Scientific Facts on

Electromagnetic fields from

Power lines, Wiring & Appliances

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Summary & Details:
GreenFacts

Level 2 - Details on Power lines, Wiring & Appliances

This Digest is a faithful summary of the leading scientific consensus report produced in 2002 by the International Agency for Research on Cancer (IARC):
"Summary of Data Reported and Evaluation of Static and Extremely Low-Frequency (ELFs) Electric and Magnetic Fields"

The full Digest is available at: https://www.greenfacts.org/en/power-lines/

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- 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 Extremely Low Frequency electromagnetic fields?

1.1 What are electromagnetic fields (EMF)?

See also GreenFacts' Digest on Static electric and magnetic fields [see https://www.greenfacts.org/en/static-fields/index.htm]

Electromagnetic fields (EMF) are a combination of invisible electric and magnetic fields of force. They occur both naturally and due to human activity.

Naturally occurring EMF are for example, the earth static magnetic field to which we are constantly exposed, electric fields caused by electric charges in the clouds or by the static electricity produced when two objects are rubbed together as well as sudden electric and magnetic fields caused by lightning, etc.

Man-made electromagnetic fields (EMF) are for example generated by extremely low frequency (ELF) sources, such as power-lines, wiring and appliances (the focus of this study) as well as by higher frequency sources such as radio and television antennas and, more recently, cellular telephones and their antennas (which are not reviewed in this study).

Figure on frequency ranges from different sources

1.2 What are ELF electromagnetic fields generated by powerlines, wiring and appliances?

All electric flows have an associated electric field and magnetic field. Both electric and magnetic fields are essentially 'invisible lines of force', each associated with a different characteristic of electricity. An electric field is the force 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 created 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 2, p. 9] (T) or sometimes in gauss [see Annex 2, p. 9] (G). The intensity of both electric and magnetic fields decreases with distance from the field source. Electric fields are more easily shielded or blocked than magnetic fields.

Both electric and magnetic fields can vary in time. Whereas, direct current (DC) fields have a steady direction, flow rate and strength, alternating current (AC) fields change direction, flow rate and strength over time with a certain frequency.

Most electricity carried in powerlines, wiring and appliances is alternating current (AC). Worldwide, altenating current (AC) moves back and forth (cycles) either 50 or 60 times per second (the latter predominantly in US), that is, at a frequency of 50Hz and 60Hz respectively. Such electromagnetic fields are classified as **Extremely Low Frequency (ELF) fields**, as their frequency is within the range of 3 to 3000 Hz.

Electromagnetic fields produced by sources other than electricity, such as cellular phone antennas, have higher frequencies and are therefore not classified as Extremely Low Frequency (ELF) fields, nor are they discussed within this study.

Figure on frequency ranges from different sources

Further details on the difference of scale of Gauss and Tesla [see Annex 2, p. 9]

1.3 How strong are ELF fields near power-lines, wiring and appliances?

Because electricity is so much a part of our lives, there are electromagnetic fields around us most of the time. We are exposed to electric and magnetic fields from many sources including high, medium and low tension (voltage) power lines, electric wiring inside buildings and electric appliances such as refrigerators, computer monitors, electric saws and drill presses.

While strong electric fields are produced by high voltage electricity, strong magnetic fields are produced by strong electric currents (high amperage). A general rule is that relatively strong electric and weak magnetic fields are observed below high voltage transmission lines, whereas household appliances and industrial devices and machines may produce weak electric and strong magnetic fields.

Both electric and magnetic fields weaken with distance away from the source. With respect to magnetic fields, field strength weakens more rapidly from point sources, such as appliances, than from line sources, such as power lines and wiring. Magnetic fields are reduced to background levels within about one meter (3-4ft) from appliances, while magnetic fields from low voltage lines delivering electricity to houses, offices and factories and high voltage lines delivering electricity from a powerplant to the power provider disappear within 20 to 60 meters (60-200ft) and 100 to 300 m (300-1000 ft) respectively.

Overlapping fields can interact to strengthen or weaken the total effect. Therefore, the strength of the electric and magnetic fields depends not only on the distance from the source but also the distance from, and location of, other nearby sources.

Table showing examples of magnetic fields generated by domestic appliances
[see Annex 3, p. 10]

2. What is known about exposure to Extremely Low Frequency (ELF) fields?

2.1

Electric and magnetic fields can be measured in practically every environment or estimated from other parameters. Environmental levels of ELF fields are very low, typically 5-50 V/m for electric fields and 0.01-0.2 μT for magnetic fields. Much higher exposures can take place in some workplaces and possibly outside the workplace for many of us for shorter durations.

