On the difference between Man-made and Natural Electromagnetic Fields/Radiation, in regard to Biological Activity

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In recent papers 'polarization' is said to make the key difference between man-made and natural electromagnetic fields/radiation. Here I explain that this is not the case. The key difference is that man-made electromagnetic fields - such as from high-voltage lines and radio-frequency antennas - have macroscopic electric and magnetic field strengths at one or a few frequencies, while for natural electromagnetic radiation – such as from the sun – these field strengths are zero at all frequencies. These man-made electromagnetic fields can thus induce oscillations of charged particles in our body, while the natural electromagnetic radiation, although having a much higher intensity, cannot do so. The higher energy photons in the natural radiation can of course be harmful on an individual basis, but that is different.

1. Introduction

Recently two papers appeared on this subject. In these 'polarization' is claimed to make the key difference between these two types of fields/radiation, in regard to biological activity. This is not correct. After the first paper in 2015 I gave my comments in private. Recently, a second paper was published with again the emphasis on 'polarization' and it was further mentioned to be a most important factor in a report which was send around by e-mail. To prevent further spreading of this false information I here explain why this is incorrect and what really makes the difference.

The first paper is by Panagopoulos et al. [1]:

'Polarization: A Key Difference between Man-made and Natural Electromagnetic Fields, in regard to Biological Activity' .

The title of my present note is a variation of this with an addition, the word 'Radiation' and an omission, the word 'Polarization'. This is essential as I will make clear.

The second paper is by Scheler[2]:

'Polarisation: Ein wesentlicher Faktor für das Verständnis biologischer effekte von gepulsten elektromagnetischen wellen niedriger intensität'

The report is by A. Hughes, in it reference is made to the importance of polarization, a statement obviously reproduced from the preceding papers.

First I will clarify what is meant in this context by Man-made and Natural Electromagnetic Fields (EMF) and Electromagnetic Radiation (EMR) .

[1] http://www.nature.com/articles/srep14914
[2] https://www.diagnose-funk.org/publikationen/artikel/detail&newsid=1170

Man-made refers to the EMF made by high-power lines and electric appliancies on the low frequency (LF) side and by antennas for wireless communication on the radio-frequency (RF) side.

Natural, as meant in the papers referred to, mainly refers to radiation from the sun, but light from lamps, flames and some infrared sources also belong to this category.

There are also natural EMF, the main ones beiing the static electric field between the ionosphere and the earth, the static magnetic field from the earth and the Schumann resonance EMF, with higher harmonics, resulting from lightning. On a microscopic scale natural EMF are very commom. Our body is full of it, think of EEG's and ECG's. These natural EMF are most important for life, but they are not important for the present discussion.

To make my points clear it will suffice to confine myself in the following to the natural EMR from the sun and the man-made EMF from power lines and electric appliances and from antennas for RF wireless communication. The reason why I use the name EMR for the sun and EMF for power lines and antennas will become clear furtheron.

2. Natural electromagnetic radiation (EMR)

The EMR from the sun comes to us in the form of photons. These have an extremely wide distribution of energies. On one side there are high-energy X-ray photons, on the other side photons at the ultra-long radio wavelengths and in between UV, visible and infrared photons. The maximum of the sun's energy output in the form of photons is in the visible light range. Throughout evolution our eyes (and we) have evolved to that. Except for some deep UV we are protected against the more energetic photons by the earth's atmosphere.

Each photon can be regarded as an electromagnetic wave. It propagates with the speed of light and is characterized by electric and magnetic field vectors perpendicular to the propagation direction. These two field vectors are mutually perpendicular. Waves are generally characterized by two quantities, frequency and wavelength. In this case, photons, the product of wavelength and frequency is equal to the speed of light and the energy of the photon is proportional to its frequency. So, the extremely wide distribution of energies of photons from the sun implies extremely wide distributions of frequencies and wavelengths. Furthermore, photons are polarized, the polarization direction is the direction of the electric field vector.

