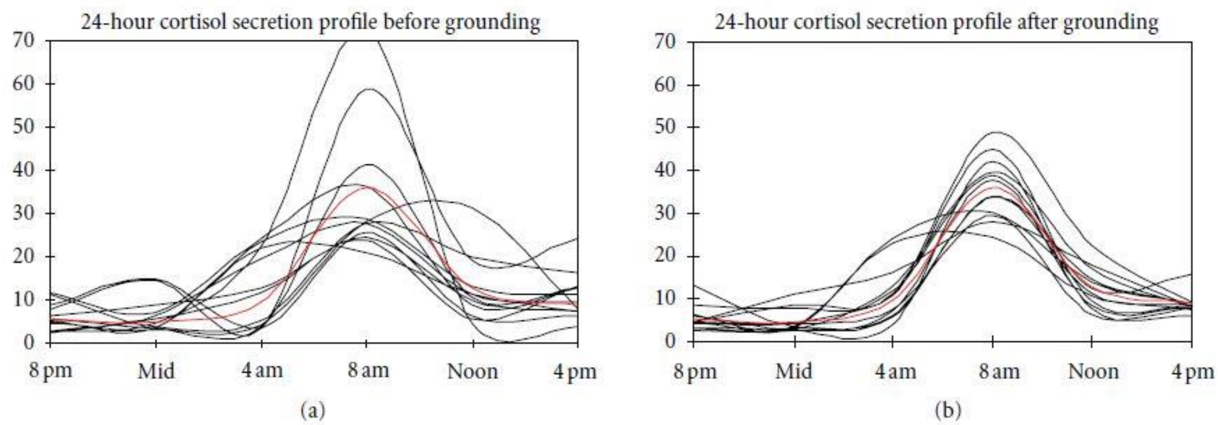


Figure 39. Cortisol levels before and after grounding. In unstressed individuals, the normal 24-hour cortisol secretion profile follows a predictable pattern: lowest around midnight and highest around 8 a.m. Graph (a) illustrates the wide variation of patterns among study participants prior to grounding. Graph (b) shows a realignment and normalization trend of the cortisol patterns after six weeks of sleeping grounded.

Eleven of the 12 participants reported falling asleep more quickly, and all 12 reported waking up fewer times at night. Grounding the body at night during sleep also appears to positively affect morning fatigue levels, daytime energy, and nighttime pain levels.

Two clinical trials used medical infrared imaging and clinical outcomes to assess changes taking place when the body was connected to the earth.[9] Inflammation is the earliest stage of almost all major chronic diseases. Because it measures heat naturally emitted from the human body, medical infrared imaging easily detects acute or chronic inflammatory conditions. The value of the technique has been documented in countless research studies. The method can measure changes as small as 1/100th of a degree C (^{o}C), providing “biomarkers”, “biofingerprints” or “risk indicators” that reveal the beginnings of tumors, toxic accumulations, and disease, months or even years earlier than other imaging methods. Medical thermal imaging experts are less interested in the absolute temperature of a part of the body than they are in locating “hot spots” and left–right imbalances that correspond to areas of discomfort indicative of inflammation. In some cases, the false temperature color scale (infrared radiations are not visible so a color scale had been devised to represent the intensity of the heat patterns) needs to be shifted to encompass the warmer thermal profiles after Earthing. As an example, **Figure 40** shows medical infrared images of a 65-year old woman with chronic thigh and knee pain on the right side, ankle and foot pain, and swelling of the left foot. The pain in her legs interfered with sleep; she woke stiff and sore and was tired all day. Prolonged medical treatment had not helped. After using the earthing sleep system for 4 nights, she reported 91% reduction in pain, 50% improvement in restful sleep, 50% reduction in insomnia, 50% reduction in sleepiness during the day, 81% reduction in pain interfering with sleep, 50% reduction in leg achiness during sleep, and 50% reduction in waking stiff and sore. The patient reported steady continued improvement at a 40-day follow-up.

