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Possible biological effects of electric and magnetic parameters in the environment

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Abstract. The features and intensities of electric and magnetic fields in the environment are described. Natural as well as technical constant and variable fields are considered in the light of their possible biological effects. The upper limits of the various fields are discussed. Results of laboratory measurements and also of epidemiological investigations are presented. The question is raised whether atmospheric small ions can cause a biological effect.
Key words. Natural and artificial electric and magnetic fields; possible biological effects of electric and magnetic fields and of atmospherics; atmospheric small ions.

Introduction and history

Visible and audible electrical phenomena have forever fascinated man, and have induced fear as well as blurry speculation about obscure influences. Lightning and thunder have been (and still are) honored as deities in certain persuasions. Immediately after electricity became popular and was studied with enthusiasm – at first, during the baroque period, in 'Electricity Cabinets' – the opinion was disseminated that electric (and magnetic) forces cause effects in body and soul, and can exert a healing power. The famous savants A. Volta and L. Galvani, the philospher E. Kant, the scientists C. W. Hufeland and A. v. Humboldt (who postulated a vital 'electric matter' in the air), and many other scholars were definitely convinced that atmospheric electricity has a direct influence on human well-being. Later, another source of fascination was provided by Geißler's gas discharge tubes, which were also applied in medicine before they finally (in the first decades of this century) met their ends at flea markets – a fate symbolical for so many fallacies in this domain. However, new fallacies arose: no sooner had the small ions in the air been discovered on the threshold of this century, than the suggestion was put forth that the positive small ions were the causal agent for unease and certain symptoms of illness, e.g. 'Foehn disease' (Foehn being a dry and warm southerly wind in the northern valleys of the Alps). Although nowadays this postulate has been divested of its arguments by authentic sciences, another belief still haunts biometeorology: that weather-dependent atmospherics, emitted in the troposphere, can directly cause weather disease. This historical overview (a detailed one is given in Reiter[21]) demonstrates that the multidisciplinary domain 'weather and man' will never be immune to fantasies. They appear mostly as a result of misinterpretation or faulty application of knowledge in an adjoining discipline. This article may help to prevent such errors in a specialized but frequently-entered domain.

Parameters: nature, environment and physical properties

The most important qualities to be considered

First of all we have to make clear which *parameters* have to be dealt with. They are 1) Time-constant (=E) and alternating (~E) electric fields; 2) magnetic fields (=M, ~M); 3) propagated electromagnetic radiation (EM), and 4) atmospheric small ions of both polarities (n^+, n^-).

Values of E are given in V/m, M in Tesla (T: the magnetic flux density, where the old unit 1 Gauss $= 10^{-4}$ T).

The electromagnetic waves EM consist of a combination of an electric (E, V/m) and a magnetic (M, T) vector.

Atmospheric ions are submicron particles carrying a positive or negative electric charge. Most important are small ions (n) which consist of a mono-molecular nucleus with one elementary charge which is encircled by 3–6 water molecule dipoles. The importance of n is due on the one hand to their high mobility through which n^- and n^+ determine the air-earth current in the atmosphere, and on the other hand to their respirability. Large ions can be disregarded in this short article: for details see Reiter[21].

In using the term *environment*, we have to consider the following categories:

1) open air in contrast to closed rooms,

2) purely natural in contrast to technically influenced environments, and

3) materials of special physical nature, clothing.

Properties of the natural environment include:

Atmospheric electric fields. The so-called fair weather electric field (=Ef), on the order of 100–150 V/m, which exists everywhere in the open air but far from materials with very weak to high electrical conductivity, is caused by the global thunderstorm activity. Its strength decreases with altitude in the free atmosphere. Local and varying fields originating from charges on clouds, rain drops or snow flakes, on aerosol and dust particles can, however, be superimposed on =Ef. The time variation of such superimposed fields is very complex and diverse, whereas =Ef shows a simple diurnal variation. Near to a shower or thundercloud, for instance, E changes its strength by an amount up to many kV/m, and its polarity, within fractions of seconds to minutes (for details see Reiter[21]). It is important to point out that =E and slowly varying ~E are totally screened by every material with an electrical conductivity significantly higher than that of air, e.g. humus, stone and rocks, concrete, wood, glass, ceramics, water, etc. Consequently the outdoor E does not penetrate into closed rooms (this is independent of the construction material), and it also does not exist inside a dense wood, for example. This is in contrast to high frequency ~E and electromagnetic radiation.