There are very precise instruments to measure electric and magnetic fields, but there is a lack of consensus on what exposure characteristics should be measured to determine health effects.

Calculation methods are available to evaluate human exposure, but there are uncertainties in the results.

2.2

ELF **electric fields** are greatly attenuated (weakened) inside the body.

A well-established interaction mechanism is that external ELF **electric and magnetic fields** induce electric fields and currents in biological tissues. This is a basic physical mechanism

for interaction of ELF fields with living organisms. The electric field induced within the body increases with the frequency of the external field and the size of the exposed body. Above a certain threshold level, these induced electric fields and currents provoke a reaction from some specific cells. This threshold is well above typical human exposure levels.

Typical exposure at home results in very small induced electric fields, while some exposure at work and exposure directly under very high-voltage power lines may be greater resulting in electric fields of about 1 mV/m in some tissues.

Beyond this well-established interaction mechanism, a number of hypothetical explanations have been proposed and may even be more relevant at typical exposure levels: radical pair mechanisms, ion charge-to-mass resonance mechanisms, stochastic resonance, action on biogenic magnetite, etc [see Annex 1, p. 8] . The relevance of these hypothetical mechanisms is being researched.

3. Do Extremely Low Frequency (ELF) fields cause cancer?

3.1

Long and short term effects of ELF magnetic fields on cancer development in animals have been investigated. Several studies focused on different types of cancer including leukaemia as well as skin, brain, liver and breast cancer. Most studies did not demonstrate any carcinogenic effect. Some studies did show an increase in cancers but these findings have not been confirmed in similar studies. No ELF magnetic field study on animals has indicated an increase in leukaemia or lymphoma.

3.2

Since 1979, when a study suggested an association between ELF fields and childhood leukaemia, many other studies have been conducted and reached the following conclusions:

Childhood leukaemia
Studies indicate that children exposed to relatively strong ELF **magnetic fields**, above 0.3-0.4 μT, are twice as likely to develop leukaemia than those exposed to ELF magnetic fields below this level. This finding is unlikely to be due to chance, but the results of the studies may be distorted by biases. Concerning **electric fields**, the data available is inadequate for evaluation.

Other childhood tumors
Studies have found no consistent relationship between childhood brain tumors or other cancers and exposure to ELF electric and magnetic fields at home. However, these studies have generally been smaller and of lower quality than those on leukaemia.

3.3

For adult cancer and residential exposure to ELF fields, including the use of appliances, data are sparse and limited by the methods used.

- No consistent association has been established between **exposure at home** and adult leukaemia or brain cancer. Evidence for other types of cancers has not been adequate for evaluation.

- Concerning **exposures** to ELF fields **in the work place**, no consistent association with any particular cancer was found. Some earlier studies with methodological limitations suggested a possible increased risk of leukaemia, brain tumors and male breast cancer for workers presumed to be exposed to above average ELF fields. Some better conducted studies in the 1990's reported increased risks of leukaemia and brain cancer, but altogether the findings were not consistent.

3.4

There is some evidence at present that ELF magnetic fields can cause cancer in humans, but it is far from conclusive: the International Agency for Research on Cancer (IARC) has classified ELF magnetic fields as "possibly carcinogenic to humans" (Group 2B).

In humans, there is limited evidence for the carcinogenicity of **ELF magnetic fields** in relation to childhood leukaemia, but there is inadequate evidence for all other cancers in children and for all cancers in adults. With respect to **ELF electric fields** there is also inadequate evidence of carcinogenicity in humans.

4. Do Extremely Low Frequency (ELF) fields cause other health effects?

4.1

Taken as a whole, the results of human studies do not establish that exposure to ELF fields harms pregnancy outcomes.

Many laboratory experiments exposing mammals and other animals to strong static magnetic and ELF electric fields, have consistently shown no harmful effects on reproduction and development.

Exposure of the fetus to ELF magnetic fields generally does not result in major harmful effects on development and reproduction in mammals.


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4.2

Many studies have examined EMF-induced genetic effects. They investigate whether EMFs are directly genotoxic (toxic to the genetic material or DNA of cells), or are able to enhance the effect of well-known mutagens (agents that can induce mutations) or carcinogens.