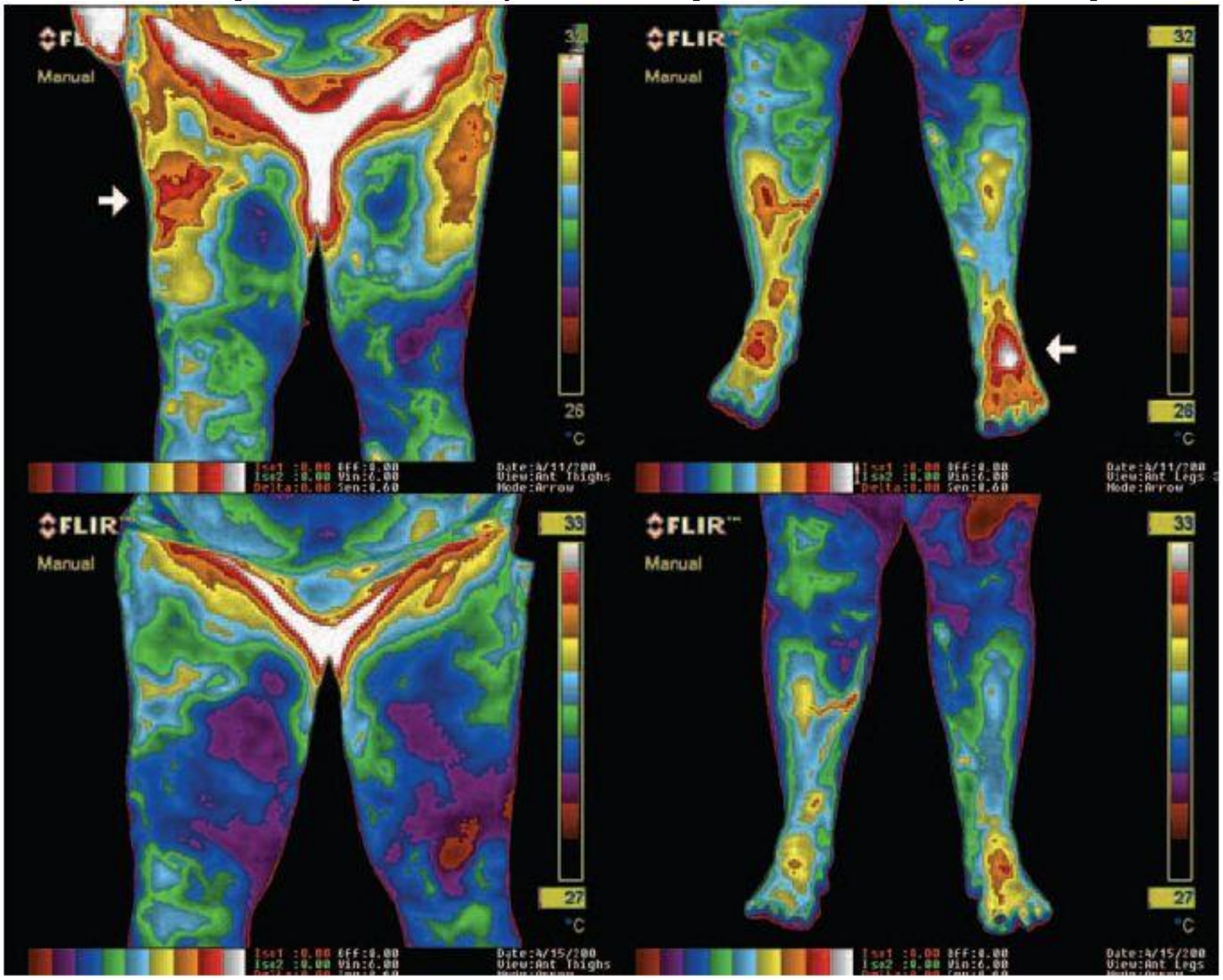


Figure 40. Medical infrared images of a 65-year-old woman with chronic thigh and knee pain on the right side, ankle and foot pain, and swelling of the left foot. Top row images show lower extremities taken before using the earthing sleep system. Arrows denote most significant areas of inflammation and correspond precisely with the subject areas of complaint. Bottom images were taken after 4 nights sleeping on earthing sleep system. Note considerable reduction in inflammation and return toward normal thermal symmetry. Patient reported steady continued improvement at a 40-day follow-up.

