Electromagnetic Fields

Electromagnetic fields are composite fields made up of electric fields and magnetic fields. Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field. An electric field will exist even when there is no current flowing. If current does flow, the strength of the magnetic field will vary with power consumption but the electric field strength will be constant. The electromagnetic field is a physical field produced by electrically charged objects. It affects the behavior of charged objects in the vicinity of the field. So, simply stated, electric fields result from the strength of the charge while magnetic fields result from the *motion* of the charge, or the current. Electric fields are easily shielded: they may be weakened, distorted or blocked by conducting objects such as earth, trees, and buildings, but magnetic fields are not as readily blocked. Electric charges with opposite signs (positive and negative) attract each other, while charges with the same sign repel each other. The forces of attraction and repulsion create electric fields whose strength is related to “voltage” (electrical pressure). These forces of attraction or repulsion are carried through space from charge to charge by the electric field. The electric field is measured in volts per meter (V/m) or in kilovolts per meter (kV/m). A group of charges moving in the same direction is called an “electric current.” When charges move they create additional forces known as a “magnetic field.” The strength of a magnetic field is measured in “gauss” (G) or “tesla” (T), while the electric current is measured in “amperes” (amps). The strength of both electric and magnetic fields decrease as one moves away from the source of these fields.

The electromagnetic field extends indefinitely throughout space and describes the electromagnetic interaction. It is one of the four fundamental forces of nature (the others are gravitation, the weak interaction, and the strong interaction).

The field can be viewed as the combination of an electric field and a magnetic field. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents); these two are often described as the sources of the field. The way in which charges and currents interact with the electromagnetic field is described by Maxwell's equations and the Lorentz Force Law.

From a classical point of view, the electromagnetic field can be regarded as a smooth, continuous field, propagated in a wavelike manner, whereas from a quantum mechanical point of view, the field can be viewed as being composed of photons.

Continuous structure

Classically, electric and magnetic fields are thought of as being produced by smooth motions of charged objects. For example, oscillating charges produce electric and magnetic fields that may be viewed in a 'smooth', continuous, wavelike manner. In this case, energy is viewed as being transferred continuously through the electromagnetic field between any two locations. For instance, the metal atoms in a radio transmitter appear to transfer energy continuously. This view is useful to a certain extent (radiation of low frequency), but problems are found at high frequencies (see ultraviolet catastrophe). This problem leads to another view.

Discrete structure

The electromagnetic field may be thought of in a more 'coarse' way. Experiments reveal that electromagnetic energy transfer is better described as being carried away in 'packets' or 'chunks' called photons with a fixed frequency. Planck's relation links the energy E of a photon to its frequency v through the equation:

$$E=hv$$

Where h is Planck's constant, named in honor of Max Planck, and v is the frequency of the photon. For example, in the photoelectric effect —the emission of electrons from metallic surfaces by electromagnetic radiation— it is found that increasing the intensity of the incident radiation has no effect, and that only the frequency of the radiation is relevant in ejecting electrons.

This quantum picture of the electromagnetic field has proved very successful, giving rise to quantum electrodynamics, a quantum field theory describing the interaction of electromagnetic radiation with charged matter.

Describing magnetic fields

The concentration of a chemical in water can be described by citing a single number. Unlike chemicals, alternating electric and magnetic fields have wave-like properties and can be described in several different ways, like sound. A sound can be loud or soft (strength), high or low-pitched (frequency), have periods of sudden loudness or a constant tone, and can be pure or jarring. Similarly, magnetic fields can be strong or weak, be of high frequency (radio waves) or low frequency (power line waves), have sudden increases (“transients”) or a constant strength, consist of one pure frequency or a single dominant frequency with some distortion of other higher frequencies (“harmonics”). It is also important to describe the direction of magnetic fields in relation to the flow of current. For instance, if a magnetic field oscillates back and forth in a line it is “linearly polarized.” It may also be important to describe how a field’s direction relates to other physical conditions such as the earth’s static magnetic fields.

The dynamics of the electromagnetic field

In the past, electrically charged objects were thought to produce two types of field associated with their charge property. An electric field is produced when the charge is stationary with respect to an observer measuring the properties of the charge and a magnetic field (as well as an electric field) is produced when the charge moves (creating an electric current) with respect to this observer. Over time, it was realized that the electric and magnetic fields are better thought of as two parts of a greater whole —the electromagnetic field.

