



## Electromagnetic fields (EMF)

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### What are electromagnetic fields?

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<http://www.who.int/peh-emf/about/WhatisEMF/en/index3.html>

# What are electromagnetic fields?

## Typical exposure levels at home and in the environment

### Definitions and sources

**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.

(Extract from **Electromagnetic fields** published by the WHO Regional Office for Europe in 1999 (Local authorities, health and environment briefing pamphlet series; 32).

### Natural sources of electromagnetic fields

Electromagnetic fields are present everywhere in our environment but are invisible to the human eye. 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 radiowaves 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 ionising radiation?**

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 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 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,  $\mu\text{T}$ ) instead. 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.

<b>Electric fields</b>	<b>Magnetic fields</b>
<ol style="list-style-type: none"> <li>1. Electric fields arise from voltage.</li> <li>2. Their strength is measured in Volts per metre (V/m)</li> <li>3. An electric field can be present even when a device is switched off.</li> <li>4. Field strength decreases with distance from the source.</li> <li>5. Most building materials shield electric fields to some extent.</li> </ol>	<ol style="list-style-type: none"> <li>1. Magnetic fields arise from current flows.</li> <li>2. Their strength is measured in amperes per meter (A/m). Commonly, EMF investigators use a related measure, flux density (in microtesla (<math>\mu\text{T}</math>) or millitesla (mT) instead.</li> <li>3. Magnetic fields exist as soon as a device is switched on and current flows.</li> <li>4. Field strength decreases with distance from the source.</li> <li>5. Magnetic fields are not attenuated by most materials.</li> </ol>



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### **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.



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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.

## How do static fields differ from 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.



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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 ( $\text{W/m}^2$ ).

#### **Key points:**

- The electromagnetic spectrum encompasses both natural and human-made sources of electromagnetic fields.
- Frequency and wavelength characterise 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. Photons of electromagnetic waves at power and radio frequencies have much lower energy that do not have this ability.
- Electric fields exist whenever charge is present and are measured in volts per metre ( $\text{V/m}$ ). Magnetic fields arise from current flow. Their flux densities are measured in microtesla ( $\mu\text{T}$ ) or millitesla ( $\text{mT}$ ).
- 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 ( $\text{W/m}^2$ ), 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.

### **Electromagnetic fields at home**

## **Background electromagnetic field levels from electricity transmission and distribution facilities**

Electricity is transmitted over long distances via high voltage power lines. Transformers reduce these high voltages for local distribution to homes and businesses. Electricity transmission and distribution facilities and residential wiring and appliances account for the background level of power frequency electric and magnetic fields in the home. In homes not located near power lines this background field may be up to about 0.2  $\mu\text{T}$ . Directly beneath power lines the fields are much stronger. Magnetic flux densities at ground level can range up to several  $\mu\text{T}$ . Electric field levels underneath power lines can be as high as 10 kV/m. However, the fields (both electric and magnetic) drop off with distance from the lines. At 50 m to 100 m distance the fields are normally at levels that are found in areas away from high voltage power lines. In addition, house walls substantially reduce the electric field levels from those found at similar locations outside the house.



## **Electric appliances in the household**

The strongest power frequency electric fields that are ordinarily encountered in the environment exist beneath high voltage transmission lines. In contrast, the strongest magnetic fields at power frequency are normally found very close to motors and other electrical appliances, as well as in specialized equipment such as magnetic resonance scanners used for medical imaging.

## **Typical electric field strengths measured near household appliances (at a distance of 30 cm)**

**(From: Federal Office for Radiation Safety, Germany 1999)**

<b>Electric appliance</b>	<b>Electric field strength (V/m)</b>
Stereo receiver	180
Iron	120
Refrigerator	120
Mixer	100
Toaster	80

Hair dryer	80
Colour TV	60
Coffee machine	60
Vacuum cleaner	50
Electric oven	8
Light bulb	5
<b>Guideline limit value</b>	<b>5000</b>

Many people are surprised when they become aware of the variety of magnetic field levels found near various appliances. The field strength does not depend on how large, complex, powerful or noisy the device is. Furthermore, even between apparently similar devices, the strength of the magnetic field may vary a lot. For example, while some hair dryers are surrounded by a very strong field, others hardly produce any magnetic field at all. These differences in magnetic field strength are related to product design. The following table shows typical values for a number of electrical devices commonly found in homes and workplaces. The measurements were taken in Germany and all of the appliances operate on electricity at a frequency of 50 Hz. It should be noted that the actual exposure levels vary considerably depending on the model of appliance and distance from it.