A study using biofeedback equipment found *reductions in overall stress levels and tension* and *shift in Autonomic Nervous System (ANS) balance toward a more relaxed state*. Fifty-eight (58) healthy adult subjects (including 30 controls) participated in a randomized double-blind pilot study investigating Earthing effects on human physiology.[10] Earthing was accomplished with a conductive adhesive patch placed on the sole of each foot connected to the outside ground using wires and a ground rod. A biofeedback system recorded electrophysiological and physiological parameters. Experimental subjects were relaxing for 28 minutes not grounded followed by 28 minutes with the earthing wires connected to the ground. Controls were unearthed for the entire 56 minutes session. Upon earthing, about half the subjects showed an abrupt, almost instantaneous change in root mean square (rms) values of electroencephalograms (EEGs) from the left hemisphere (but not the right hemisphere) at all frequencies analyzed by the biofeedback system (beta, alpha, theta, and delta). Such changes seen on two subjects are presented in **Figure 41**.

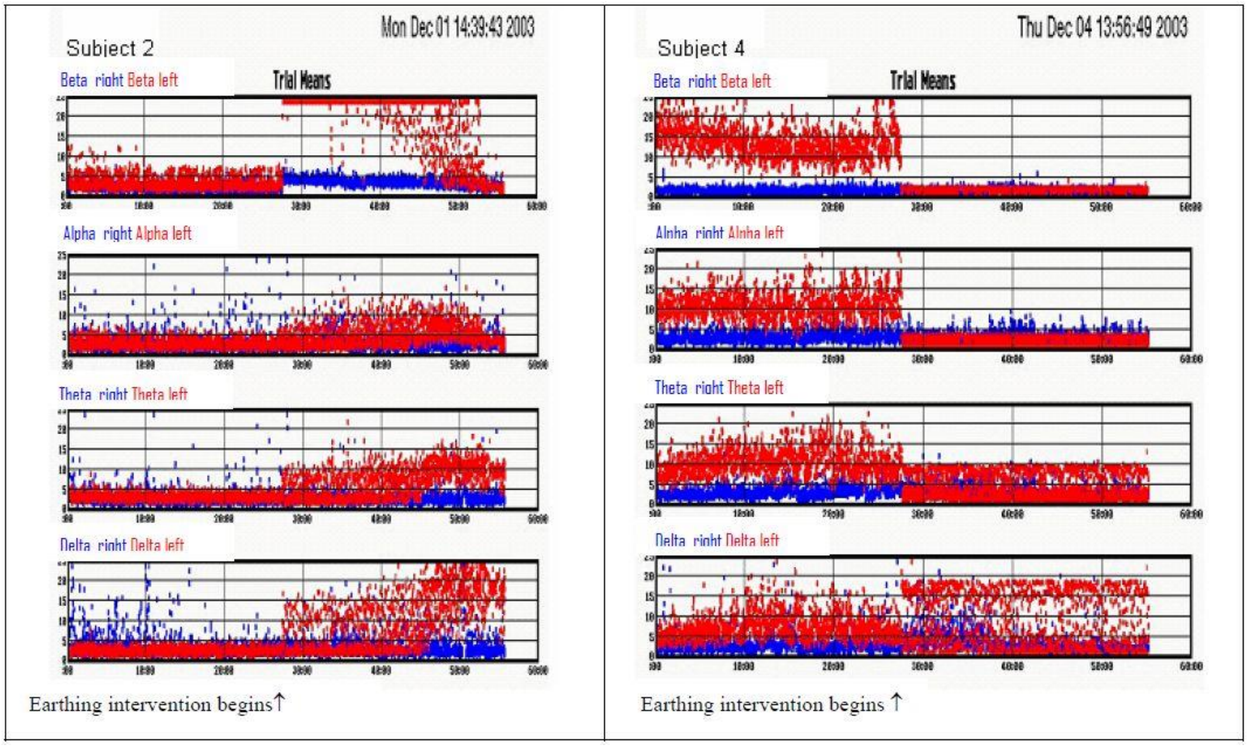


Figure 41. EEG changes in left hemisphere rms recordings. First 28 minutes pre-earthing; second 28-minute after earthing (arrow shows when earthing intervention begins). An immediate and abrupt shift occurs in the left hemisphere (red) in one or more of the EEG scales (Beta, Alpha, Theta, Delta) when subjects are earthed; changes are maintained throughout the earthing period. The right hemisphere (blue) did not change.

All grounded subjects presented an abrupt change in rms values of surface electromyograms (SEMGs) from right and left upper trapezius muscles. Earthing decreased blood volume pulse (BVP) in 19 of 22 experimental subjects (statistically significant) and in 8 of 30 controls (not significant). Earthing the human body showed significant effects on electrophysiological properties of the brain and musculature, on the BVP, and on the noise and stability of electrophysiological recordings. Taken together, the changes in EEG, EMG, and BVP suggest reductions in overall stress levels and tensions and a shift in ANS balance upon earthing. The results extend the conclusions of previously mentioned studies.

