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The magnetotherapy delusion

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Sumario. En años recientes ha ocurrido una "resurrección" de las denominadas terapias magnéticas basadas en la aplicación de imanes en diferentes partes del cuerpo. La aplicación generalizada de estas "terapias", así como la difusión de información falsa asociada al tema, nos ha llevado a pensar que el engaño debía ser expuesto, o al menos mencionado, en los cursos de física básica. Se discuten algunos argumentos haciendo énfasis en la física del fenómeno, con la intención de que la información sea útil para todos aquellos que se dedican a la enseñanza de la física en ciencias e ingeniería. Se recuerda que un campo magnetostático no es capaz de transferir energía de ningún tipo a partículas en movimiento, mostrando la falsedad de algunos razonamientos usuales en la literatura pseudocientífica. El ignorar tanto la historia de la medicina como los métodos científicos y la bioética puede ser una posible explicación de por qué algunas de estas terapias aún sean consideradas de valor por algunos.

Abstract. In recent years there has been a "resurrection" of the so-called magnetic therapies, based on the application of permanent magnets in different parts of the body. The widespread application of these "therapies", as well as the distribution of false information connected to the subject, have led us to think that the hoax should be exposed, or at least mentioned, in the courses of basic physics. Some detailed arguments stressing the physics on the subject are discussed, with the feeling that the information could be helpful for all those who teach physics in science and engineering. It is recalled that a magnetostatic field cannot transfer magnetic energy to moving charged particles, showing the falsehood of some statements appearing in the pseudoscientific literature. Disregard of the history of medicine as well as scientific methods and bioethics could be the explanation of why some of these therapies are so far claimed as valuable for some people.

Keywords. Magnetostatic field 41.20.Gz, electromagnetism 41.20.–q.

1 Introduction

In recent years there has been a "resurrection" of the so-called "magnetic therapies", based on the application of permanent magnets to different parts of the body. You may visit a community therapy center –as I did– and some technician will put a magnet in your hand for a while "to see if there are not adverse reactions" (sic). Afterwards, you may go into a therapy session that simply consists in remaining a few minutes with one or more permanent magnets set in some place of your skin. Some doctors prescribe this "alternative medicine" for the treatment of very different illness, from pain relief to prostate problems.

Even though it is not possible to find any endorsement in the standard medical literature for this kind of therapy, you may find many non-scientific reports about the supposed effectiveness of magnetotherapy in non-specialized journals, medical congress, books and Internet. For instance, a magnetostatic device claiming to heal leg ulcers was released –and severely criticized by a former president of the British Society of the History of Pharmacy- in March 2006.[1] Undoubtedly, these reports may be very confusing for common people and for the non-specialists, even for physicist working in fields far off electromagnetism.

Unlike others more evident delusions such as the "pyramidal energy", where the scientific discussion endorsing their supporters' reports never shows up[2,3], the ability of permanent magnets to interact at distance with iron-related compounds may provide some sort of distorted technical arguing and a "veil of truthfulness" to what is not.

The term *resurrection* has been used here because it seems that there is some kind of cyclic pattern involved in the attempts to promote this "universal healing therapy". In a previous paper[4] some historical facts were discussed showing that in fact there is nothing "new" about the subject (see Fig. 1). A more recent german paper discloses that, from the 1780s to the 1830s, physicians at the Charité hospital in Berlin conducted clinical trials designed to test the therapeutic effectiveness of "animal and mineral magnetism" -an earlier designation of what is known today as magnetotherapy. The paper reads: "Whereas in the 1790s the plausibility of therapeutic claims about animal magnetism demanded recourse to the magnetic practitioner's body, by the 1830s the embodied evidence on which those claims rested had lost it's persuasive power and been relegated to the netherworld of quacks and charlatans"[5].

A detailed account of known "magnetotherapists" beginning with Paracelsus (1493-1541), may be found in many WEB sites (see, for instance, http://en.wikipedia.org/wiki/History_of_hypnosis or in http://www. world widecchool.org/library/books/relg/socialeccltheology/MemoirsofPopularDelusionsV3/chap45.html). More negative evidence can be found anywhere[6,7] including legal complaints issued by the U.S. Federal Trade Commission (http://www.ftc.gov/) against false magnetotherapy advertisements, and decisions of the U.S. Food and Drug Administration (www.fda.gov/) with similar aims.

The intention here is to discuss some detailed arguments stressing the physics on the subject, hoping that this information be helpful for all those who teach physics in science and engineering.