– *Electrostatics.* In our usual environment, electric charges are induced on special materials by manifold processes, such as rubbing against surfaces of fur, carpets or furniture. Furthermore, the friction of different textiles on our body causes extremely high charges and electric fields so that tiny flashes appear.

– *Electromagnetic waves.* Electromagnetic waves of natural origin in the troposphere (atmospherics) come into being by dipole-like electric discharges (cloud to ground as well as intracloud lightning flashes) which cause damped EM pulses but additionally – to a slight degree as a weak electromagnetic high frequency noise – by point discharges even on precipitation and in cloud particles (for details see Reiter[21]). Generation and propagation of atmospherics occur exclusively in the way expressed by Maxwell's equations. Here it must be pointed out that it is erroneous to assert that atmospherics can originate only because of countermovements of different air masses without primary electric discharges[10, 11]. Recently[13] it has again been demonstrated how VLF atmospherics (3–30 kHz) come into being as a result of electric discharges, and how they are propagated over large distances. They show a complex frequency mixture from the ELF to the VHF range, and are able to enter closed rooms provided not too much metal is included in their construction. The potency of penetration depends on the frequency of the EM waves and on the electrical conductivity of the material to be penetrated. In this article only those EM waves which do not induce any thermal effect are considered. The electric vector of atmospherics ranges from fractions of mV/m to some V/m. The magnetic vector is on the order of μT, depending on the distance from the source and on the atmospheric propagation conditions.

– *Magnetic fields.* The overall existing =M-field is the geomagnetic field which cannot be shielded against without an enormous effort (e.g. by the use of the expensive mumetal). ~M-fields in the ELF range are a typical parameter of the technical environment, for example near electric power lines and electrical household and industrial appliances.

– *Small atmospheric ions.* These exist everywhere in the air. The concentration (number density = ions per cc) outdoors as well as inside rooms depends on the balance of production and decline. Responsible for the production is – apart from cosmic rays – the total of radioactive material in the air (radon + daughters), and in every concrete material and soil (uranium, radium + daughters). The decline results from recombination and attachment to aerosol particles and surfaces. The outdoor small ion number density is on the order of some hundreds to thousands per cc.

The technical environment

Technical sources of E and M in our normal environment are high-tension power lines, transformer stations, the electrical installations in houses and rooms (and also in factories) and electrical appliances. There is much serious concern about the impressive high-tension power lines operated with 50 or 60 Hz. In Europe these are designed for up to 380 kV, in the USA and in Russia up to 765 kV (higher tensions are planned). Rough figures (after WHO[26]) for ~E (kV/m)/~M (μT) below a 380 kV line with 3 cables are: at the center line: 3.3/3; 20 m distant from the center line: 4/0.8; and 60 m distant: 0.8/0.3. Transformer stations may also cause problems because of the noise they generate, but significant levels of ~E and ~M do not actually exist in their vicinity. Of more interest are ~M fields near installations in buildings, which depend on the currents in the cables; however, no general ~M values can be given. Concern is certainly justified, however, in connection with many appliances[8, 21]: for example, near welding and soldering equipment ~M values of about 1000 μT are found; an electrical massager produces ~M about 200 μT, a heating pad ~M ≈ 20 μT, and a television set 1 μT (at about 1 m distance) the same value as 20 m away from a high-power line. Here, one has to consider the different duration of exposure. After all, the dose is mainly decisive.

The parameters in the light of biological effects

Biological effectiveness requires penetrative ability. Without that, any agent can be disregarded.