Some of these results were confirmed in another study. A multi-parameter double-blind study was designed to reproduce and expand on the previous electrophysiological and physiological parameters measured immediately after grounding with an improved methodology and state-of-the-art equipment.[11] Fourteen men and 14 women, in good health, ages 18–80, were tested while seated in a comfortable recliner during 2-hour grounding sessions, leaving time for signals to stabilize before, during, and after grounding (40 minutes for each period). Sham 2-hour grounding sessions were also recorded with the same subjects as controls. For each session, statistical analyses were performed on four 10-minute segments: before and after grounding (sham grounding for control sessions) and before and after ungrounding (sham ungrounding for control sessions). The following results were documented:

(i) an immediate decrease (within a few seconds) in *skin conductance (SC)* at grounding and an immediate increase at ungrounding. No change was seen for the control (sham grounding) sessions;

(ii) *respiratory rate (RR) increased* during grounding, an effect that lasted after ungrounding. RR variance increased immediately after grounding and then decreased;

(iii) *blood oxygenation (BO) variance decreased* during grounding, followed by a dramatic increase after ungrounding;

(iv) *pulse rate (PR) and perfusion index (PI) variances* increased toward the end of the grounding period, and this change persisted after ungrounding.

The immediate decrease in SC indicates a rapid activation of the parasympathetic nervous system and corresponding deactivation of the sympathetic nervous system. The immediate increase in SC at cessation of grounding indicates an opposite effect. Increased RR, stabilization of BO, and slight rise in heart rate suggest the start of a metabolic healing response necessitating an increase in oxygen consumption.