2 Time varying magnetic fields

It is important not to confuse magnetostatic therapies with electromagnetic ones. Magnetostatic therapies are based on the application of *motionless* magnetic fields to the patient's skin using *magnets* (and hence the name magnetotherapy). Electromagnetic therapies are based on the application of *time-varying magnetic fields*, usually generated at low frequencies by an alternating current passing through a coil. At ultra high frequencies (UHF) and beyond, *magnetrons* and similar devices are used for that purpose (see, for instance, http://en.wiki pedia.org/wiki/Magnetron).

The essential difference with static fields is that time-varying magnetic fields can generate *electric* fields with significant intensity inside the body, and its value may be estimated using the integral form of *Faraday's law*

$$\oint_{\ell} \vec{E} \cdot d\vec{\ell} = \frac{d}{dt}\int_S \vec{B} \cdot d\vec{s}\,,$$

where B and E represent the magnetic and electric field respectively; S is the surface area defined by any closed curve taken in the region of space where B is present and ℓ the path bounding that area. It is important to notice that for a given area S, the intensity of the electric field generated –and hence its possible effects on the tissues- do not depend on the magnitude of B, but rather on its rate of change dB/dt. Magnetostatic fields do not have an associated electric field (dB/dt = 0).

Figure 1. The delusion is not a new one. Magnetic corsets, patented in 1891 by Cornelius Bennett "for women of all ages". In the yellow fan you may read, "They cure wear back".

The reciprocal is also true, i.e., a time-varying electric field gives rise to an also time-varying magnetic one, every field continually generating one-another. The full description of the combined phenomenon is analytically given by the Maxwell's equations,

$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

$$\nabla \times \vec{B} = \mu\vec{J} + \mu\varepsilon\frac{d\vec{E}}{dt}\,.$$

J is the current density at the considered point and μ, ε the magnetic and dielectric constants (permeability and permittivity) of the material media where the fields are immersed. The arrangement of these equations when $J = 0$ leads to the wave equations,

$$\nabla^2 \vec{E} = \mu\varepsilon \frac{\partial^2 \vec{E}}{\partial t^2}$$

$$\nabla^2 \vec{B} = \mu\varepsilon \frac{\partial^2 \vec{B}}{\partial t^2}$$

whose solution shows that the generated electromagnetic pulse (or wave) of interlaced time-varying electric and magnetic fields will travel in all directions with a velocity given by $v_p = 1/\sqrt{\mu\varepsilon}$, which is about 300 000 km/s in vacuum (the velocity of light). The Poynting's vector

$$\vec{S} = \frac{1}{\mu}\vec{E}\times\vec{B}$$

is a measure of the energy flow carried by the combined *electromagnetic radiation* in a given direction[8].

Most waves used in medical applications are sinusoidal, and it has been estimated that arbitrarily shaped pulses will affect biology little differently than sinusoidal ones with the same frequency and intensity[9]. Hence, in the following we will refer only to sinusoidal waves. For these waves, the field intensity E at a distance x of the source in a given direction may be represented at any time t as

$$E = E_o \operatorname{sen}(kx - \omega t),$$

with a similar expression for the magnetic field B, where $B_o = E_o/v_p$. The alternating fields E and B are perpendicular to the direction of x, E_o is the *amplitude* or maximum value of E, k the *wave number* and $\omega = 2\pi f$, where f is the *frequency*, i.e., the number of times that the fields E and B reverse its direction in the time unit. It is measured in Hertz; (1 Hz = 1 oscillation per second).

The penetrations of electromagnetic radiation in tissues and its effects depend strongly on the wave frequency. Penetrations are fairly well known (Table I)[10], but most effects and interactions with tissues are yet under study and remain unknown. Note that penetration is higher the lower the frequency and that at any frequency below 10 MHz the radiation will completely go throughout the human body. Microwave radiation with a frequency of about 2500 MHz, used regularly in diathermia therapy to induce heat in tissues by a similar mechanism as that taking place in a microwave oven, has an approximate penetration in tissues of 2 to11 cm.

Many papers have been published in the last years about therapies based on low frequency pulsed magnetic fields (60-100Hz). It is claimed, for instance, that it may speed up the healing of broken bones due to bones' piezoelectric properties, i.e., to their ability to stress and stretch under the influence of the changing induced electric field. Often, in this and other applications, it is assumed *a priori* that the low frequency therapy will not be injurious to the patient, and it has been often applied without the firm evidence of a previous full research[11]. In respect to this matter, you can find reports, based on *theoretical* evaluations, stating that low-frequency electric fields cannot affect DNA or other internal cell organelles directly[12]. However, there is also recent *experimental* evidence in support of the contrary; a 60 Hz sinusoidal magnetic field of low intensity (0.01 mT) applied for 24 hour to rats showed an increase in DNA single- and double-strand breaks in their brain cells.[13] Therefore, low-frequency therapies should be at least considered with care, especially when applied near the head.

