The Basics of Electromagnetic Fields

Definitions and sources

An electromagnetic field is both a physical field produced by electrically charged objects, and a term used to describe a field of force having both electric and magnetic components and containing a definite amount of electromagnetic energy.

The electromagnetic field, referred to simply as EMF, is 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 the sources of the field.

Electric fields are created by differences in voltage, which is the measure of the charge difference between any two points in space: 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 nearly constant.

Natural sources of electromagnetic fields

Electromagnetic fields (EMF) are present everywhere in our environment but are imperceptible to humans, all EMF except for visible light. Electric fields are produced by the local build-up of electric charges in the atmosphere associated with thunderstorms. The earth's magnetic field causes a compass needle to orient in a North-South direction and is used by birds and fish for navigation.

Human-made sources of electromagnetic fields

Besides natural sources the electromagnetic spectrum also includes fields generated by human-made sources: X-rays are employed to diagnose a broken limb after a sport accident. The electricity that comes out of every power socket has associated low frequency electromagnetic fields. And various kinds of higher frequency radio waves are used to transmit information – whether via TV antennas, radio stations or mobile phone base stations.

The basics of wavelength and frequency

What makes the various forms of electromagnetic fields so different?
One of the main characteristics which defines 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.

A simple analogy should help to illustrate the concept: Tie a long rope to a door handle and keep hold of the free end. Moving it up and then down slowly will generate a single big wave; more rapid motion will generate a whole series of small waves. The length of the rope remains constant, therefore, the more waves you generate (higher frequency) the smaller will be the distance between them (shorter wavelength).

What is the difference between non-ionizing electromagnetic fields and ionizing radiation?
Wavelength and frequency determine another important characteristic of electromagnetic fields: Electromagnetic waves can be described as 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 metre (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.

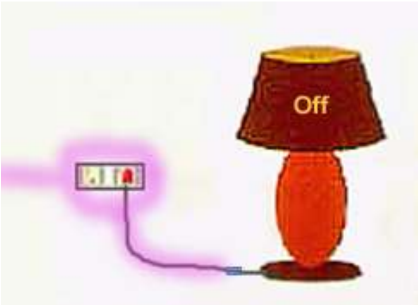
Electric fields (EF) are strongest close to a charge or charged conductor, and their strength rapidly diminishes with distance from it. Conductors such as metal shield them very effectively. Other materials, such as building materials and trees, provide some shielding capability. Therefore, the electric 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 (MF) 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 instead (in microtesla, µT, or gauss, G, which is the older term for MF measurement). In contrast to electric fields, a magnetic field is only produced once a device is switched on and current flows. 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.

Comparison of EF and MF

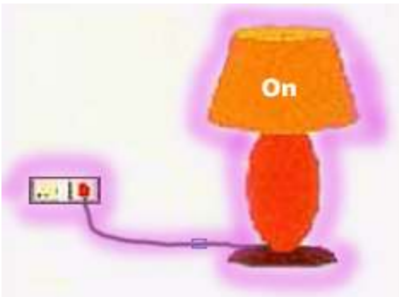
Electric Fields (EF)	**Magnetic Fields (MF)**
1. Electric fields arise from charge accumulation (voltage). 2. Their strength is measured in Volts per metre (V/m). 3. An electric field can be present even when a device is switched off. 4. Field strength decreases with distance from the source. 5. Most building materials shield (i.e. attenuate) electric fields to some extent.	1. Magnetic fields arise from current (charge) flows. 2. Their strength is measured in amperes per meter (A/m). Commonly, EMF investigators use a related measure, flux density instead (in microtesla (µT) or millitesla (mT), and as an alternative unit of measurement, Gauss (G) or milligauss (mG). 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

Electric fields

Plugging a wire into an outlet creates electric fields around the appliance that are generated by voltage in the electrical wire in the wall, and in the appliance wire. Fields (depicted here in pink) are created up to the on/off switch, which is here in the 'off' position). The higher the voltage the stronger the electrical 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.



Electric & Magnetic Fields

Magnetic fields and Electric Fields (with current flowing)

Magnetic fields are created only when the electric current flows. Magnetic fields and electric fields then exist together in the room environment and in the walls as well. The greater the current the stronger the magnetic field produced. Relatively low voltages are used in the home, whereas high voltages are used for the transmission of electricity to the home. The voltages used by power transmission equipment vary little from day to day, however currents through a transmission line vary with household 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. However, they will still exist around the electrical wiring (cable) within/behind the wall.

Electric and Magnetic Fields in Walls

Another an appliance may be unplugged, the voltage in the electrical wire in your walls still exists, which creates electrical fields that radiate into the room environment. Moreover, if there is even one other appliance in use downstream (turned "on" in operation or with some type of standby indicator-light "on") using the same electrical circuit, the entire length of that wall wiring will also create magnetic fields radiating electromagnetic fields into your environment. The more appliances that are using current on that circuit wiring the higher the field strength.


Electric and Magnetic Fields

How do static fields differ from time-varying fields?
The previous illustrations demonstrate EMF in relation to Alternating Current, or AC, the electrical systems that are commonly found in homes around the world. This is known as a time-varying field, since it is characterized by alternating (changing) current and voltage. There is one other type of electrical system, known as Direct Current, or DC, and this is known as a static field, since it is characterized by non-alternating (non-changing) current and voltage.

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.)

Other non-thermal effects of EMF are now being investigated for their potential harm to biological systems, by interfering with electrically based bio-systems, such as voltage-gated ion exchange across cell membranes, and DNA damage.

Additionally the damaging biological effect of non-ionizing radiation is now known to be cumulative, like ionizing radiation is, in the human body, plant and animal life, etc.

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), or microwatts per meter squared ($\mu W/m^2$).

Key points:

- The electromagnetic spectrum encompasses both natural and human-made sources of electromagnetic fields.

- Frequency and wavelength characterize an electromagnetic field. In an electromagnetic wave, these two characteristics are directly related to each other: the higher the frequency the shorter the wavelength.

- Ionizing radiation such as X-ray and gamma-rays consists of photons which carry sufficient energy to break molecular bonds and create ions. . Photons of electromagnetic waves at power and radio frequencies have much lower energy that do not have this ability. They have other abilities, such as tissue heating, and non-heating effects as newer studies are showing they are capable of interfering with cell function, including damaging DNA. Additionally, the biological effects caused by low level, non-ionizing radiation is now known to be cumulative, like ionizing radiation.

- Electric fields exist whenever charge is present and are measured in volts per metre (V/m). Magnetic fields exist wherever there is current flow. Their flux densities (field strengths) are measured in microtesla (µT) or millitesla (mT). Or the also commonly used units, Gauss (G) (mG).

- At radio and microwave frequencies, electric and magnetic fields are considered together as the two components of an electromagnetic wave. Power density, measured in watts per square metre (W/m^2), describes the intensity of these fields.

- Low frequency and high frequency electromagnetic waves affect the human body in different ways.

- Electrical power supplies and appliances are the most common sources of low frequency electric and magnetic fields in our living environment. Everyday sources of radiofrequency electromagnetic fields are telecommunications, broadcasting antennas and microwave ovens.

(Expanded upon by Chris Young, P.E. to clarify an **Electromagnetic fields** publication by the WHO Regional Office for Europe in 1999. Local authorities, health and environment briefing pamphlet series; 32).