Another study looked at how grounded subjects respond to *pain* compared to non-grounded subjects. Pain reduction from sleeping grounded has been documented in previous studies. This pilot study looked for blood markers that might differentiate between grounded and ungrounded subjects who completed a single session of intense, eccentric exercise resulting in delayed-onset muscle soreness (DOMS) of the gastrocnemius.[11] If markers were able to differentiate these groups, future studies could be done in greater detail with a larger subject base. DOMS is a common complaint in the fitness and athletic world following excessive physical activity and involves acute inflammation in overtaxed muscles. It develops in 14 to 48 hours and persists for more than 96 hours. No known treatment reduces the recovery period, but apparently massage and hydrotherapy and acupuncture can reduce pain. Eight healthy men ages 20–23 were put through a similar routine of toe raises while carrying on their shoulders a barbell equal to one-third of their body weight. Each participant was exercised individually on a Monday morning and then monitored for the rest of the week while following a similar eating, sleeping, and living schedule in a hotel. The group was randomly divided in half and either grounded or sham grounded with the use of a conductive patch placed at the sole of each foot during active hours and a conductive sheet at night. Complete blood counts, blood chemistry, enzyme chemistry, serum and saliva cortisol, magnetic resonance imaging and spectroscopy, and pain levels (a total of 48 parameters) were taken at the same time of day before the eccentric exercise and at 24, 48, and 72 hours afterwards. Parameters consistently differing by 10 percent or more, normalized to baseline, were considered worthy of further study. Parameters that differed by these criteria included white blood cell counts, bilirubin, creatine kinase, phosphocreatine/inorganic phosphate ratios, glycerolphosphorylcholine, phosphorylcholine, the visual analogue pain scale, and pressure measurements on the right gastrocnemius.

The results showed that grounding the body to the Earth alters measures of immune system activity and pain. Among the ungrounded men, for instance, there was an expected, sharp increase in white blood cells at the stage when DOMS is known to reach its peak and greater perception of pain (see **Figure 42**). This effect demonstrates a typical inflammatory response. In comparison, the grounded men had only a slight decrease in white blood cells, indicating scant inflammation, and, for the first time ever observed, a shorter recovery time. Brown later commented that there were "significant differences" in the pain these men reported.

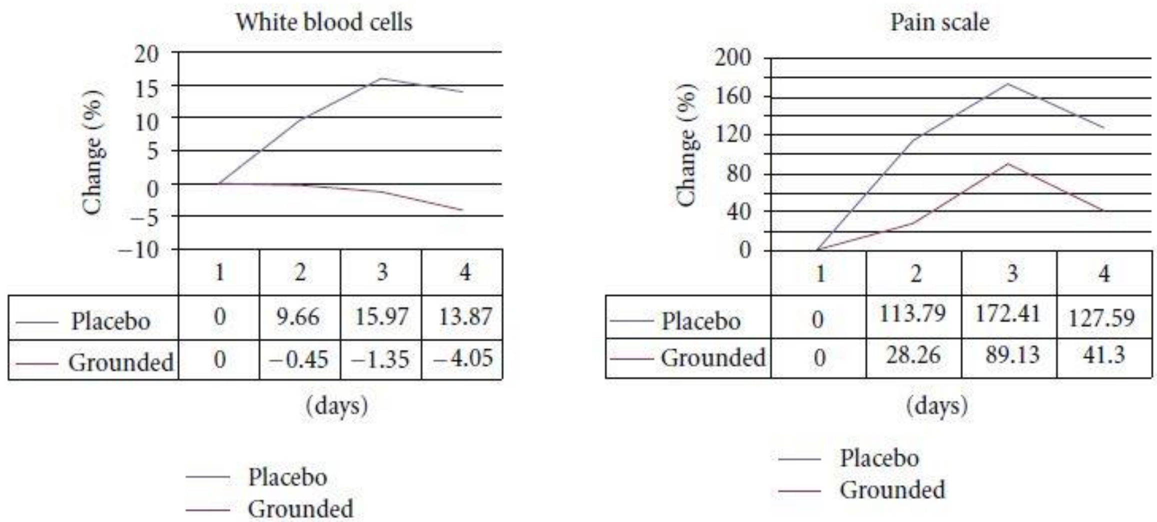


Figure 42. Delayed onset muscle soreness and grounding. Consistent with all measurements, ungrounded subjects expressed the perception of greater pain. Related to the pain finding was evidence of a muted white blood cell response indicating that a grounded body experiences less inflammation.