Time constant electric fields

Atmospheric electric fields have existed in the open air forever. Therefore there have been, and still are, speculations that man has become adapted to this quality during evolution – all the more so, considering that in ancient times human beings mainly lived and worked in the open air. Nowadays people spend their lives in buildings and partially in cars in which =E does not exist. Must, consequently, the agent =E not be artificially maintained inside rooms? Because =E cannot penetrate into the human body, this question should be disregarded. Nonetheless, equipment is still being offered commercially[25] which produces a 'fair weather electric field' inside rooms.

Here some words should be added concerning the clothes we wear. As mentioned above, the electric charges on them are remarkably high. Electric fields near a person can be on the order of, or even higher than, those below a thundercloud[21], and this is apparently without positive or negative biological effect (or does wearing a cat's fur ease pain from rheumatism because of electrostatics?). Incidentally, charges on clothes have never been taken into account in laboratory experiments with persons in artificial electric fields.

Natural alternating electric fields, electromagnetic waves

~E fields and electromagnetic waves penetrate into biological tissues. Because of that, atmospheric variable electric fields and EM radiations must be considered briefly.

Induced displacement currents. Although =E fields do not penetrate into a tissue, displacement currents are induced in it when E is subject to rapid changes. This happens in nature when high electric charges exist which are suddenly eliminated by a spark or flash. However, the current densities are so small (some nA^{-2}) in this case that they can be disregarded. (Galvani, of course, connected a frog's nerve with an outdoor antenna by a wire when a thunderstrom was near and observed contractions during lightning strokes. This was, however, a nerve-stimulation and not an induction.)

Atmospherics. The energy of atmospheric pulses is as low as that of common LF and VLF radio waves, which are not known to have any biological effect. The mean energy flux of atmospherics is on the order of some 10^{-11} W/cm^{-2}.

Alternating technical ~E fields

Oscillating ~E penetrate into biological tissues to a significant extent when the frequency is higher than around 10 Hz. The penetration depth of ~E depends on the frequency, on the strength of the field, and on the electric conductivity of the tissue involved.

Magnetic fields

Every magnetic field, whether constant or alternating, penetrates biological tissues totally.

Small ions

As stated, only small atmospheric ions with one elementary charge are of interest in biometeorology and medicine. The size of these ions is about 3×10^{-4} to 10^{-3} µm radius and the medium mobility of n^+ is 1.14, that of n^- 1.24×10^{-4} m^2/Volt.sec. For details about small ion physics and chemistry, and about small ions in the troposphere see Reiter[21]. Small ions have been applied for healing open wounds[19], and there have been, and still are, speculative theories that they influence the body after deposition in the alveoli. However, do inhaled small ions actually penetrate the respiratory tract down to the alveoli? This has been taken for granted by many scientists[16,23] who postulated effects based on a variety of experiments, and who speculated erroneously[15] that small ions penetrate the alveolar barrier and enter the blood in the capillaries. This supposition is a fallacy. First, only about 0.04% of inhaled small ions reach the alveoli[1], and secondly they decay at the moment when they touch the inside surface of the alveoli. Consequently, biological effects of inhaled small ions cannot be expected.

Knowledge about biological effects of electric qualities

Atmospherics

That the appearance of a significantly increased impulse frequency of atmospherics of different wavelengths is directly linked with synoptic scale meteorological conditions has been well known for a very long time (for details see Reiter[21]). The amount of tropospheric instability broadly correlates with the impulse frequency of atmospherics because of their generation by thunderstorms and showers. These are attributes of biotropical weather situations and consequently the pulse frequency of atmospherics can be used as an indicator for a large range of biotropical weather conditions as was done by Reiter[20]. By this method, and on the basis of about 1 million single biological facts, he could demonstrate how well synchronous reactions of ill and sound persons are linked with weather processes in large areas. These findings, however, do not allow us to deduce that there is a direct biological effect of electromagnetic waves like atmospherics.