#### **Typical magnetic field strength of household appliances at various distances**

Electric appliance	3 cm distance (μT)	30 cm distance (μT)	1 m distance (μT)
Hair dryer	<b>6 – 2000</b>	0.01 – 7	0.01 – 0.03
Electric shaver	<b>15 – 1500</b>	0.08 – 9	0.01 – 0.03
Vacuum cleaner	200 – 800	<b>2 – 20</b>	0.13 – 2
Fluorescent light	40 – 400	<b>0.5 – 2</b>	0.02 – 0.25
Microwave oven	73 – 200	<b>4 – 8</b>	0.25 – 0.6

Portable radio	16 – 56	<b>1</b>	< 0.01
Electric oven	1 – 50	<b>0.15 – 0.5</b>	0.01 – 0.04
Washing machine	0.8 – 50	<b>0.15 – 3</b>	0.01 – 0.15
Iron	8 – 30	<b>0.12 – 0.3</b>	0.01 – 0.03
Dishwasher	3.5 – 20	<b>0.6 – 3</b>	0.07 – 0.3
Computer	0.5 – 30	< <b>0.01</b>	
Refrigerator	0.5 – 1.7	<b>0.01 – 0.25</b>	<0.01
Colour TV	2.5 - 50	0.04 – 2	<b>0.01 – 0.15</b>
With most household appliances the magnetic field strength at a distance of 30 cm is well below the guideline limit for the general public of 100 $\mu$ T.			

(Source: Federal Office for Radiation Safety, Germany 1999) Normal operating distance is given in bold

The table illustrates two main points: First, the magnetic field strength around all appliances rapidly decreases the further you get away from them. Secondly, most household appliances are not operated very close to the body. At a distance of 30 cm the magnetic fields surrounding most household appliances are more than 100 times lower than the given guideline limit of 100  $\mu$ T at 50 Hz (83  $\mu$ T at 60 Hz) for the general public.



### Television sets and computer screens

Computer screens and television sets work on similar principles. Both produce static electric fields and alternating electric and magnetic fields at various frequencies. However, screens with liquid crystal displays used in some laptop computers and desktop units do not give rise to



significant electric and magnetic fields. Modern computers have conductive screens which reduce the static field from the screen to a level similar to that of the normal background in the home or workplace. At the position of operators (30 to 50 cm from the screen), alternating magnetic fields are typically below 0.7  $\mu\text{T}$  in flux density (at power frequencies). Alternating electric field strengths at operator positions range from below 1 V/m up to 10 V/m.

### **Microwave ovens**

Domestic microwave ovens operate at very high power levels. However, effective shielding reduces leakage outside the ovens to almost non-detectable levels. Furthermore microwave leakage falls very rapidly with increasing distance from the oven. Many countries have manufacturing standards that specify maximum leakage levels for new ovens; an oven that meets the manufacturing standards will not present any hazard to the consumer.

### **Portable telephones**

Portable telephones operate at much lower intensities than mobile phones. This is because they are employed very close to their home base station, and so do not need strong fields to transmit over long distances. As a consequence, the radiofrequency fields that surround these devices are negligible.

## **Electromagnetic fields in the environment**

### **Radar**

Radars are used for navigation, weather forecasting, and military applications, as well as a variety of other functions. They emit pulsed microwave signals. The peak power in the pulse can be high even though the average power may be low. Many radars rotate or move up and down; this reduces the mean power density to which the public is exposed in the vicinity of radars. Even high power, non-rotating military radars limit exposures to below guideline levels at locations of public access.

### **Security systems**

Anti-theft systems in shops use tags that are detected by electrical coils at the exits. When a purchase is made the tags are removed or permanently deactivated. The electromagnetic fields from the coils do not generally exceed exposure guideline levels. Access control systems work in the same way with the tag incorporated into a key ring or identity card. Library security systems use tags that can be deactivated when a book is borrowed and reactivated when it is returned. Metal detectors and airport security systems set up a strong magnetic field of up to 100  $\mu\text{T}$  that is disturbed by the presence of a metal object. Close to the frame of the detector, magnetic field strengths may approach and occasionally exceed guideline levels. However, this does not constitute a health hazard, as will be discussed in the section on guidelines. (see Are exposures above the guidelines harmful?)



### **Electric trains and trams**

Long-distance trains have one or more engine cars that are separate from the passenger cars. Thus passenger exposure comes mainly from the electricity supply to the train. Magnetic fields in the passenger cars of long-distance trains can be several hundred  $\mu\text{T}$  near the floor, with lower values (tens of  $\mu\text{T}$ ) elsewhere in the compartment. Electric field strengths may reach 300 V/m. People living in the vicinity of railway lines may encounter magnetic fields from the overhead supply which, depending on the country, may be comparable to the fields produced by high-voltage power lines.



Motors and traction equipment of trains and trams are normally located underneath the floors of passenger cars. At floor level, magnetic field intensities may amount to tens of  $\mu\text{T}$  in regions of the floor just above the motor. The fields fall off quickly with distance from the floor, and exposure of the upper bodies of passengers is much lower.