Since all these experiments gave interesting results on parameters measured from the outside of the body, it would be interesting to find if there are changes in the body too. The first study to show that was a study on the zeta potential of red blood cells (RBCs) and RBC aggregation. Zeta potential is a parameter closely related to the number of negative charges on the surface of an RBC. The higher the number, the greater the ability of the RBC to repel other RBCs. Thus, the greater the zeta potential the less coagulable is the blood. Ten relatively healthy subjects participated in the study.[12] They were seated comfortably in a reclining chair and were grounded for two hours with electrode patches placed on their feet and hands, as in previous studies. Blood samples were taken before and after.

Grounding the body to the earth substantially increases the zeta potential and decreases RBC aggregation, thereby reducing blood viscosity. Subjects in pain reported reduction to the point that it was almost unnoticeable. The results strongly suggest that earthing is a natural solution for patients with excessive blood viscosity, an option of great interest not just for cardiologists, but also for any physician concerned about the relationship of blood viscosity, clotting, and inflammation. In 2008, Adak and colleagues reported the presence of both hypercoagulable blood and poor RBC zeta potential among diabetics. Zeta potential was particularly poor among diabetics with cardiovascular disease.[13]

Another study that showed changes inside the body was published in 2012 by 2 doctors, K. Sokal and P. Sokal, cardiologist and neurosurgeon father and son on the medical staff of a military clinic in Poland. Several investigations were carried out on 4 people (2 women, 2 men) aged 20–52 years with an average weight of 68 kg (150 lbs; standard deviation = 10 kg or 22 lbs) in a room on the ground floor with an insulated floor, in a recumbent position.[14] The temperature of the room was 21ºC and the atmospheric pressure 101.2 kPa (75.906 centimeter of mercury or 0.998766 atmosphere [standard]). The temperature near of the surface of the Earth was 8ºC, and the measurements were taken during fine weather. Two (2) earthing connections were made: first for the examining electrode, second for the earthing of a person. The Earthing plates (6 cm×25-cm size of a foot) were placed on moistened earth. Both insulated conductors had diameters of 3 mm and length of 400 cm. An examining electrode (5mm×40mm) served for measurements on moistened skin, and a second examining electrode (4mm×30 mm) was used on mucous membranes, teeth, and nails. The earthing electrode was also a plate (30mm×80 mm). Plates and wire were made of copper. In determining the voltage in venous blood, an intravenous cannula with a sterile copper conductor (diameter of 0.2 mm) inside (to insulate it from the skin) was used. After subjects were in a recumbent position for 5 minutes, the values of the electrostatic potential were noted. Then, earthing was connected and the measurements were made after 5 minutes and again at 1 hour. Measurements were made again after 5 minutes the interruption of contact.

In the unearthed human organism in the lying position, the electric potential measured at the examined points is around 0 mV. Contact of the Earth using a copper conductor with a moistened surface of the human body evokes a rapid decrease of electrostatic potential on the body and in venous blood to the value of approximately - 200 mV. This effect is immediate and general. Interruption of contact with the Earth causes a rapid return of the potential to its initial values in the examined points. Changes in electric potential measured in venous blood and on the mucosal membrane of the tongue reflect alterations in electric potential of the aqueous, electrical environment. Up-and-down movement of the insulated human organism causes transient changes in potential in the human electrical environment. During the same movement, values of the potential inside the earthed human body remained constant. These results indicate that the elimination of electrical potentials inside the human organism by the Earth's mass during up-and-down movements may play a fundamental role in the regulation of bioelectrical and bioenergetical processes by *maintaining a stable electric environment inside the body*.