Recently, Baumer and Eichmeier[3,4] observed a correlation between the pulse rate of atmospherics and the diffusion time of ions in gelatine films, from which they hypothesized[5] that atmospherics may be absorbed in gelatine and trigger a change in pore size and subsequent ion diffusion in the film. The authors speculate that, by this mechanism, a direct effect of atmospherics on biological tissue seems to be possible. However, neither the results of those experiments nor the theoretical supposition have been confirmed until now. A correlation between atmospherics and the onset of epileptic seizures has been reported[22]. The observation period lasted only 6 months. The correlation with 28 kHz atmospherics was positive, but with 10 kHz it was negative. This makes the result questionable because a selective and opposite direct effect of atmospherics in these two nearby frequency ranges appears to be unlikely, since atmospherics are not harmonic oscillations. The

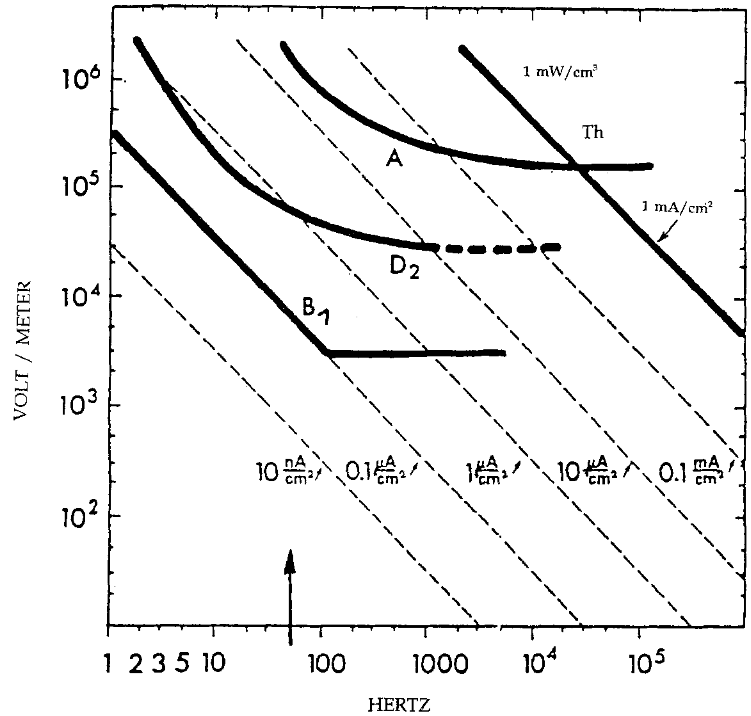

Figure 1. Model calculation by Bernhardt et al.[6]. Induced current densities in the living tissue as function of ~E in V/m, and frequency in Hz (from Reiter[21]).

above-named frequencies appear artifically by filtering from a complex mixture of a very noisy signal.

Biological effects of fields caused by power supply equipment

Results of theoretical considerations for 50 Hz. Calculations by a number of authors (see Reiter[21]) have shown that near (30 m from centerline) to a 380 kV power line the following values can be expected in the tissue of a person standing upright: Current densities in µA/cm²/ electric fields in mV/m in: head 0.0015/0.8, neck 0.15/8, center of the body 0.05/2.5, ankle 0.5/27.

The threshold values of current densities in tissues which trigger excitations are: Brain + nerve excitation 0.1 µA/cm², nerve to muscle excitation 50 µA/cm³, trans-membrane current 100 µA/cm².