The case of the so-called "magnetotherapy" is a very different one, because there is not any true physics behind its proposals.

3 Magnetostatic fields and living tissues

Basic physics courses show that the magnetostatic field cannot interact with neutral particles or charged ones at rest, but it does with charged particles and ions in movement. However, it is well known that this type of interaction cannot transfer the field energy to the moving particles. Let us see this in detail[14].

Table I

Established bands according to absorption characteristics (1 MHz = 10^6 Hz)	**Frequency** (MHz)	**Penetration depth** (cm)	
		Muscles, skin and tissues with high water content	Fat, bones and tissues with low water content
Subresonance band f < 30 MHz. Override surface absorption in body, but not in neck and legs. Absorption decreases fast with rising frequency.	1 10 27.12	91.30 21.60 14.30	- - 159.0
Resonance band 30 MHz < f < 400 MHz. High absorption due to resonances of the whole body (~70 MHz), or partial like in the head (~400 MHz)	40.68 100 200 300	11.20 6.66 4.79 3.89	118.0 60.4 39.2 32.1
Hot points band 400 MHz < f < 2000 MHz. There is localized absorption due to resonances or quasi-optical focusing. The size of the hot points change between 1 and several centimeters.	433 750 915 1500	3.57 3.18 3.04 2.42	26.2 23.0 17.7 13.9
Surface absorption band 2 GHz < f < 300 GHz. Energy is dissipated in the body surface in a similar way to infrared radiation. (1 GHz = 10^9 Hz).	2450 3000 5000 5300 8000 10000	1.70 1.61 2.78 0.72 0.41 0.34	11.20 9.74 6.67 5.24 4.61 3.39

The interaction or *Lorentz force* $\vec{F} = q\vec{v}\times\vec{B}$ is always normal to the magnetic induction $\vec{B}$ and to the particle's velocity **v** (and therefore to its displacement). Here q is the particle electric charge. Since force and displacement are perpendicular at any time, the work done on the particle by F will always be null (dot product of perpendicular vectors). Analytically,

$$W = \int \vec{F}\cdot d\vec{r} = \int (q\vec{v}\times\vec{B})\cdot\vec{v}dt = 0 \ .$$

But the also well known Work and Energy Theorem states that the resultant work done on a particle must be equal to the change of its kinetic energy; i.e.; $W_R = \Delta E_k$. Therefore, if there is no work, neither can be magnetostatic contribution to the kinetic energy E_k of the particle, and the particle energy will remain constant, as well as the absolute value of the velocity. There are many complex instruments, such as low-energy cyclotrons and mass spectrometers, which works based on this property of the magnetic field; i.e., that *a magnetostatic field may change the direction of particles, but not its energy* (see Fig. 2).

To avoid any possible misreading, let us show two more examples; that of the turning coil of a dynamo (Fig. 3, *left*) and a magnet moving in front of a coil (Fig. 3, *right*). Although the electric current is induced by the presence of the magnetostatic field, *the energy comes from the external agent moving the coil or the magnet, and not from the field itself.*

Besides, in each case the acting field is no longer magnetostatic, but a *time varying field* due to the change in the relative geometry of the system; i.e. the circuit "sees" a time-varying magnetic field, and not a static one.

Therefore, on the light of this brief discussion it becomes clear that statements like the following are absolutely false when referred to permanent magnets: *"When the human body interacts with a magnet, a weak electric current is generated in the blood... the amount of ions notably increase … (and) the general metabolic system is beneficiated visibly"*, or this other one, *"the magnetic flux provides additional energy"* [15]. In respect to the first one, it is clear that the blood or the tissues have nothing to do with electrons in a moving coil. In a coil electrons are loosely bound sharing the same energy bands and free to move in the so-called *metallic bond*; in organic molecules and atoms electrons are tightly bounded in *covalent* or *ionic* bonds, and the electric currents that may appear are millionths times smaller than those in metals.