The Sokals published another very interesting study in 2011. They conducted a series of experiments to determine whether contact with the Earth via a copper conductor can affect physiological processes.[15] Their investigations were prompted by the question as to whether the natural electric charge on the surface of the Earth influences the regulation of human physiological processes. They found a reduction of *primary indicators of osteoporosis*, *improvement of glucose regulation*, and *immune response*. Double-blind experiments were conducted on groups ranging from 12 to 84 subjects who followed similar physical activity, diet, and fluid intake during the trial periods. Grounding was achieved with a copper plate (30mm×80mm) placed on the lower part of the leg, attached with a strip so that it would not come off during the night. The plate was connected by a conductive wire to a larger plate (60mm×250mm) placed in contact with the Earth outside.

In the first experiment with non-medicated subjects, grounding during a single night of sleep resulted in statistically significant changes in concentrations of minerals and electrolytes in the blood serum: *iron, ionized calcium, inorganic phosphorus, sodium, potassium*, and *magnesium*. Renal excretion of both calcium and phosphorus was reduced significantly. The observed reductions in blood and urinary calcium and phosphorus directly relate to *osteoporosis*. The results suggest that Earthing for a single night reduces primary indicators of osteoporosis. Earthing continually during rest and physical activity over a 72-hour period *decreased fasting glucose* among patients with non-insulin-dependent diabetes mellitus. Patients had been well controlled with glibenclamide, an anti-diabetic drug, for about 6 months, but at the time of study had unsatisfactory glycemic control despite dietary and exercise advice and glibenclamide doses of 10mg/day.

In a second experiment, K. Sokal and P. Sokal drew blood samples from 6 male and 6 female adults with no history of thyroid disease. A single night of grounding produced a significant decrease of free tri-iodothyronine and an increase of free thyroxin and thyroid-stimulating hormone. The meaning of these results is unclear but suggests an earthing influence on hepatic, hypothalamus, and pituitary relationships with *thyroid function*. Ober et al.[2] have observed that many individuals on thyroid medication reported symptoms of hyperthyroid, such as heart palpitations, after starting grounding. Such symptoms typically vanish after medication is adjusted downward under medical supervision. Through a series of feedback regulations, thyroid hormones affect almost every physiological process in the body, including growth and development, metabolism, body temperature, and heart rate. Clearly, further study of earthing effects on thyroid function is needed.

In a third experiment, the effect of grounding on the classic immune response following vaccination was examined. Earthing *accelerated the immune response*, as demonstrated by *increases in gamma globulin concentration*. This result confirms an *association between earthing and the immune response*, as was suggested in the DOMS study.[11]

From these experiments, K. Sokal and P. Sokal concluded that earthing the human body influences human physiological processes, including increasing the activity of catabolic processes and may be "*the primary factor regulating endocrine and nervous systems*."

In summary of this section, emerging evidence shows that contact with the Earth—whether being outside barefoot or indoors connected to grounded conductive systems— may be a simple, natural, and yet profoundly effective environmental strategy against chronic stress, ANS dysfunction, inflammation, pain, poor sleep, disturbed HRV, blood viscosity, hypercoagulable blood, and many common health disorders, including cardiovascular disease. The research done to date supports the concept that grounding or earthing the human body may be an essential element in the health equation along with sunshine, clean air and water, nutritious food, and physical activity.

4- How to Measure Body Voltage

For details on how to measure body voltage click here: How to Measure the Effects of Earthing on body voltage.

4.1- Consequences of body voltage

Research has shown that the sleeping area in many homes has the highest electric field, from wiring in the walls, floors, and ceilings, and from cords to appliances. Cells and tissues are generally transparent to magnetic fields. The main influence of magnetic fields is on tissues such as blood and some glands that have iron-containing molecules. The magnetic fields are therefore probably less important than the electric fields in terms of health effects. However, this whole area is very controversial, with some scientists firmly convinced that both the magnetic and the electric fields found in home wiring can have health effects and others just as firmly convinced that the evidence is not adequate to make such a statement. Until large-scale studies and mechanistic investigations are completed, many scientists and many electric utilities have suggested that those who use electrical appliances utilize "prudent avoidance" meaning that they should minimize their exposure to sources of electric power until the scientific evidence is more definitive.