It is obvious that the current density thresholds are much higher than the actual current densities to be expected near to a 380 kV line. Figures 1 (for ambient electric fields ~E) and 2 (for ~M) show generally accepted and confirmed results of model calculations by Bernhardt et al.[6]. They present field-induced current densities as a function of field strength in V/m and T, respectively. The absolute upper threshold (with 1 mA/cm²) is line Th, beyond which there is a danger of injury due to heating. Below threshold B_1 (0.1 µA/cm²) no effects on tissues will appear, it marks sufficient security. D_2 is the level where the first, but still weak, effects are

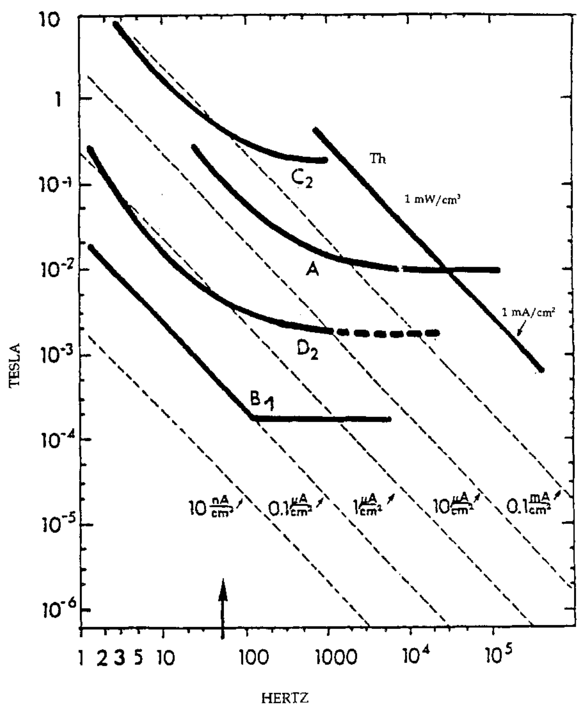

Figure 2. Similar to figure 1 for the magnetic flux density in Tesla (from Reiter[21]).

shown. The arrows indicate 50 Hz: 6 kV/m of ~E (the field at the place where the person stands, but without the person) and $0.5\ 10^{-3}$ T of ~M touch the lines B_1.

Such fields are, consequently, without effects near power lines and appliances.

Coming back to atmospherics, it was mentioned above that their energy flux is on the order of 10^{-11} W/cm^2. This is 4 orders of magnitude lower than the energy flux on line B_1 which represents 10^{-7} W/cm^2. Thus it is inconceivable that atmospherics can cause excitation in tissues.

Laboratory measurements. A large number of laboratory measurements with volunteers have been made by many independent groups in different countries (Reiter[21]). In summary it was found that no pathological effects appear, when $^{\sim}E < 10$ kV/m and $^{\sim}M <$ 0.5 mT. In stronger fields, however, departures of physiological and blood parameters from the normal are found, but only within the normal physiological range (similar to changes produced, for example, by jogging).

Epidemiological studies. Results of epidemiological studies, based on observations comparing unexposed persons with those who have involuntarily been occupationally exposed over a long time period to high $^{\sim}E$ and $^{\sim}M$ have shown that there is no significant relationship between exposure and those phenomena that have been investigated. Investigations have mainly concentrated on the emergence of leukemia, because most concern has been focussed on the induction of cancer.

A different enquiry, however, has caused some rumors: Wertheimer and Leeper[24] claimed that there was a connection between leukemia in children and the high-current wiring configurations in the Denver region. However, the $^{\sim}M$ values were not measured. This study initiated a spate of research activity. In the end, it could not be clearly shown that the exposure to $^{\sim}M$ was the actual cause, in view of the many other factors which may also induce cancer (for details see Reiter[21]).

Innovative considerations for biological effects of $^{\sim}M$

Recently, unique observations and perceptions have opened the door to new concepts regarding neuroendocrine effects of low frequency fields. Two branches are presently being considered (for more details see Reiter[21]):

1) It has been shown that ELF $^{\sim}M$ fields influence the function of the pineal gland in such a way that melatonin synthesis is affected. This is of great interest because melatonin influences the growth of malignant neoplasms.