### **TV and radio**

When choosing a radio station on your stereo at home, have you ever wondered what the familiar abbreviations AM and FM stand for? Radio signals are described as amplitude-modulated (AM) or frequency-modulated (FM) depending on the way in which they carry information. AM radio signals can be used for broadcasting over very long distances whereas FM waves cover more localized areas but can give a better sound quality.

AM radio signals are transmitted via large arrays of antennas, which can be tens of metres high, on sites which are off-limits to the public. Exposures very close to antennas and feed cables can be high, but these would affect maintenance workers rather than the general public.

TV and FM radio antennas are much smaller than AM radio antennas and are mounted in arrays at the top of high towers. The towers themselves serve only as supporting structures. As exposures near the foot of these towers are below guideline limits, public access to these areas may be possible. Small local TV and radio antennas are sometimes mounted on the top of buildings; if this is the case it may be necessary to control access to the roof.



### **Mobile phones and their base stations**

Mobile phones allow people to be within reach at all times. These low-power radiowave devices transmit and receive signals from a network of fixed low power base stations. Each base station provides coverage to a given area. Depending on the number of calls being handled, base stations may be from only a few hundred metres apart in major cities to several kilometres apart in rural areas.

Mobile phone base stations are usually mounted on the tops of buildings or on towers at heights of between 15 and 50 metres. The levels of transmissions from any particular base station are variable and depend on the number of calls and the callers' distance from the base station. Antennas emit a very narrow beam of radiowaves which spreads out almost parallel to the ground. Therefore, radiofrequency fields at ground level and in regions normally accessible to the public are many times below hazard levels. Guidelines would only be exceeded if a person were to approach to within a metre or two directly in front of the antennas. Until mobile phones became widely used, members of the public were mainly exposed to radiofrequency emissions from radio and TV stations. Even today, the phone towers themselves add little to our total exposure, as signal strengths in places of public access are normally similar to or lower than those from distant radio and TV stations.

However, the user of a mobile phone is exposed to radiofrequency fields much higher than those found in the general environment. Mobile phones are operated very close to the head. Therefore, rather than looking at the heating effect across the whole body, the distribution of absorbed energy in the head of the user must be determined. From sophisticated computer modeling and measurements using models of heads, it appears that the energy absorbed from a mobile phone is not in excess of current guidelines.



Concerns about other so-called non-thermal effects arising from exposure to mobile phone frequencies have also been raised. These include suggestions of subtle effects on cells that could have an effect on cancer development. Effects on electrically excitable tissues that may influence

the function of the brain and nervous tissue have also been hypothesized. However, the overall evidence available to date does not suggest that the use of mobile phones has any detrimental effect on human health.

### **Magnetic fields in everyday life: are they really that high?**

In recent years, national authorities in different countries have conducted many measurements to investigate electromagnetic field levels in the living environment. None of these surveys has concluded that field levels could bring about adverse health effects.

The Federal Office for Radiation Safety in Germany recently measured the daily exposure to magnetic fields of about 2000 individuals across a range of occupations and public exposures. All of them were equipped with personal dosimeters for 24 hours. The measured exposure varied widely but gave an average daily exposure of 0.10  $\mu\text{T}$ . This value is a thousand times lower than the standard limit of 100  $\mu\text{T}$  for the public and five thousand times lower than the 500  $\mu\text{T}$  exposure limit for workers. Furthermore, the exposure of people living in the centres of cities showed that there are no drastic differences in exposure between life in rural areas and life in the city. Even the exposure of people living in the vicinity of high voltage power lines differs very little from the average exposure in the population.

### **Key points**

- Background electromagnetic field levels in the home are mainly caused by the transmission and distribution facilities for electricity or by electrical appliances.
- Electrical appliances differ greatly in the strength of fields they generate. Both electric and magnetic field levels decrease rapidly with distance from the appliances. In any event, fields surrounding household appliances usually are far below guideline limits.
- At operator positions the electric and magnetic fields of television sets and computer screens are hundreds of thousands times below guideline levels.
- Microwave ovens meeting the standards are not hazardous to health.
- As long as close public access to radar facilities, broadcasting antennas and mobile phone base stations is restricted, exposure guideline limits for radiofrequency fields will not be exceeded.
- The user of a mobile phone encounters field levels that are much higher than any levels in the normal living environment. However, even these increased levels do not appear to generate harmful effects.
- Many surveys have demonstrated that exposure to electromagnetic field levels in the living environment is extremely low.

