



Scientific Facts on Static Fields

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Level 2 - Details on Static Fields

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This Digest is a faithful summary of the leading scientific consensus report produced in 2006 by the World Health Organization (WHO):
"Environmental Health Criteria 232 : Static Fields"

The full Digest is available at: <http://www.greenfacts.org/en/static-fields/>

i This PDF Document is the Level 2 of a GreenFacts Digest. GreenFacts Digests are published in several languages as questions and answers, in a copyrighted user-friendly Three-Level Structure of increasing detail:

- Each question is answered in Level 1 with a short summary.
- These answers are developed in more detail in Level 2.
- Level 3 consists of the Source document, the internationally recognised scientific consensus report which is faithfully summarised in Level 2 and further in Level 1.

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1. What are static electric and magnetic fields?

Electric and magnetic fields are invisible lines of force generated by natural phenomena such as the Earth's magnetic field or lightning, but also by human activities, mainly through the use of electricity.

- An **electric field** is the force field created by the attraction and repulsion of electric charges (the cause of electric flow), and is measured in volts per meter (V/m).
- A **magnetic field** is a force field created by a magnet or as a consequence of the movement of the charges (flow of electricity). The magnitude (intensity) of a magnetic field is usually measured in Tesla [see Annex 1, p. 11] (T [see Annex 1, p. 11] or mT).

The term **static** refers to a situation where the fields do not vary with time. Static electric and magnetic fields are two distinct phenomena, both characterized by steady direction, flow rate and strength (thus a frequency of 0 Hz).

- A **static electric field** (also referred to as electrostatic field) is created by charges that are fixed in space;
- A **static magnetic field** is created by a magnet or charges that move as a steady flow (as in appliances using direct current).

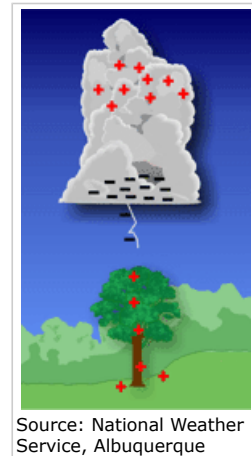
In contrast, time-varying electromagnetic fields, which reverse their direction at a regular frequency, are produced by appliances using alternating current (AC) as well as by cellular telephone antennas, microwaves, etc. In this case, the electric and magnetic fields are interrelated and are both associated with a specific frequency.

Both electric and magnetic fields weaken with distance from the source.

(For more information on low frequency fields, see our study on Power lines [see <http://www.greenfacts.org/en/power-lines/index.htm>].)

2. What are the sources of static electric fields?

- In the atmosphere, static electric fields (also referred to as electrostatic fields) occur naturally, in fair weather, but especially under thunderclouds. A charge imbalance within the clouds or between a thundercloud and the ground generates fields that can result in electrical transfers which are visible as lightning (see illustration).
- Friction can also separate positive and negative charges and generate strong static fields. In daily life we may experience sparks or rising hair as a result of friction for example from walking on a carpet.
- The use of direct current (DC) is another source of static electric fields. This is for example the case of rail systems using DC that can generate fields inside the train.
- Televisions and computer screens with cathode ray tubes¹ can also generate electrostatic fields. These fields become visible, for instance, when screens attract dust.



Source: National Weather Service, Albuquerque



Static electric fields of screens
[see Annex 2, p. 11]
Source:WHO

3. What are the sources of static magnetic fields?

The Earth's static magnetic field is attributed to electric currents in the Earth's core. Its strength varies at the surface between about 0.035–0.070 mT [see Annex 1, p. 11]. Certain animal species make use of this field for orientation and migration.

Man-made static magnetic fields are generated wherever electricity is used in the form of direct current (DC), such as in some transportation systems powered by electricity, in industrial processes such as aluminium production and in gas welding. These man-made fields can be more than 1000 times stronger than the Earth's natural magnetic field (up to 60 mT [see Annex 1, p. 11]).



Compass detecting the Earth's magnetic field

The invention of superconductors in the 1970s and 1980s allowed for the use of magnetic fields more than 100 000 times stronger than the Earth's natural magnetic field (up to 9400 mT [see Annex 1, p. 11]).

Such fields are used in nuclear magnetic resonance (NMR) techniques which are the basis for medical imaging technologies such as magnetic resonance imaging (MRI) and spectroscopy (MRS).

Magnetic Resonance Imaging (MRI) provides three-dimensional images of soft body tissue such as the brain and the spinal cord. So far an estimated 200 million MRI scans have been performed worldwide.