In the context of "prudent avoidance" some promoters of grounding systems have suggested that grounding greatly reduces one's exposure to power frequency fields, using evidence provided by the body voltage meter as shown above. Recent research has shown that being grounded prevented induction of voltages and currents in the body, helping to maintain the inside of the body in a stable condition. However, the more significant benefit of Earthing for health is the ability of grounding systems to deliver antioxidant electrons that stabilize the operation of the immune system and other physiological processes in the body.

A concern was a safety issue related to a grounded person touching a metal fixture that is electrically "hot" because of a broken protective system (PEN) in the wiring. The possibility of an electrical shock from such a situation is actually impossible due to the inclusion of a 100,000 ohm resistor in the cords of all grounding systems. This resistance does not allow an unsafe level of current to flow through a grounding system to the earth.[4]

5- How to Measure the Sources of the EMFs that Produce Body Voltage

For details on how to measure EMFs that produce body voltage in your environment click here: How to Measure the Effects of Earthing on body voltage.

6- What happens when the body is not grounded

This section describes what happens electrically to the body upon grounding. When the body is not grounded, the body potential start to rise slowly (becoming more positive with time). This is due to a number of factors:

1) The air around us is at a higher electric potential than the surface of the Earth. For a person 6 feet tall, this means the electric potential of the air molecule that person breathe is at about 250 volts. So by breathing in air molecules, negative charges inside the body are neutralized, slowly increasing the number of positive charges inside it.

2) If the food we heat is acidic, this means the food lack electrons. This is usually the case as most food test for an oxidation/reduction potential that is positive.

The book by Ober, Sinatra and Zucker (2010) described people who are hypersensitive to power frequency energy fields and who have benefited from grounding their bodies.[5] But the most important reason the incidence of degenerative diseases soared since the 1960s is lack of proper grounding. Over the years it has been observed that many people who were exposed to very low levels of environmental fields still developed crippling diseases such as arthritis that were relieved by grounding. The main factor that compromises health seems to be a lack of grounding. When grounding is restored, people recognize an improvement in their condition, usually within 30 minutes, even in the presence of EMFs. There are no inflammatory problems that are not improved by earthing. Even severe autoimmune diseases are improved.

No one can claim that earthing is a "treatment" or a "cure" for anything. Because the body evolved in contact with the earth, it is an essential condition or "nutrient: the body needs to function normally. An important example of what happens when a person is not grounded for long periods of time is the inflammatory process. Over ages, the body developed a means to kill bacteria using reactive oxygen species (ROS) which are very effective at their task but are also very reactive biochemically. ROS are electron-hungry molecules that need to be neutralized after their job is done and before they begin to damage healthy tissues. For that purpose negative charges are needed. Since the body was always in contact with the earth during millions of years of evolution, it developed a mechanism using molecules with very high electron affinity to kill bacteria and viruses. That seemed a good strategy. The reason for the body not developing its own system to neutralize ROS is that negative charges were always present to prevent the process from going beyond what was needed in any particular situation. All of this changed when we began to wear shoes with rubber and plastic soles.

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[2] Ober, A.C., Sinatra, S.T., and Zuker, Martin. 2014. Earthing: The most important health discovery ever? Second Edition. Basic Health Publications, Laguna Beach, California.

[3] The unit of electric charge is the *coulomb* (C). It is named after the French physicist Charles-Augustin de Coulomb (1736 – 1806). The electric charge of a proton is equal to 1.602×10^{-19} C and the electric charge of an electron is -1.602×10^{-19} C. By definition, one *coulomb* is the amount of electric charges transported in one second by a steady current of one *ampere*. It is a huge number: 6.24×10^{18} charges or 6.24 billions billions charges (except in liquids and gases, the electric charges forming an electric current are electrons). The unit of current, the *ampere*, is named after the French physicist and mathematician André-Marie Ampère (1775 – 1836) who was one of the founders of the science of classical electromagnetism.

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