# What are electromagnetic fields?

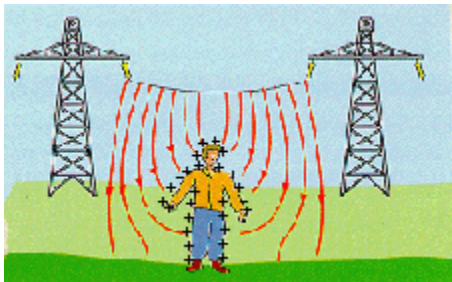
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## Summary of health effects

### What happens when you are exposed to electromagnetic fields?

Exposure to electromagnetic fields is not a new phenomenon. However, during the 20th century, environmental exposure to man-made electromagnetic fields has been steadily increasing as growing electricity demand, ever-advancing technologies and changes in social behaviour have created more and more artificial sources. Everyone is exposed to a complex mix of weak electric and magnetic fields, both at home and at work, from the generation and transmission of electricity, domestic appliances and industrial equipment, to telecommunications and broadcasting.

Tiny electrical currents exist in the human body due to the chemical reactions that occur as part of the normal bodily functions, even in the absence of external electric fields. For example, nerves relay signals by transmitting electric impulses. Most biochemical reactions from digestion to brain activities go along with the rearrangement of charged particles. Even the heart is electrically active - an activity that your doctor can trace with the help of an electrocardiogram.



**Low-frequency electric fields** influence the human body just as they influence any other material made up of charged particles. When electric fields act on conductive materials, they influence the distribution of electric charges at their surface. They cause current to flow through the body to the ground.

Low-frequency magnetic fields induce circulating currents within the human body. The strength of these currents depends on the intensity of the outside magnetic field. If sufficiently large, these currents could cause stimulation of nerves and muscles or affect other biological processes.

Both electric and magnetic fields induce voltages and currents in the body but even directly beneath a high voltage transmission line, the induced currents are very small compared to thresholds for producing shock and other electrical effects.



Heating is the main biological effect of the electromagnetic fields of radiofrequency fields. In microwave ovens this fact is employed to warm up food. The levels of radiofrequency fields to which people are normally exposed are very much lower than those needed to produce significant heating. The heating effect of radiowaves forms the underlying basis for current guidelines. Scientists are also investigating the possibility that effects below the threshold level for body heating occur as a result of long-term exposure. To date, no adverse health effects from low level, long-term exposure to radiofrequency or power frequency fields have been confirmed, but scientists are actively continuing to research this area.

### **Biological effects or health effects? What is a health hazard?**

Biological effects are measurable responses to a stimulus or to a change in the environment. These changes are not necessarily harmful to your health. For example, listening to music, reading a book, eating an apple or playing tennis will produce a range of biological effects. Nevertheless, none of these activities is expected to cause health effects. The body has sophisticated mechanisms to adjust to the many and varied influences we encounter in our environment. Ongoing change forms a normal part of our lives. But, of course, the body does not possess adequate compensation mechanisms for all biological effects. Changes that are irreversible and stress the system for long periods of time may constitute a health hazard.

An adverse health effect causes detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

It is not disputed that electromagnetic fields above certain levels can trigger biological effects. Experiments with healthy volunteers indicate that short-term exposure at the levels present in the environment or in the home do not cause any apparent detrimental effects. Exposures to higher levels that might be harmful are restricted by national and international guidelines. The current debate is centered on whether long-term low level exposure can evoke biological responses and influence people's well being.



## **Widespread concerns for health**

A look at the news headlines of recent years allows some insight into the various areas of public concern. Over the course of the past decade, numerous electromagnetic field sources have become the focus of health concerns, including power lines, microwave ovens, computer and TV screens, security devices, radars and most recently mobile phones and their base stations.

## **The International EMF Project**

In response to growing public health concerns over possible health effects from exposure to an ever increasing number and diversity of electromagnetic field sources, in 1996 the World Health Organization (WHO) launched a large, multidisciplinary research effort. The International EMF Project brings together current knowledge and available resources of key international and national agencies and scientific institutions.

## **Conclusions from scientific research**

In the area of biological effects and medical applications of non-ionizing radiation approximately 25,000 articles have been published over the past 30 years. Despite the feeling of some people that more research needs to be done, scientific knowledge in this area is now more extensive than for most chemicals. Based on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields. However, some gaps in knowledge about biological effects exist and need further research.

## **Effects on general health**

Some members of the public have attributed a diffuse collection of symptoms to low levels of exposure to electromagnetic fields at home. Reported symptoms include headaches, anxiety, suicide and depression, nausea, fatigue and loss of libido. To date, scientific evidence does not support a link between these symptoms and exposure to electromagnetic fields. At least some of these health problems may be caused by noise or other factors in the environment, or by anxiety related to the presence of new technologies.

## **Effects on pregnancy outcome**

Many different sources and exposures to electromagnetic fields in the living and working environment, including computer screens, water beds and electric blankets, radiofrequency welding machines, diathermy equipment and radar, have been evaluated by the WHO and other organizations. The overall weight of evidence shows that exposure to fields at typical environmental levels does not increase the risk of any adverse outcome such as spontaneous



abortions, malformations, low birth weight, and congenital diseases. There have been occasional reports of associations between health problems and presumed exposure to electromagnetic fields, such as reports of prematurity and low birth weight in children of workers in the electronics industry, but these have not been regarded by the scientific community as being necessarily caused by the field exposures (as opposed to factors such as exposure to solvents).