If we consider ionic conduction instead of electronic conduction, since the mass of an ion is millions of times larger that the one of an elemental particle like the electron, the effect of the magnetic forces on the particle direction can be completely disregarded when compared with other usual biological interactions. This is observed in practice in Magnetic Resonance Imaging (MRI) equipments every day, where patients are exposed to fields of about 2 Tesla or more, -many times larger than that of a common permanent magnet-, without any reported collateral effects. (A 10 Tesla magnetic field is predicted to change the vascular pressure in a human by no more than 0.2%)[16]. Due to the magnitude of the forces and the mass of the particles involved, the same arguments are equally valid when you slowly move the magnet over the skin.

The second statement, *"the magnetic flux provides additional energy"* is false when referred to kinetic energy, since the interaction of the magnetostatic field with charged moving particles cannot affect it, as we have previously seen.

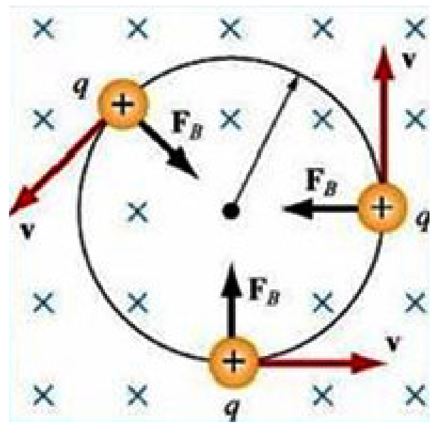

Figure 2. Forces acting on protons in a cyclotron. The magnetostatic field B goes into the plane of the paper $\otimes$. Magnetic forces are represented by **F**, and velocities by **v**.

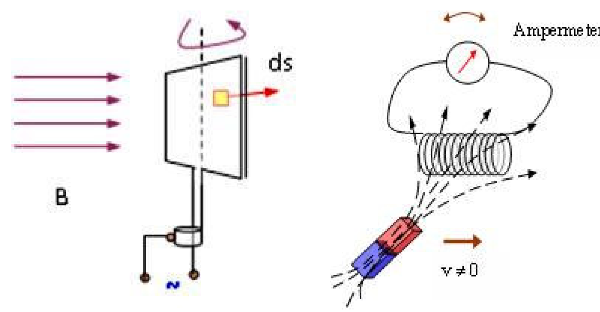

Figure 3. *Left. Moving coil*. The coil rotates with constant angular velocity and an EMF appears in the contacts. The field is constant, but the coil "sees" a varying field. *Right. Moving magnet*. In a common cathedra experiment, an induced current appears in the circuit when the magnet is moved in front of the fixed coil.

The other possible energy type present would be the potential energy $U = -\vec{\mu}\cdot\vec{B}$, due to the interaction of the magnetostatic field $\vec{B}$ with the magnetic moment $\vec{\mu}$ of any paramagnetic atom or ion present in the tissues. (In principle, diamagnetism is always present in all atoms, but the strength of diamagnetic forces is usually many times less than that of paramagnetic ones and completely negligible).

In any case, it is well known that the magnetostatic field can be derived from a scalar potential, and hence magnetostatic forces forms a *conservative* field of forces. Therefore, *the total work done by the magnetic force on a magnetic dipole in any closed trajectory will always be zero*, and the increase in potential energy when a particle approaches the magnet will be cancelled by the decrease when the particle retreats; i.e., there is no way that some permanent magnetic energy could be transferred to the blood –or any other place– by means of this mechanism.

A last remark: in the world wide well-known 2006 Physics and Astronomy Classification Scheme (PACS), there are about 18 entries under the term "therapy" (including electrotherapy), but "magnetotherapy" is missing.

4 Conclusions

From the middle ages to present, firm medical evidence in support of magnetotherapy has not come out. In addition, a possible mechanism to explain the supposed effects of magnets on tissues does not exist. Then, why this -and others- false therapies are so far claimed as valuable for some people? Possibly due, in most cases, to the complete *disregard of history of medicine, bioethics and scientific methods together*, leaving entirely aside facts such as *medical protocols of investigation* or the *placebo effect*, very well known to research physicians –but usually not to physicists or engineers!–. The placebo is some inert substance used in medical control experiments instead of the active drug or therapy. A group receives the drug, and other the placebo, without knowing it. In any medical experiment of this kind, it is well known that always a significant amount of patients in the control group will show improvement. A 2005 paper on the subject has shown a definite connection between a placebo and the activity of the endogenous opioid system on μ-opioid receptors in the human brain, using molecular imaging techniques[17] .

Another source of deception may be the suggestion, of both patient and physician. For this reason, double blind experiments are common nowadays. In a double blind experiment, neither the patient nor the evaluating physician knows about who really received the therapy and who did not. For more details, see ref. [2].

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