In a clinical setting, MRI scanners routinely use static magnetic fields in the range of 200–3000 mT [see Annex 1, p. 11]. These fields are generated by permanent magnets, by the flow of direct current (DC) through superconductors, and by combinations of the



MRI scanner (3000 mT [see Annex 1, p. 11])
Source: McKnight Brain Institute, U of Florida

two. In medical research, fields of up to 9400 mT [see Annex 1, p. 11] are used to scan the entire body of patients.

Operators of MRI scanners can be exposed to significant magnetic fields; exposure levels at the console are typically about 0.5 mT [see Annex 1, p. 11] , but may be higher. Workers can be exposed to fields exceeding 1000 mT [see Annex 1, p. 11] during the construction and testing of these devices, or during medical procedures when MRI scans are performed before, during, and after an intervention such as the removal of a brain tumour (interventional MRI).

Moreover, several physics research facilities and high-energy technologies employ superconductors. As a result workers can be exposed regularly and for long periods to fields as high as 1500 mT [see Annex 1, p. 11] .

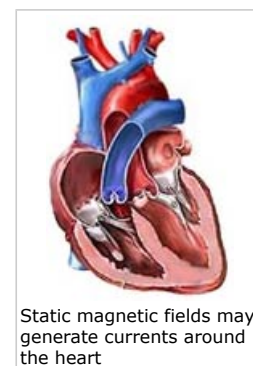
4. How may static magnetic fields interact with the body?

Exposure to a static electric field does not produce a significant field inside the body, but instead leads to the build up of electric charges on the body surface. In contrast, magnetic fields are virtually as strong inside the body as outside, which can lead to interactions within the body.

4.1 Through what mechanisms may static magnetic fields affect the body?

Experimental data have established that static magnetic fields can interact with different components of the body in the following ways:

- By exerting forces on moving charges in the blood, such as ions, they generate electrical fields and currents around the heart and major blood vessels, and slightly impede the flow of blood.
- By exerting forces that result in changes in the orientation or position of biological molecules and cellular components according to their magnetic properties, although these forces are very small, and by exerting large forces on implanted metallic devices such as pacemakers present inside the body.
- By interfering with certain types of chemical reactions that take place in the body, though it does not appear that this could cause measurable changes in cellular functions, or result in mutations in the long term.

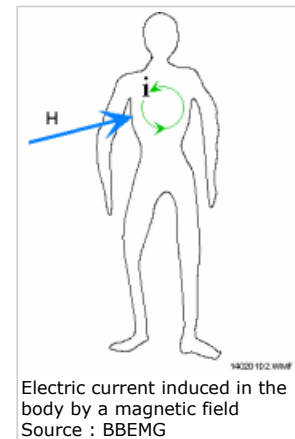


Static magnetic fields may generate currents around the heart

4.2 What determines the strength of static magnetic fields inside the body?

The interactions of biological tissue with a static magnetic field depend on the physical properties of the field such as the strength and direction of the field at a given place inside the body.

The interactions with biological tissue that are likely to be of most consequence for health occur when there is movement in the field, such as body motion or blood flow. Movement in a static magnetic field can induce an electric field and current in the body, which may account for the reports of vertigo and light flashes (phosphenes) from people moving in fields stronger than 2000 or 3000 mT [see Annex 1, p. 11] .



Computer models and direct measurements are used in order to estimate the strength of the internal electric fields in humans or animals that are induced by a given magnetic field. Induced electric fields are estimated to be substantial during normal movement around or within a magnetic field of more than 2 000 or 3 000 mT [see Annex 1, p. 11] .

There are many sources of exposure to static magnetic fields, but one of the strongest and most common is Magnetic Resonance Imaging (MRI) equipment. In the past decade, the field strengths used in MRI equipment has increased significantly. The most common system in current clinical use has a field of 1 500 mT [see Annex 1, p. 11] , but more than one hundred 3 000 mT [see Annex 1, p. 11] -systems were already operational worldwide in 2004. Systems ranging from 4 000 to 9 400 mT [see Annex 1, p. 11] are now being developed for clinical imaging.

With this move towards high field strengths, understanding the interactions between the fields generated by MRI systems and the human body has become more important since the potential for interactions increases accordingly. This can be studied through further computer modelling as well as experimental observations.