Once this electromagnetic field has been produced from a given charge distribution, other charged objects in this field will experience a force (in a similar way that planets experience a force in the gravitational field of the Sun). If these other charges and currents are comparable in size to the sources producing the above electromagnetic field, then a new net electromagnetic field will be produced. Thus, the electromagnetic field may be viewed as a dynamic entity that causes other charges and currents to move, and which is also affected by them. These interactions are described by Maxwell's equations and the Lorentz force law.

The electromagnetic field as a feedback loop

The behavior of the electromagnetic field can be resolved into four different parts of a loop:

1. The electric and magnetic fields are generated by electric charges.
2. The electric and magnetic fields interact only with each other.
3. The electric and magnetic fields produce forces on electric charges.
4. The electric charges move in space.

The feedback loop can be summarized in a list, including phenomena belonging to each part of the loop:

1. Charges generate fields
2. Gauss's law and Coulomb's law: charges generate electric fields
3. Ampère's law: currents generate magnetic fields
4. The fields interact with each other
5. Displacement current: changing electric field acts like a current, generating 'vortex' (curl) of magnetic field
6. Faraday induction: changing magnetic field induces (negative) vortex of electric field
7. Lenz's law: negative feedback loop between electric and magnetic fields
8. Maxwell-Hertz equations: simplified version of Maxwell's equations

9. Electromagnetic wave equation
10. Fields act upon charges
11. Lorentz force: force due to electromagnetic field
12. Electric force: same direction as electric field
13. Magnetic force: perpendicular both to magnetic field and to velocity of charge
14. Charges move
15. Continuity equation: current is movement of charges

The basics of wavelength and frequency

One of the main characteristics which define an electromagnetic field (EMF) is its frequency or its corresponding wavelength. Fields of different frequencies interact with the body in different ways. One can imagine electromagnetic waves as series of very regular waves that travel at an enormous speed, the speed of light. The frequency simply describes the number of oscillations or cycles per second, while the term wavelength describes the distance between one wave and the next. Hence wavelength and frequency are inseparably intertwined: the higher the frequency the shorter the wavelength.

Wavelength and frequency determine another important characteristic of electromagnetic fields: Electromagnetic waves are carried by particles called quanta. Quanta of higher frequency (shorter wavelength) waves carry more energy than lower frequency (longer wavelength) fields. Some electromagnetic waves carry so much energy per quantum that they have the ability to break bonds between molecules. In the electromagnetic spectrum, gamma rays given off by radioactive materials, cosmic rays and X-rays carry this property and are called 'ionizing radiation'. Fields whose quanta are insufficient to break molecular bonds are called 'non-ionizing radiation'. Man-made sources of electromagnetic fields that form a major part of industrialized life - electricity, microwaves and radiofrequency fields – are found at the relatively long wavelength and low frequency end of the electromagnetic spectrum and their quanta are unable to break chemical bonds.

Electromagnetic fields at low frequencies

Electric fields exist whenever a positive or negative electrical charge is present. They exert forces on other charges within the field. The strength of the electric field is measured in volts per meter (V/m). Any electrical wire that is charged will produce an associated electric field. This field exists even when there is no current flowing. The higher the voltage, the stronger the electric field at a given distance from the wire.

As previously noted, electric fields are strongest close to a charge or charged conductor, and their strength rapidly diminishes with distance from it. Conductors such as metal shield them very effectively. Other materials, such as building materials and trees, provide some shielding capability. Therefore, the electric fields from power lines outside the house are reduced by walls, buildings, and trees. When power lines are buried in the ground, the electric fields at the surface are hardly detectable.

Magnetic fields arise from the motion of electric charges. The strength of the magnetic field is measured in amperes per meter (A/m); more commonly in electromagnetic field research, scientists specify a related quantity, the flux density (in microtesla, µT) instead. In contrast to electric fields, a magnetic field is only produced once a device is switched on and current flows. Remember, the higher the current, the greater the strength of the magnetic field.

Like electric fields, magnetic fields are strongest close to their origin and rapidly decrease at greater distances from the source. Magnetic fields are not blocked by common materials such as the walls of buildings.