Unlike ionizing radiation, ELF fields are not powerful enough to break (ionize) chemical bonds; they are therefore called non ionizing radiations. Overall, there is no indication from most studies that ELF electromagnetic fields are genotoxic. However, several studies have reported that ELF magnetic fields enhance the effect of agents (such as ionizing radiation), which are known to damage DNA and chromosomes, i.e. it is possible that ELF fields are co-mutagens or co-carcinogens.

4.3

Many studies have investigated the effect of ELF fields on the immune system, blood formation, melatonin hormone and other hormone levels, behavior and other parameters. No consistent effects have been observed. In particular, no convincing effect on melatonin levels has been seen in monkeys and no long-term behavioural deficits have been seen in rodents.

4.4

Exposure to high levels of extremely low frequency (ELF) electromagnetic fields was investigated by a number of epidemiological investigations and laboratory studies on human volunteers, which concluded:

- Too few studies have been done to reach any conclusions regarding effects on the **immune system and blood**.
  Too few studies have been done to reach any conclusions.
- No effects on **melatonin hormone** levels were observed in volunteers exposed to ELF fields at night. In contrast, a small reduction has been observed in workplace and residential environments, but effects of various other environmental factors are difficult to separate.
- Few effects on the **cardiovascular system** and the **central nervous system** have been observed, and findings are generally weak and inconsistent.

Annex

Annex 1:
Interaction Mechanisms

A number of explanations have been proposed, and are being researched, to better understand the interaction mechanisms between Extremely Low Frequency (ELF) magnetic fields and living organisms. The most important are:

Induced currents mechanism
Radical pair mechanism
Ion charge-to-mass resonance mechanism
Stochastic resonance mechanism
Biogenic magnetite mechanism

Induced currents mechanism

A basic physical interaction mechanism of ELF magnetic fields and living organisms. It is well-established that external ELF magnetic fields induce electric fields and currents in biological tissues. The electric field induced within the body increases with the frequency of the external field and the size of the exposed body. Above a certain threshold level, these induced electric fields provoke a reaction from some specific cells. This threshold is well above typical human exposure levels.

Typical exposure at home results in very small induced electric fields, while some exposure at work and exposure directly under very high-voltage power lines may be greater resulting in electric fields of about 1 mV/m in some tissues.

Radical pair mechanism

A suggested interaction mechanism between ELF magnetic fields and living organisms based on the effects of static (DC) magnetic fields on the rate of the chemical reactions that involve free radicals. A free radical is an atom or molecule that contains an unpaired electron in the outer shell, as a result of which it is highly reactive. Since these free-radicals have lifetimes in the microsecond range, and power-frequency fields have a cycle time in the millisecond range, a power-frequency field acts like a static field during the time scale in which these reactions occur. Static (DC) magnetic fields can affect the reaction rates of chemical reactions that involve free radical. However, one should consider the ELF field as a static field when single elementary chemical reactions are considered and then no detectable biological effect should be expected. In biochemical systems involving enzymes, sequences of elementary reactions can affect biological tissues, even at low field-strength but experimental evidence for the radical-pair mechanism in biological processes at field strengths below 500μT is still lacking.

Ion charge-to-mass resonance mechanism

This interaction mechanism, still under research, suggest that Extremely Low Frequency (ELF) magnetic fields, added to the Earth's static magnetic field, may affect the transfer of ions through cell membranes. We all are exposed to the inevitable Earth's geomagnetic field (a static field). When our cells are exposed to an alternating electric or magnetic field this exposure is thus superimposed on the Earth's static field (resonance). Experimental studies have shown that this may affect ion transfer through cell membranes. However,

there is no definite experimental evidence and no accepted explanation at either the microscopic or molecular level of how such field combinations could be effective.

Stochastic resonance mechanism

This suggested interaction mechanism is based on the following phenomena: under certain circumstances, the addition of a small amount of input noise to a larger input signal can greatly increase the output signal and the output signal-to-noise ratio. The phenomena has been labeled "stochastic resonance" though the process does not involve ordinary resonance. Such stochastic-resonance enhancements have been observed in certain cells of cray fish. However, it is highly speculative to connect stochastic resonance to predict enhanced ELF electro magnetic field sensitivity in biological matter. Since the addition of a small input signal to a larger input noise does not result in an increased output signal-to-noise ratio, it would not seem that the stochastic resonance phenomena would enhance ELF electro magnetic field sensitivity in biological matter.