5. How may static fields affect cells or animals?

5.1 What have studies on cells revealed about the effect of static magnetic fields?

Studies on cells or cellular components are useful for understanding interaction mechanisms of static magnetic fields. They are not sufficient to identify health effects, but can give an indication of the sorts of effects that might be investigated in animals and humans. Static electric fields generate a surface electric charge and are not appropriately studied in vitro.

A number of different biological effects of static magnetic fields have been explored, by studying cells or their components and processes. These include changes in cellular processes, gene expression, cell growth and genetic material. The findings have been contradictory. Several effects have been observed at field strengths lower than 1000 mT [see Annex 1, p. 11] , but most results were not replicated by other researchers. Overall, the experiments on cells conducted so far do not present a clear picture of specific effects of static magnetic fields and do not indicate possible adverse health effects.

5.2 How can laboratory animals be affected by static electric or magnetic fields?

5.2.1 Few studies have been carried out on the effects of static electric fields on animals. The only effects observed in these were linked to the perception of the surface electric charge because of its interaction with body hair and other effects such as spark discharges. No evidence of adverse health effects has been reported.

In contrast, a large number of studies have been carried out in order to investigate possible effects of static magnetic fields on animals. The studies which are the most relevant for human health are those that have examined the acute effects of field strengths considerably higher than that of the natural geomagnetic field, and equivalent to those used in industrial processes (in the mT [[see Annex 1, p. 11](#)] range) or in magnetic resonance imaging (exceeding 1000 mT [[see Annex 1, p. 11](#)]).

Few studies, however, have examined possible chronic effects of exposure, particularly in relation to cancer.

5.2.2 Studies focussing on the nervous system consistently indicate that laboratory rodents feel discomfort when moving in static magnetic fields of 4000 mT [[see Annex 1, p. 11](#)] or more and thus try to avoid them. This is thought to be linked to effects of magnetic fields on the system in the inner ear which controls balance and body orientation.

Certain animal species appear to be able to use the Earth's magnetic fields for orientation. Such effects are not present in humans, and therefore this has no implications on human health.

5.2.3 There is good evidence that exposure to static magnetic fields can induce electric charges around the heart and major blood vessels. This has been observed in smaller animals when fields exceed about 1000 mT [[see Annex 1, p. 11](#)] (and in larger animals 100 mT [[see Annex 1, p. 11](#)]), but possible health consequences are unclear. In pigs, several hours of exposure to very high fields (up to 8000 mT [[see Annex 1, p. 11](#)]) did not result in any such effects. However, in rabbits, short- and long-term exposures to much lower fields have been reported to have a slight influence on the heart rhythm and the circulation of the blood, although the evidence for this is not strong.

It is difficult to reach any firm conclusions until more of these results have been replicated by other researchers.

5.2.4 Few studies have looked at the possible effect of static magnetic fields on blood cells, on the endocrine system, or on reproduction and development. Most of the results are not consistent and have not been replicated, so further studies are needed in order to assess the health risk.

In general, so few animal studies have been carried out with regard to harmful effects on genetic material and cancer that it is not possible to draw any firm conclusions from them.

6. How may humans be affected by static fields?

6.1 Have experiments on humans shown effects of static fields?

Static electric fields do not penetrate the human body but they can induce a surface electric charge. A sufficiently large charge may be perceived through its interaction with body hair and by other effects such as spark discharges. Painful sparks can occur for instance when a person who is well insulated from the ground, through wearing shoes with plastic soles touches an object that is electrically connected to the ground.

For **static magnetic fields** a range of possible health effects have been investigated, from changes in brain function, blood pressure and body temperature to possible therapeutic effects. Exposure to both pure static fields and Magnetic Resonance Imaging (MRI) have been studied, with fields as strong as 8000 mT [see Annex 1, p. 11] , and, with exposure duration ranging from a few seconds to nine hours.

The results are in general inconclusive. Apart from vertigo and nausea reported by people moving in a static magnetic field, the results do not seem to indicate any significant effects of static magnetic fields on human health, nor can such effects be ruled out. However, most of the studies on humans only used a few participants, which were not necessarily representative of the larger population. Thus, it is not possible to draw any conclusions regarding the wide variety of possible health effects examined in this report

6.2 What health effects were seen in people exposed to static magnetic fields through their work?

Studies on work exposure and health effects have been carried out almost exclusively on workers exposed to moderate static magnetic fields generated by equipment using large DC currents. These were welders, aluminium smelters, or workers in various industrial plants using large electrolytic cells in chemical separation processes. However, such work is also likely to involve exposure to a variety of potentially hazardous fumes and aerosols, making the exact cause of any observed effects unclear.