Let’s recap in layman’s terms:

Electric fields

1. Electric fields arise from voltage.
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.
4. Field strength decreases with distance from the source.
5. Most building materials shield electric fields to some extent.

Magnetic fields

1. Magnetic fields arise from current flows.
2. Their strength is measured in amperes per meter (A/m). Commonly, EMF investigators use a related measure, flux density (in microtesla (µT) or millitesla (mT) instead.
3. Magnetic fields exist as soon as a device is switched on and current flows.
4. Field strength decreases with distance from the source.
5. Magnetic fields are not attenuated by most materials.

Electric fields

Plugging a wire into an outlet creates electric fields in the air surrounding the appliance. The higher the voltage the stronger the field produced. Since the voltage can exist even when no current is flowing, the appliance does not have to be turned on for an electric field to exist in the room surrounding it.

Magnetic fields

Magnetic fields are created only when the electric current flows. Magnetic fields and electric fields then exist together in the room environment. The greater the current the stronger the magnetic field. High voltages are used for the transmission and distribution of electricity whereas relatively low voltages are used in the home. The voltages used by power transmission equipment vary little from day to day, currents through a transmission line vary with power consumption.

Electric fields around the wire to an appliance only cease to exist when the appliance is unplugged or switched off at the wall. They will still exist around the cable behind the wall.

Static fields verses time-varying fields

A static field does not vary over time. A direct current (DC) is an electric current flowing in one direction only. In any battery-powered appliance the current flows from the battery to the appliance and then back to the battery. It will create a static magnetic field. The earth's magnetic field is also a static field. So is the magnetic field around a bar magnet which can be visualized by observing the pattern that is formed when iron filings are sprinkled around it.

In contrast, time-varying electromagnetic fields are produced by alternating currents (AC). Alternating currents reverse their direction at regular intervals. In most European countries electricity changes direction with a frequency of 50 cycles per second or 50 Hertz. Equally, the associated electromagnetic field changes its orientation 50 times every second. North American electricity has a frequency of 60 Hertz.

What are the main sources of low, intermediate and high frequency fields?
The time-varying electromagnetic fields produced by electrical appliances are an example of extremely low frequency (ELF) fields**.** ELF fields generally have frequencies up to 300 Hz. Other technologies produce intermediate frequency (IF) fields with frequencies from 300 Hz to 10 MHz and radiofrequency (RF) fields with frequencies of 10 MHz to 300 GHz. The effects of electromagnetic fields on the human body depend not only on their field level but on their frequency and energy. Our electricity power supply and all appliances using electricity are the main sources of ELF fields; computer screens, anti-theft devices and security systems are the main sources of IF fields; and radio, television, radar and cellular telephone antennas, and microwave ovens are the main sources of RF fields. These fields induce currents within the human body, which if sufficient can produce a range of effects such as heating and electrical shock, depending on their amplitude and frequency range. (However, to produce such effects, the fields outside the body would have to be very strong, far stronger than present in normal environments.)

Electromagnetic fields at high frequencies

Mobile telephones, television and radio transmitters and radar produce RF fields. These fields are used to transmit information over long distances and form the basis of telecommunications as well as radio and television broadcasting all over the world. Microwaves are RF fields at high frequencies in the GHz range. In microwaves ovens, we use them to quickly heat food.

At radio frequencies, electric and magnetic fields are closely interrelated and we typically measure their levels as power densities in watts per square metre (W/m^2).

Electric and magnetic fields are invisible fields of force created by electric voltage (electric fields) and by electric current (magnetic fields). Wherever there is a flow of electricity, both electric and magnetic fields are present. Electric fields exist when appliances are plugged in. Magnetic fields exist when appliances are turned on

EMFs are higher the closer they are measured to their source. In fact, EMF levels are greater next to an appliance and almost disappear at distances of 3-5 feet. This is one reason why home appliances may produce higher levels of EMFs in a house as opposed to a power line that may be nearby.

Measuring magnetic field strength

The strength or intensity of magnetic fields is commonly measured in a unit called a Gauss or Tesla by magnetic field meters called “gauss meters.” A milligauss (mG) is a thousandth of a gauss, and a microtesla (uT) is a millionth of a tesla (one milligauss is the same as 0.1 microtesla).