2) A kind of 'cyclotron resonance' has been suggested which forces free, dehydrated ions (first Ca^{++} was investigated) in biological tissues to undergo cyclonal movements in the cell. This resonance comes into being when a very low frequency alternating $^{\sim}M$ is superimposed on a time-constant weak $=M$ (the geomagnetic field is sufficient). Ca^{++} comes to full resonance in the case of 16 Hz. Such an ion-resonance occurring in a cell could influence the permeability of cell membranes, which in its turn can influence, control or trigger cell physiological processes. These findings are too new for further speculations, and some criticism has recently arisen.

Effects of time-constant magnetic fields

Apart from the possible biological importance of the geomagnetic field, as discussed in the section above, it must be mentioned that animals can detect the geomagnetic field when a very small amount of magnetite is incorporated into certain neural organs. This is known to be the case in fishes and migratory birds. On flights over long distances in meridional directions migrating birds use the geomagnetic field as a compass by sensing the degree of inclination of the $=M$ field lines. It is suspected but not proved that humans may also have a certain geomagnetic sensitivity.

Effects of small atmospheric ions

First it must be pointed out that in most laboratory experiments extremely high ion number densities have been used, which are unrealistic, and do not exist in the natural environment.

Effects of small ions on plants[2,14] and on small animals[7] have been observed. However, apart from the possibility that nitrous oxides and/or ozone are produced by point discharges, it has been shown recently[12] that the very reactive peroxide anion is produced by point discharge, which also makes most of the 'small ion effects' questionable.

A biological effect of small atmospheric ions in vertebrates requires their penetration into the respiratory tract. That this does not happen has been discussed already in the section on 'small ions'. Nevertheless, there are some errors which should be discussed briefly here, because they have caused avalanches of fallacies. After Krueger and Smith[17] (details in[21]) postulated a direct biological effect of small ions (release of serotonin (5HT)), Sulman was stimulated to explain the occurrence of disease in situations with warm and dry winds (e.g. Foehn in Central Europe, Sharav in Israel) exclusively in terms of the inhalation of positive small ions. This story was initiated by Czermak[9] who found a surplus of positive small ions in Innsbruck in 1900 during 'foehn' conditions. Sulman carried out measurements of small ions and other atmospheric electric parameters in Israel, and performed tests on serotonin (5HT and 5HIAA) with patients. However, the measurements were carried out in an incorrect manner, and in the meantime it has become clear that all this work was of questionable value and could not be confirmed (see Reiter[21]). The story could be forgotten if it were not for the fact that Sulman distributed his theories in public magazines, which had consequences: many companies jumped on the bandwagon and began to produce and to sell useless 'ionizers', emitting negative ions in order to overcompensate the unhealthy positive ions in rooms. Their appealing cry was, and still is, 'produce a sound climate in your room like the climate in the mountains or over a lake' – where, actually, no surplus of negative small ions exists.

Conclusions

First on the basis of our current knowledge, there is no chance of explaining the impact of weather on man by direct effects of atmospheric electrical parameters, whatever they might be.

Second, our common technical environment is in a form in which it cannot influence or reduce health and well-being even during long-term exposures. When groups or certain persons try to discredit the present energy supply systems, the result is that concern and anxiety spreads and befalls people. The end is unease and fear. What is the sense of proposals like: 'Disconnect your residence from the electric power system at night', or 'Take away the electric clock from your bedside table'? It is sad that groundless worry concerning power supply equipment is even being injected by scientists of rank. For example, a recent book by Marino[18] says 'that many present-day exposure patterns, such as living near a powerline, are exactly the kind of physical intervention upon subjects that is proscribed by law and applicable ethical principle. In the USA, civil remedies exist ... to counter such activity, including the law of nuisance, battery, personal injury, and inverse condemnation. Although some of these actions are presently encumbered with significant evidentiary problems for the plaintiff, the problems become fewer with time because of the reports, latches of the defendants, and other factors. Laboratory studies show that electromagnetic fields can be stressors ... and are therefore factors for disease .... The health risk associated with electromagnetic fields has developed because the emerging scientific picture runs markedly counter to the long-standing interests of some industries and government agencies in unbridled use of the electromagnetic spectrum'. Comment is needless.

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