### **Cataracts**

General eye irritation and cataracts have sometimes been reported in workers exposed to high levels of radiofrequency and microwave radiation, but animal studies do not support the idea that such forms of eye damage can be produced at levels that are not thermally hazardous. There is no evidence that these effects occur at levels experienced by the general public.

### **Electromagnetic fields and cancer**

Despite many studies, the evidence for any effect remains highly controversial. However, it is clear that if electromagnetic fields do have an effect on cancer, then any increase in risk will be extremely small. The results to date contain many inconsistencies, but no large increases in risk have been found for any cancer in children or adults.

A number of epidemiological studies suggest small increases in risk of childhood leukemia with exposure to low frequency magnetic fields in the home. However, scientists have not generally concluded that these results indicate a cause-effect relation between exposure to the fields and disease (as opposed to artifacts in the study or effects unrelated to field exposure). In part, this conclusion has been reached because animal and laboratory studies fail to demonstrate any reproducible effects that are consistent with the hypothesis that fields cause or promote cancer. Large-scale studies are currently underway in several countries and may help resolve these issues.

### **Electromagnetic hypersensitivity and depression**

Some individuals report "hypersensitivity" to electric or magnetic fields. They ask whether aches and pains, headaches, depression, lethargy, sleeping disorders, and even convulsions and epileptic seizures could be associated with electromagnetic field exposure.

There is little scientific evidence to support the idea of electromagnetic hypersensitivity. Recent Scandinavian studies found that individuals do not show consistent reactions under properly controlled conditions of electromagnetic field exposure. Nor is there any accepted biological mechanism to explain hypersensitivity. Research on this subject is difficult because many other subjective responses may be involved, apart from direct effects of fields themselves. More studies are continuing on the subject.

### **The focus of current and future research**

Much effort is currently being directed towards the study of electromagnetic fields in relation to cancer. Studies in search for possible carcinogenic (cancer-producing) effects of power frequency fields is continuing, although at a reduced level compared to that of the late 1990's.

The long-term health effects of mobile telephone use is another topic of much current research. No obvious adverse effect of exposure to low level radiofrequency fields has been discovered.



However, given public concerns regarding the safety of cellular telephones, further research aims to determine whether any less obvious effects might occur at very low exposure levels.

### **Key points**

1. A wide range of environmental influences causes biological effects. 'Biological effect' does not equal 'health hazard'. Special research is needed to identify and measure health hazards.
2. At low frequencies, external electric and magnetic fields induce small circulating currents within the body. In virtually all ordinary environments, the levels of induced currents inside the body are too small to produce obvious effects.
3. The main effect of radiofrequency electromagnetic fields is heating of body tissues.
4. There is no doubt that short-term exposure to very high levels of electromagnetic fields can be harmful to health. Current public concern focuses on possible long-term health effects caused by exposure to electromagnetic fields at levels below those required to trigger acute biological responses.
5. WHO's International EMF Project was launched to provide scientifically sound and objective answers to public concerns about possible hazards of low level electromagnetic fields.
6. Despite extensive research, to date there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health.
7. The focus of international research is the investigation of possible links between cancer and electromagnetic fields, at power line and radiofrequencies.

### **Progress in research**

If electromagnetic fields constitute a health hazard, there will be consequences in all industrialized countries. The public demands concrete answers to the ever more pressing question, whether everyday electromagnetic fields cause adverse health effects. The media often seem to have definitive answers. However, one should judge these reports with caution and take into account that the primary interest of the media is not education. A journalist may select and report a story driven by a range of non-technical reasons: journalists compete with one another for time and space and different journals and newspapers compete for circulation numbers. Novel sensational headlines that are relevant to as many people as possible aid them in achieving these goals - bad news is not only the big news, it is often the only news we hear. The large number of studies which suggest that electromagnetic fields are harmless receive little if any coverage. Science cannot provide a guarantee of absolute safety yet but the development of research is reassuring overall.

### **Different types of studies are needed**



A mix of studies in different research areas is essential for the evaluation of a potential adverse health effect of electromagnetic fields. Different types of studies investigate distinct aspects of the problem. Laboratory studies on cells aim to elucidate the fundamental underlying mechanisms that link electromagnetic field exposure to biological effects. They try to identify mechanisms based on molecular or cellular changes that are brought about by the electromagnetic field - such a change would provide clues to how a physical force is converted into a biological action within the body. In these studies, single cells or tissues are removed from their normal living environment which may inactivate possible compensation mechanisms.

Another type of study, involving animals, is more closely related to real life situations. These studies provide evidence that is more directly relevant to establishing safe exposure levels in humans and often employ several different field levels to investigate dose-response relationships.