In general waves can add up but in this case, photons from the sun, this does not happen. Photons from the sun are mutually completely independent. They have different frequencies, different polarizations, different phases and don't come to us along the same paths. The energy deposited by them on earth can be appreciable. In the middle of a sunny day in the summer it can be over[3] 1000 W/m^2. However, because of their independence there is no constructive nor destructive interference between them. So their energy is

[3] https://en.wikipedia.org/wiki/Sunlight

deposited on earth, but because of the absence of constructive interference there is no build up of a macroscopic electric field at any frequency. This last point is the essence why we can tolerate sunlight with an energy deposition on the earth's surface of 100 times the ICNIRP norm (10 W/m^2) for UMTS radiation. There is a lot of energy which on our skin - apart from sunburn and possibly melanoma after long time exposure to deep UV - is partly reflected and partly absorbed and converted to heat, with some benificial effects in addition, but there is no macroscopic electric field at any frequency.

3. Man-made electromagnetic fields (EMF) / radiation (EMR)

When an oscillating current flows through an antenna one gets a macroscopic EMF around it which oscillates at the same frequency. Close to the antenna, in the so called near field[4], this EMF is quite complicated, the strengths of the electric and magnetic field components have no fixed well defined ratio, which is a prerequisite[5] for calling it EMR. In the near field there is around the antenna therefore no EMR and there are no photons. The near field extends to about one wavelength from the antenne. The consequences are interesting.

A high-voltage power line can be regarded as an antenna. In Europe 50 Hz alternating current (AC) is used and the corresponding wavelength is 6000 km. The near field thus extends up to 6000 km beyond the power line. On such a power line one can put a high voltage without drawing a current[6]. One then gets an electric field which radially extends from the power line, while the magnetic field is zero. Once a current flows through the power line one gets a magnetic field which is proportional to the current, while the electric field remains the same. So it is clear that the electric and magnetic field components are independent and that there is therefore no EMR and there are no photons.

In the radiofrequency range used for wireless communication the carrier frequencies range from below 1 GHz to above 2 GHz and the corresponding wavelengths from above 30 cm to below 15 cm.

The implication is that when we hold a smartphone next to our ear or have a laptop on our lap, our head or some of our more sensitive parts are in the near field. Thus they are not subjected to EMR but to an EMF with independent electric and magnetic field components. To come back to the statement that 'polarization' makes the key difference one can question here: polarization of what? Not of photons, because there are no photons in the near field.

Beyond the 15 to 30 cm, depending on wavelength, we are in the far field[4] in which there is a fixed relation between the electric and magnetic field components. In this case the EMF is also EMR. Apart from some complications I will mention furtheron this EMR is very different from the EMR from the sun. The EMR from the sun consists of mutually independent photons with different frequencies, different polarizations and different

[4] https://en.wikipedia.org/wiki/Near_and_far_field
[5] https://en.wikipedia.org/wiki/Electromagnetic_radiation
[6] For simplicity I neglect the small blind current needed to sustain the AC high voltage on the power line.

phases. There is therefore no constructive nor destructive interference between them. In contrast, the EMF/EMR in the far field of an antenna has only one basic frequency, the carrier frequency, and because of the way this radiation is produced, by an oscillating current through an antenna, all photons have the same phase and the same polarization. Because of these three properties, one frequency, the same phase and the same polarization, there is constructive interference and the photon contributions add up. This results in an EMF with electric and magnetic field strengths dependent on the current through and the voltage over the antenna and, in this far field, the fixed ratio between these two field strengths which is characteristic for EMR.

4. Classical EMF, the basis for model calculations

Let us now suppose we want to make model calculations of the effect of man-made EMF on biological material. We then have to know the electric and magnetic field strengths throughout that material as a function of time. The first step will then be to calculate the field distributions in the absence of the biological material, This is done in principle from Maxwell's equations[5,7], which among other things describe how electric and magnetic fields are generated by charges, currents and changes of each other. In all cases considered, LF, near-field RF and far-field RF, one then gets the distribution throughout space and time of these electric and magnetic field components. This is called a classical electromagnetic field. Maxwell's equations were derived well before the year 1900, some decennia before one knew that photons existed. That the far field RF EMF happens to be build up of individual photons is unimportant. What I mean is that the photon energies are so small that as separate photons they would not have any biological effect. It is just their combined effect which results in a macroscopic EMF with appreciable strength. And the word polarization? Well it is being used to describe the interaction of an electric field with a dielectric material, which is then polarized[7], but this is different from the meaning of that word in the papers referred to in the beginning.