Increased risks of various cancers were reported, but results were not consistent across studies. In general, assessment of exposure has been poor, the number of participants in some of the studies has been very small. Thus these studies would only be able to detect very elevated risks for such rare diseases. At present, there is inadequate data for a health evaluation.

7. What are the health risks associated with static fields?

7.1 What are the health risks associated with static electric fields?

Few studies have been carried out on the effects of **short term** exposure to static electric fields. On the whole, the results suggest that the only adverse acute health effects are associated with the direct perception of fields through their interaction with body hair and discomfort from spark discharges. Chronic or delayed effects of static electric fields have not been investigated.

Note: For a Health Risk Assessment of Extremely Low Frequency fields (ELF), see the GreenFacts study on Power lines [see <http://www.greenfacts.org/en/power-lines/index.htm>]

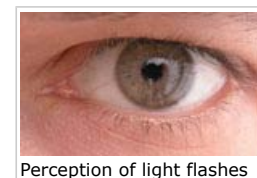


7.2 What are the health risks associated with static magnetic fields?

Short-term exposure to very strong **static magnetic fields** seems to induce a number of acute effects. For instance, fields up to 8000 mT [see Annex 1, p. 11] have occasionally led to observable effects on the heart and on blood circulation. Changes in blood pressure and heart rate have however been within the range of the normal functioning of the body.

Computer simulations suggest possible effects on the heart of electric currents induced by blood flowing through a strong magnetic field, although this has not been experimentally verified. These possible effects range from minor changes in heartbeat to an increase in the risk of abnormal heart rhythms (arrhythmia) that might be life-threatening (such as ventricular fibrillation). The magnetic field strengths at which those effects are expected to occur are difficult to assess at present because the electric currents in the heart are difficult to simulate in a computer model.

Physical movement within a static magnetic field in which the strength changes by more than 2000 mT [see Annex 1, p. 11] in a given direction (magnetic field gradient) can induce sensations of vertigo and nausea, and sometimes a metallic taste in the mouth and perceptions of light flashes. Although only temporary, such effects may be a safety concern for workers executing delicate procedures (such as surgeons performing operations using MRI).



Other acute effects of **static magnetic fields** have been reported, but it is difficult to reach any firm conclusion without independent replication of these results.

For **static magnetic fields**, the available evidence is not sufficient to draw any conclusions with regard to chronic and delayed effects.

8. Should the public and workers be protected from the effects of static fields?

National authorities should set up programs to protect both the public and workers from possible negative effects of static fields.

In the case of **static electric fields**, since the main effect is discomfort from electric discharges to the body, it could be sufficient to provide information on exposure to large electric fields and how to avoid them.

In the case of **static magnetic fields**, because the level of information on possible long-term or delayed effects of exposure is currently insufficient, precautionary measures such as those being developed by WHO (www.who.int/emf [see <http://www.who.int/emf>]) may be justified to limit the exposures of workers and the public.

WHO recommends that authorities take the following measures for static magnetic fields:

- Adopt science-based standards to limit human exposure.
- Take protective measures for the industrial and scientific use of magnetic fields by keeping a distance from fields that may pose a significant risk, by enclosing the fields, or by applying administrative controls such as staff education programs.
- Consider licensing Magnetic Resonance Imaging (MRI) units in order to ensure that protective measures are implemented.
- Fund research to fill the large gaps in knowledge regarding the safety of people.
- Fund MRI units and databases to collect information on exposure of workers and patients.

9. What further research is needed on the possible health effects of static fields?

9.1 Is further research needed on health effects of static electric fields?

There appears to be little benefit in continuing research into the effects of static electric fields on health. None of the studies conducted to date suggest any negative health effects, except for possible stress resulting from prolonged exposure to very small electric shocks. Furthermore significant exposure to static electric fields at home or at work is not very likely.

Therefore, no further research concerning biological effects from exposure to static electric fields is recommended.

9.2 Is further research needed on health effects of static magnetic fields?

For static magnetic fields, research carried out to date has not been systematic and has often been performed without appropriate methodology and exposure information. Coordinated research programs are recommended as an aid to a more systematic approach.

Along with studies on cells, animals and humans, computer simulations can help understand the link between an external static magnetic field, the internal electric fields and induced currents in moving living tissues. Some models have been widely used in studies with time-varying electromagnetic fields such as those generated by powerlines. However, very little work has been done with static fields, and more refined models should be developed.