Epidemiological studies or human health studies are another direct source of information on long-term effects of exposure. These studies investigate the cause and distribution of diseases in real life situations, in communities and occupational groups. Researchers try to establish if there is a statistical association between exposure to electromagnetic fields and the incidence of a specific disease or adverse health effect. However, epidemiological studies are costly. More importantly, they involve measurements on very complex human populations and are difficult to control sufficiently well to detect small effects. For these reasons, scientists evaluate all relevant evidence when deciding about potential health hazards, including epidemiology, animal, and cellular studies.

### **Interpretation of epidemiological studies**

Epidemiological studies alone typically cannot establish a clear cause and effect relationship, mainly because they detect only statistical associations between exposure and disease, which may or may not be caused by the exposure. Imagine a hypothetical study showing a link between electromagnetic field exposure in electrical workers of the company "X-Electricity" and an increased risk of cancer. Even if a statistical association is observed, it could also be due to incomplete data on other factors in the workplace. For example, electrical workers may have been exposed to chemical solvents with the potential to cause cancer. Moreover, an observed statistical association may be due only to statistical effects, or the study itself may have suffered from some problem with its design.

Therefore, finding an association between some agent and a specific disease does not necessarily mean that the agent caused the disease. Establishing causality requires that an investigator consider many factors. The case for a cause-and-effect link is strengthened if there is a consistent

and strong association between exposure and effect, a clear dose-response relationship, a credible biological explanation, support provided by relevant animal studies, and above all consistency between studies. These factors have generally been absent in studies involving electromagnetic fields and cancer. This is one of the strongest reasons why scientists have generally been reluctant to conclude that weak electromagnetic fields have health effects.

### **Difficulties in ruling out the possibility of very small risks**

"The absence of evidence of detrimental effects does not seem to suffice in modern society. The evidence of their absence is demanded more and more instead". (Barnabas Kunsch, Austrian Research Centre Seibersdorf)

"There is no convincing evidence for an adverse health effect of electromagnetic fields" or "A cause-effect link between electromagnetic fields and cancer has not been confirmed" are typical of the conclusions that have been reached by expert committees that have examined the issue. This sounds as if science wanted to avoid giving an answer. Then why should research continue if scientists have already shown that there is no effect?

The answer is simple: Human health studies are very good at identifying large effects, such as a connection between smoking and cancer. Unfortunately, they are less able to distinguish a small effect from no effect at all. If electromagnetic fields at typical environmental levels were strong carcinogens, then it would have been easy to have shown that by now. By contrast, if low level electromagnetic fields are a weak carcinogen, or even a strong carcinogen to a small group of people in the larger population, that would be far more difficult to demonstrate. In fact, even if a large study shows no association we can never be entirely sure that there is no relationship. The absence of an effect could mean that there really is none. But just as well it could mean that the effect is simply undetectable with our method of measurement. Therefore, negative results are generally less convincing than strong positive ones.

The most difficult situation of all, which unfortunately has developed with epidemiology studies involving electromagnetic fields, is a collection of studies with weak positive results, which however are inconsistent among each other. In that situation, scientists themselves are likely to be divided about the significance of the data. However, for the reasons explained above, most scientists and clinicians agree that any health effects of low level electromagnetic fields, if they exist at all, are likely to be very small compared to other health risks that people face in everyday life.

### **What's in the future?**

The main aim of WHO's International EMF Project is to initiate and co-ordinate research worldwide to produce a well-founded response to public concerns. This evaluation will integrate results from cellular, animal and human health studies to allow as comprehensive a health risk assessment as possible. A holistic assessment of a variety of relevant and reliable studies will provide the most reliable answer possible about the adverse health effects, if any exist, of long term exposure to weak electromagnetic fields.



review of the literature, ICNIRP produces guidelines recommending limits on exposure. These guidelines are reviewed periodically and updated if necessary.

Electromagnetic field levels vary with frequency in a complex way. Listing every value in every standard and at every frequency would be difficult to understand. The table below is a summary of the exposure guidelines for the three areas that have become the focus of public concern: electricity in the home, mobile phone base stations and microwave ovens. These guidelines were last updated in April 1998.

### Summary of the ICNIRP exposure guidelines

	European power frequency		Mobile phone base station frequency		Microwave oven frequency
	50 Hz	50 Hz	900 MHz	1.8 GHz	2.45 GHz
	Electric field (V/m)	Magnetic field ( $\mu$ T)	Power density ( $W/m^2$ )	Power density ( $W/m^2$ )	Power density ( $W/m^2$ )
Public exposure limits	5 000	100	4.5	9	10
Occupational exposure limits	10 000	500	22.5	45	

ICNIRP, EMF guidelines, Health Physics 74, 494-522 (1998)

The exposure guidelines may differ by a factor of more than 100 between some former Soviet countries and Western countries. With the globalization of trade and the rapid introduction of telecommunications worldwide there is a need for universal standards. As many countries from the former Soviet Union are now considering new standards, the WHO has recently launched an initiative to harmonize exposure guidelines worldwide. Future standards will be based on the results of the WHO's [International Electromagnetic Field Project](#).