5. EMF versus EMR, the key difference(s)

So, what is left of the argument that polarization would make the main difference between Man-made and Natural Electromagnetic Fields? The answer is: nothing in the near field. In the far field it is one of the three essential factors when the far field is described as being build up of photons. Man-made electromagnetic fields, as produced by high-voltage power lines and antennas for wireless communication, can be regarded as classical EMF. In the LF and near-field RF range there are no photons and there is no EMR. In the far-field RF range the names EMF and EMR can both be used, with the restriction that this is an EMR with only one frequency and with moreover constructive interference in such a way that this EMR is an EMF.

[7] https://en.wikipedia.org/wiki/Maxwell's_equations

The indication EMF is complete, it tells that there are electric and magnetic field vectors with magnitudes that can be calculated from Maxwell's equations. The indication EMR is in this case applicable only in the far-field RF range and is not complete. The word polarization does not give any additional information, it only indicates the direction of the electric field vector. This electric field vector has in addition a magnitude and thus gives more information.

Natural EMF are mainly those mentioned in the beginning, the static electric field between the ionosphere and the earth, the static magnetic field from the earth and the Schumann resonance frequency EMF with higher frequency harmonics. But, as said, these are not important for the present discussion. And the macroscopic EMF from the radiation coming to us from the sun? Well, as I have explained, that is zero for all frequencies, so it is non-existent.

To conclude, the main difference between man-made and natural EMF is that the man-made EMF referred to here are made with appreciable strength and that the natural EMF resulting from the photons from the sun (or lamps, or flames) is zero at all frequencies. EMR is the appropriate name for the suns photons, but their contributions don't add up to yield a macroscopic EMF. EMF is the most appropriate name for all the fields made by power lines, electrical appliances and RF antennas.

6. Additional remarks.

The above is meant to be tutorial and describes only basic concepts. The actual man-made EMF for wireless communication are more complicated because the data information, including bacon signals, is superposed on the carrier frequency signals.

It is known from experiment that these pulsed RF signals are responsible for most of the harmful biological effects and are responsible for a lowering of some of the threshold intensities at which these effects do occur, as compared to non-pulsed signals.

In many places there is not one antenna but there are more. Each gives its own EMF. These EMF add up and result in a more complicated sum EMF. When different antennas work at different frequencies one gets an EMF with these frequencies and with sum and difference frequencies. In some cases different (two) polarization directions are used as well. The end result is always an EMF, although possibly a complicated one.

Another difference between the EMR from the sun and the EMF from RF wireless communication is that the central frequency of the sun's radiation lies a factor of about a million above the RF frequencies used for wireless communication. At the visible frequencies photons don't penetrate into our body, at the RF frequencies the field does and is largely absorbed there, possibly doing harm.

The importance of the existence of an EMF is that the force on charged particles in our body is directly proportional to the electric field strength. The EMF induces oscillations of these charged particles, while the EMR from the sun does not, apart from the fact that this radiation does not pass our skin.

From the preceding explanation it follows that it is perfecty safe to use sun glasses with polarization filters (polaroid for example). One then gets polarized light entering into our eyes, but the photons in it are still independent, with different frequencies and phases, implying that the resulting EMF is zero at all frequencies. Light reflected from a water surface under Brewster angle can also be polarized and that is also safe, for the same reason.

On the first paper[1] more comments can be made, I give two.

In it I read, for example: "Consider two incoherent, unpolarized electromagnetic rays with electric components E1, E2". My two objections here are that unpolarized electromagnetic rays don't exist - electromagnetic rays or waves are by definition polarized – and that the word unpolarized is in contradiction with the electric field vectors **E1** and **E2**, because these vectors[8] by definition give the polarization directions of the electromagnetic rays.

My second comment may be of interest to those who wish to make model calculations. One then generally starts the damped harmonic oscillator driven by the electric field. The solution in[1] is not correct. The correct solution is given in a Wikipedia paper[9].

Finally, I did not use any formulae in this note. These, with explanations and definitions, can all be found in the Wikipedia articles referred to.

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[8] To distinguish vectors from scalars, bold lettering is always used in physics papers for vectorial quantities

[9] https://en.wikipedia.org/wiki/Harmonic_oscillator