Biogenic magnetite mechanism

A suggested interaction mechanism between Extremely Low Frequency (ELF) magnetic fields and the particules of magnetite present in certain living organisms has been studied. Small magnetic particles (magnetite) have been found in many organisms (bacteria, honeybees, fish, birds, etc.) and even in the human brain. In animals they seem to play a role in their orientation towards the earth's static magnetic field. It was suggested that ELF-magnetic fields could directly act on such particles and that this could explain adverse biological effects. This would however require 50/60 Hz fields of more than 1 μT.

Source & © based on the US Medical College of Wisconsin (US MCW) FAQ webpage on Power Lines and Cancer www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ/toc.html#18C [see http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ/toc.html#18C]

Annex 2:
Magnetic Field Intensity Units

The International System (SI) unit of field intensity for magnetic fields is Tesla (T). One tesla (1 T) is defined as the field intensity generating one newton of force per ampere of current per meter of conductor:

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

Certain other non-SI units, like Gauss (G), are still occasionally used. Some are important for the interpretation of older scientific texts but their use is not encouraged. One gauss (1 G) is the field intensity generating 0.1 dyne of force per ampere of current per centimeter of conductor. Therefore, the difference between tesla and gauss remains in the units used to define them. Thus, one tesla equals 10000 gauss (1 T = 10000 G), or one gauss equals 0.0001 tesla (1 G = 0.0001 T). Other units commonly used are microtesla (μT) and miligauss (mG). The next table shows the conversion factors from one unit to another:

Tesla (T)	Microtesla (μT)	Gauss (G)	Miligauss (mG)
1	1000000	10000	10000000
0.000001	1	1000	10
0.0001	0.001	1	1000
0.0000001	0.1	0.001	1

A magnetic field of one tesla is quite strong. That is why magnetic fields are usually expressed in microtesla (μT). Typical values of field intensity for some magnetic fields are:

Field	µT
Strongest fields available in laboratories	20 000 000
Earth's magnetic field intensity, at its surface	50
Domestic electrical appliances	0.02 to 7
Interstellar magnetic field	0.000 000 3

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 3:

Magnetic Fields generated by domestic appliances

The table below provides examples of magnetic field strengths at particular distances from appliance surfaces. They are expressed in microtesla (µT). Click here [see Annex 2, p. 9] for further information on magnetic field units.

	Microtesla (µT)	
Appliance	At 30 cm	At 1 meter
aquarium pump	0.035 - 1.821	0.001 - 0.117
band saw	0.051 - 1.424	0.005 - 0.075
can opener	0.719 - 16.302	0.13 - 0.644
clock	0.034 - 1.318	0.003 - 0.068
clothes iron	0.166 - 0.293	0.025 - 0.037
coffee machine	0.009 - 0.73	0 - 0.061
computer monitor	0.02 - 13.47	0.001 - 0.937
copier	0.005 - 1.838	0 - 0.239
desktop light	3.281	0.121
dishwasher	0.498 - 0.891	0.084 - 0.163
drill press	0.021 - 3.333	0.003 - 0.835
fax machine	0.016	0.003
food processor	0.619	0.035
garbage disposal	0.272 - 0.779	0.019 - 0.151
microwave oven	0.059 - 5.433	0.011 - 0.466
mixer	0.049 - 4.121	0.009 - 0.393
portable heater	0.011 - 1.96	0 - 0.138
printer	0.074 - 4.311	0.018 - 0.245
portable fan	0.004 - 8.564	0.003 - 0.312
radio	0.048 - 0.407	0.003 - 0.098
range	0.06 - 3.593	0.005 - 0.283
refrigerator	0.012 - 0.299	0.001 - 0.06
scanner	0.218 - 2.691	0.009 - 0.348
sewing machine	0.379 - 0.77	0.035 - 0.045
tape player	0.013 - 0.601	0.001 - 0.166
television	0.18 - 1.299	0.007 - 0.111
toaster	0.029 - 0.463	0.001 - 0.047
vacuum cleaner	0.706 - 2.262	0.051 - 0.128
VCR	0.019 - 0.463	0.001 - 0.041
vending machine	0.046 - 0.505	0.002 - 0.059

Source: Modified from L. Zaffanella (1997) in the California EMF Program "Evaluation of the Possible Risks From Electric and Magnetic Fields (EMFs) From Power Lines, Internal

Wiring, Electrical Occupations and Appliances", 2002. (The source of Question 1 in this study).