### What are guidelines based on?

An important point to make is that a guideline limit is not a precise delineation between safety and hazard. There is no one level above which exposures become hazardous to health; instead, the potential risk to human health gradually increases with higher exposure levels. Guidelines indicate that, below a given threshold, electromagnetic field exposure is safe according to

scientific knowledge. However, it does not automatically follow that, above the given limit, exposure is harmful.

Nevertheless, to be able to set limits on exposure, scientific studies need to identify the threshold level at which first health effects become apparent. As humans cannot be used for experiments, guidelines critically rely on animal studies. Subtle behavioural changes in animals at low levels often precede more drastic changes in health at higher levels. Abnormal behaviour is a very sensitive indicator of a biological response and has been selected as the lowest observable adverse health effect. Guidelines recommend the prevention of electromagnetic field exposure levels, at which behavioural changes become noticeable.

This threshold level for behaviour is not equal to the guideline limit. ICNIRP applies a safety factor of 10 to derive occupational exposure limits, and a factor of 50 to obtain the guideline value for the general public. Therefore, for example, in the radiofrequency and microwave frequency ranges, the maximum levels you might experience in the environment or in your home are at least 50 times lower than the threshold level at which first behavioural changes in animals become apparent.

### **Why is the safety factor for occupational exposure guidelines lower than for the general public?**

The occupationally exposed population consists of adults who generally experience known electromagnetic field conditions. These workers are trained to be aware of potential risk and to take appropriate precautions. By contrast, the general public consists of individuals of all ages and of varying health status. In many cases, these are unaware of their exposure to EMF. Moreover, individual members of the public cannot be expected to take precautions to minimize or avoid exposure. These are the underlying considerations for more stringent exposure restrictions for the general public than for the occupationally exposed population.

As we have seen earlier, low frequency electromagnetic fields induce currents in the human body (see *What happens when you are exposed to electromagnetic fields?*). But various biochemical reactions within the body itself generate currents as well. The cells or tissues will not be able to detect any induced currents below this background level. Therefore, at low frequencies, exposure guidelines ensure that the level of currents induced by an electromagnetic fields is below that of natural body currents.

The main effect of radiofrequency energy is the heating of tissue. Consequently, exposure guidelines for radiofrequency fields and microwaves are set to prevent health effects caused by localized or whole-body heating (see *What happens when you are exposed to electromagnetic fields?*). Compliance with the guidelines will ensure that heating effects are sufficiently small not to be harmful.

### **What guidelines cannot account for...**

At present, speculations about potential long-term health effects cannot form the basis for the issuing of guidelines or standards. Adding up the results of all scientific studies, the overall

weight of evidence does not indicate that electromagnetic fields cause long-term health effects such as cancer. National and international bodies set and update standards on the basis of the latest scientific knowledge to protect against known health effects.

Guidelines are set for the average population and cannot directly address the requirements of a minority of potentially more sensitive people. Air pollution guidelines, for example, are not based on the special needs of asthmatics. Similarly, electromagnetic field guidelines are not designed to protect people from interference with implanted medical electronic devices such as heart pacemakers. Instead, advice about exposure situations to be avoided should be sought from the manufacturers and from the clinician implanting the device.

**What are typical maximum exposure levels at home and in the environment?**

Some practical information will help you to relate to the international guideline values given above. In the following table you will find the most common sources of electromagnetic fields. All values are maximum levels of public exposure – your own exposure is likely to be much lower. For a closer look at field levels around individual electrical appliances, please see the section Typical exposure levels at home and in the environment.

Source	Typical maximum public exposure	
	Electric field (V/m)	Magnetic flux density (µT)
Natural fields	200	70 (Earth's magnetic field)
Mains power (in homes not close to power lines)	100	0.2
Mains power (beneath large power lines)	10 000	20
Electric trains and trams	300	50

TV and computer screens  (at operator position)	10	0.7
	Typical maximum public exposure (W/m <sup>2</sup> )	
TV and radio transmitters	0.1	
Mobile phone base stations	0.1	
Radars	0.2	
Microwave ovens	0.5	

Source: WHO Regional Office for Europe

### **How are guidelines put into practice and who checks on them?**

The responsibility to investigate fields around power lines, mobile phone base stations or any other sources accessible to the general public lies with government agencies and local authorities. They must ensure that compliance with guidelines is maintained.

With electronic devices, the manufacturer is responsible for complying with the standard limits. However, as we have seen above, the nature of most devices ensures that the emitted fields are well below the cut-off values. Furthermore, many consumer associations carry out tests on a regular basis. In case of any particular concern or worry, contact the manufacturer directly or enquire with your local public health authority.