The magnetic field strength in the middle of a typical living room measures about 0.7 milligauss or 0.07 microtesla. As noted above, the strength of the magnetic field is only one component of the mixture that characterizes the field in a particular area. Measuring only magnetic field strength may not capture all the relevant information any more than the decibel volume of the music you are playing captures the music’s full impact. The main health studies to date have only measured magnetic field strength directly or indirectly and assessed its association with disease.

Some scientists wonder if the weak association between measured magnetic fields and cancer in these studies might appear stronger if we knew which aspect of the EMF mixture to measure. Other scientists wonder if any such aspect exists.

Common as dirt - 60 Hz EMF

There are “power frequency” electric and magnetic fields almost everywhere we go because 60 Hz electric power is so widely used. Exposure to magnetic fields

comes from many sources, like high voltage “transmission” lines (usually on metal towers) carrying electricity from generating plants to communities and “distribution” lines (usually on wooden poles) bringing electricity to our homes, schools, and work places. Other sources of exposure are internal wiring in buildings, currents in grounding paths (where low voltage electricity returns to the system in plumbing pipes), and electric appliances such as TV monitors, radios, hair dryers and electric blankets. Sources with *high voltage* produce strong electric fields, while sources with *strong currents* produce strong magnetic fields. The strength of both electric and magnetic fields weakens with increasing distance from the source (table 1). Magnetic field strength falls off more rapidly with distance from “point” sources such as appliances than from “line” sources (power lines). The magnetic field is down to “background” level (supposed to be no greater than that found in nature)
3-4 feet from an appliance, while it reaches background level around 60-200 feet from a distribution line and 300-1000 feet from a transmission line. Fields and currents that occur at the same place can interact to strengthen or weaken the total effect. Hence, the strength of the fields depends not only on the distance of the source but also the distance and location of other nearby sources.

Examples of magnetic field strengths
Source: L. Zaffanella, School Exposure Assessment Survey,
California EMF Program, interim results, November, 1997.

MILLIGAUSS (mG)	**at 1 foot**	**at 3 feet**
Aquarium pump	0.35-18.21	0.01-1.17
Band saw	0.51-14.24	0.05-0.75
Can opener	7.19-163.02	1.30-6.44
Clock	0.34-13.18	0.03-0.68
Clothes iron	1.66-2.93	0.25-0.37
Coffee machine	0.09-7.30	0-0.61
Computer monitor	0.20-134.7	0.01-9.37
Copier	0.05-18.38	0-2.39
Desktop light	32.81	1.21
Dishwasher	4.98-8.91	0.84-1.63
Drill press	0.21-33.33	0.03-8.35
Fax machine	0.16	0.03
Food processor	6.19	0.35
Garbage disposal	2.72-7.79	0.19-1.51
Microwave oven	0.59-54.33	0.11-4.66
Mixer	0.49-41.21	0.09-3.93
Portable heater	0.11-19.60	0-1.38
Printer	0.74-43.11	0.18-2.45
Portable fan	0.04-85.64	0.03-3.12
Radio	0.43-4.07	0.03-0.98
range	0.60-35.93	0.05-2.83
Refrigerator	0.12-2.99	0.01-0.60

Scanner	2.18-26.91	0.09-3.48
Sewing machine	3.79-7.70	0.35-0.45
Tape player	0.13-6.01	0.01-1.66
Television	1.80-12.99	0.07-1.11
Toaster	0.29-4.63	0.01-0.47
Vacuum cleaner	7.06-22.62	0.51-1.28
VCR	0.19-4.63	0.01-0.41
Vending machine	0.46-5.05	0.02-0.59

Identifying sources of elevated magnetic fields

Sometimes fairly simple measurements can identify the external or internal sources creating elevated magnetic fields. For example, turning off the main power switch of the house can rule out sources from use of power indoors. Magnetic field measurements made at different distances from power lines can help pinpoint them as sources of elevated residential magnetic fields. Often, however, it takes some detective work to find the major sources of elevated magnetic fields in or near a home. Currents in grounding paths (where low voltage electricity returns to the system in plumbing pipes) and some common wiring errors can lead to situations in which source identification is difficult and requires a trained technician. It is almost always possible to find and correct the sources of elevated magnetic fields when they are due to faulty electrical wiring, grounding problems, or appliances such as lighting fixtures.