Table 1 : Overview of research needs for static magnetic fields

	Research Needs	Priority
Computer models <i>More...</i> [see http://www.greenfacts.org/en/static-fields/1-3/9-research-needs.htm#2p1]	Women and pregnant women (and not only adult males)	Medium
	Induced currents in the head (leading to visual phosphenes and vertigo)	High
	Electric currents in the heart (considering effects on heart beat)	High
	Fetus(considering currents induced by movements in a strong field)	High
In vitro studies on cells <i>More...</i> [see http://www.greenfacts.org/en/static-fields/1-3/9-research-needs.htm#2p2]	Effects on the interaction of ions (e.g. Ca ²⁺ or Mg ²⁺) with enzymes and on other biochemical reactions	Medium
	Role in development of mutations in human cells	High
	Possible effects on gene expression in human cells using techniques such as proteomics and genomics	Low
Experimental studies with animals <i>More...</i> [see http://www.greenfacts.org/en/static-fields/1-3/9-research-needs.htm#2p3]	Cancer and other possible effects of long term exposure	High
	Possible effects on development (particularly of the brain)	High
	Fields of more than 10 000 mT [see Annex 1, p. 11]	Medium
	Broad animal studies covering different possible effects	Low
Experimental studies with volunteers <i>More...</i> [see http://www.greenfacts.org/en/static-fields/1-3/9-research-needs.htm#2p4]	Possible effects on the organ of balance and on head and eye coordination (relevant to interventional MRI)	High
	Possible effects on cognitive performance and behavior	Medium
	Possible effects on heart and blood circulation	Low
Epidemiological studies <i>More...</i> [see http://www.greenfacts.org/en/static-fields/1-3/9-research-needs.htm#2p5]	For rare diseases such as cancer, feasibility studies are needed in order to see if highly exposed occupational groups could be assessed in international epidemiological studies	High
	Cohort study of short-term effects in highly exposed occupations (including MRI technicians, workers at aluminium smelting plants, and certain transportation workers)	High
	Pregnancy outcomes in relation to occupational exposure and MRI examinations	High
	Reliable exposure measurement through the use of personal dosimeters	High

Annex

Annex 1:

Magnetic flux density

The International System (SI) unit of field "magnetic flux density" is the tesla (T).

A magnetic field of one tesla is relatively strong. That is why magnetic fields are also expressed in militesla (mT) and microtesla (μ T).

$$1 \text{ T} = 1\,000 \text{ mT} = 1\,000\,000 \mu\text{T}$$

To facilitate comparisons GreenFacts has systematically used the unit mT in its static field summaries.

Typical values for static magnetic fields (the most commonly used unit is marked in grey)

Magnetic field	T	mT	μ T
Earth's magnetic field intensity at its surface		0.035- 0.070 mT	35 - 70 μ T
Inside electric trains	up to 0.002 T	up to 2 mT	up to 2000 μ T
Aluminium production	up to 0.06 T	up to 60 mT	up to 60000 μ T
Magnetic Resonance Imaging (MRI) scanner used in a clinical setting	0.2 - 3 T	200- 3000 mT	
Fields reported to induce vertigo and phosphenes in people moving in them	above 2-3 T	above 2000-3000 mT	
Fields for which health effects have been studied so far	up to 8 T	up to 8000 mT	
Strongest fields now being developed for clinical imaging	up to 9.4 T	up to 9400 mT	

In the International System (SI) one tesla (1 T) is defined as the field intensity generating one newton of force per ampere of current per meter of conductor:

$$T = \text{Nw} \cdot \text{A}^{-1} \cdot \text{m}^{-1} = \text{kg} \cdot \text{s}^{-2} \cdot \text{A}^{-1}$$

The International Bureau of Weights and Measures (BIPM) provides further information on the International System of Units (SI) at www.bipm.org/en/si/ [see <http://www.bipm.org/en/si/>] and on prefixes of the International System of Units (SI) at www.bipm.fr/en/si/prefixes.html [see <http://www.bipm.fr/en/si/prefixes.html>]

Annex 2:

Static electric fields of TV 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.



Static electric fields of screens
Source:WHO

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 μT in flux density (at power frequencies). Alternating electric field strengths at operator positions range from below 1 V/m up to 10 V/m."

Source & © WHO (www.who.int [see <http://www.who.int/peh-emf/about/WhatisEMF/en/index3.html>])

Partner for this publication

The Levels 1 & 2 are summaries written by GreenFacts with financial support from the International EMF Project [see <http://www.who.int/peh-emf/en/>] of the World Health Organization (WHO).