### **Are exposures above the guidelines harmful?**

It is perfectly safe to eat a pot of strawberry jam up to the expiration date – but if you consume the jam any later the manufacturer cannot guarantee good food quality. Nevertheless, even a few weeks or months after the expiration date, it will usually be safe to eat the jam. Similarly, electromagnetic field guidelines ensure that, within the given exposure limit, no known adverse health effects will occur. A large safety factor is applied to the level known to cause a health consequence. Therefore, even if you experienced field strengths several times higher than the given limit value, your exposure would still be within this safety margin.



In everyday situations, most people do not experience electromagnetic fields that exceed the guideline limits. Typical exposures are far below these values. However, there are occasions where a person's exposure may, for a short period, approach or even exceed the guidelines. According to ICNIRP, radiofrequency and microwave exposures should be averaged over time to address cumulative effects. The guidelines specify a time-averaging period of six minutes and short-term exposures above the limits are acceptable.

In contrast, exposure to low frequency electric and magnetic fields is not time-averaged in the guidelines. To make things even more complicated, another factor called coupling comes into play. Coupling refers to the interaction between the electric and magnetic fields and the exposed body. This depends on the size and shape of the body, the type of tissue and the orientation of the body relative to the field. Guidelines must be conservative: ICNIRP always assumes maximum coupling of the field to the exposed individual. Thus the guideline limits provide maximum protection. For example, even though the magnetic field values for hairdryers and electric shavers appear to exceed the recommended values, extremely weak coupling between the field and the head prevents the induction of electrical currents that could exceed guideline limits.

### **Key points**

- ICNIRP issues guidelines on the basis of the current scientific knowledge. Most countries draw on these international guidelines for their own national standards.
- Standards for low frequency electromagnetic fields ensure that induced electric currents are below the normal level of background currents within the body. Standards for radiofrequency and microwaves prevent health effects caused by localized or whole body heating.
- Guidelines do not protect against potential interference with electromedical devices.
- Maximum exposure levels in everyday life are typically far below guideline limits.
- Due to a large safety factor, exposure above the guideline limits is not necessarily harmful to health. Furthermore time-averaging for high frequency fields and the assumption of maximum coupling for low frequency fields introduce an additional safety margin.

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## **What are electromagnetic fields?**

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### **Precautionary approaches**

With more and more research data available, it has become increasingly unlikely that exposure to electromagnetic fields constitutes a serious health hazard, nevertheless, some uncertainty remains. The original scientific discussion about the interpretation of controversial results has shifted to become a societal as well as political issue.

The public debate over electromagnetic fields focuses on the potential detriments of electromagnetic fields but often ignores the benefits associated with electromagnetic field technology. Without electricity, society would come to a standstill. Similarly, broadcasting and

telecommunications have become a simple fact of modern life. An analysis of the balance between cost and potential hazards is essential.

### **Protection of public health**

International guidelines and national safety standards for electromagnetic fields are developed on the basis of the current scientific knowledge to ensure that the fields humans encounter are not harmful to health. To compensate uncertainties in knowledge (due, for example, to experimental errors, extrapolation from animals to humans, or statistical uncertainty), large safety factors are incorporated into the exposure limits. The guidelines are regularly reviewed and updated if necessary. It has been suggested that taking additional precautions to cope with remaining uncertainties may be a useful policy to adopt while science improves knowledge on health consequences. However, the type and extent of the cautionary policy chosen critically depends on the strength of evidence for a health risk and the scale and nature of the potential consequences. The cautionary response should be proportional to the potential risk. For more information, see the WHO Backgrounder on Cautionary Policies.

Several policies promoting caution have been developed to address concerns about public, occupational and environmental health and safety issues connected with chemical and physical agents.

### **What should be done while research continues?**

One of the objectives of the International EMF Project is to help national authorities weigh the benefits of using electromagnetic field technologies against the possibility that a health risk might be discovered. Furthermore, the WHO will issue recommendations on protective measures, if they may be needed. It will take some years for the required research to be completed, evaluated and published. In the meantime, the World Health Organization has issued a series of recommendations:

- Strict adherence to existing national or international safety standards: such standards, based on current knowledge, are developed to protect everyone in the population with a large safety factor.
- Simple protective measures: barriers around strong electromagnetic field sources help preclude unauthorized access to areas where exposure limits may be exceeded.
- Consultation with local authorities and the public in siting new power lines or mobile phone base stations: siting decisions are often required to take into account aesthetics and public sensitivities. Open communication during the planning stages can help create public understanding and greater acceptance of a new facility.
- Communication: an effective system of health information and communication among scientists, governments, industry and the public can help raise general awareness of programmes dealing with exposure to electromagnetic fields and reduce any mistrust and fears.

For further information, see the [WHO Fact Sheets on Electromagnetic Fields and Public Health](#)