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Electromagnetic radiation and health

by Nick Doe

Asking if exposure to electromagnetic radiation is hazardous to your health is a bit like asking if it's safe to ingest chemicals. The answer is—it all depends….

By definition, some chemicals in food are nutritious; others, called vitamins, are essential; but many are not. Some chemicals in food are perfectly harmless; a few are poisonous; and others, although beneficial in moderation, are toxic in quantity—*folic acid* and *chromium* come to mind. All that we eat, including all that healthy organic stuff, comprises chemicals of every category. Coffee, olives, and Lord help us, pickled onions are rumoured to contain the suspected carcinogen, *acrylamide*. Every produce aisle of every grocery store offers potatoes; yet, potatoes contain natural neurotoxins—they're called *solanine* and *chaconine*. Every produce aisle offers broccoli and other related vegetables that are rich in vitamins, minerals, and fibre; yet, they may also contain the natural pesticide, *glucosinolate*. High concentrations of *tannin* and the *pyrrolizidine alkaloids* found in some teas have been shown to cause tumours in laboratory animals. The list goes on…. Sometimes cooking food helps, some types of otherwise poisonous mushroom for example; other times, it just creates trouble, as does toasting bread.

Plants have evolved toxins to protect themselves from insects, predators, and diseases, and all herbivores and omnivores have evolved mechanisms to counter the effects of eating at least some of them. Squirrels don't fall ill if they eat acorns even though cows do. Whether our human defences can also cope with all manufactured chemicals is a good question, just as is whether we have adequate natural defences against *manufactured* radiation.

"Good" radiation

Beneficial "natural" electromagnetic radiation includes most of the radiation from the sun that reaches the earth's surface, which, in one way or another, keeps us warm, enables us to see, and without which we could not possibly survive. Ionizing electromagnetic radiation at the high end of the sun's spectrum that is not blocked by the atmosphere is, on the other hand, harmful. But even there, the characterization is not black and white.[1] Skin, exposed to ultraviolet radiation (UV-A), produces vitamin-D which, it's generally agreed, is a "good thing"—a deficiency of vitamin-D is a fairly serious condition.

Far-infrared radiation is sometimes used in medical treatments; it reduces inflammation, and eases pain. Some people claim that magnetic fields are also good for you[2]—they buy magnets from health-food stores—but then others are equally adamant that magnetic fields from power lines are not. Some, rather enigmatically, take the position that both views are right.[3]

[1] No pun intended. Ionizing radiation is thought to grey your hair as damaged and hence potentially cancerous radiation-stressed cells are discarded.

[2] How magnets might work to relieve pain is not clear. Magnet therapy may be effective in treating diabetic neuropathy and osteoarthritis, but as a treatment for many other conditions the evidence is either insufficient to reliably judge its effectiveness or has been shown to be ineffective. Sales of therapeutic magnets nevertheless run into billions of dollars annually.

[3] A Boston psychiatrist is credited with observing that some depressed people get a mood lift when tested

Fields

Electromagnetic fields comprise an electric and a magnetic field. A changing or moving magnetic field always generates an electric field, and a changing or moving electric field always generates a magnetic field. In an electromagnetic wave, the movement is self-contained. The wave propagates at the speed of light and the energy of the wave alternates continuously between being contained in the electric field and being contained in the magnetic field. The rate of exchange is its *frequency*[4] and the distance travelled while completing one cycle is the field's *wavelength*.

At less than very-low frequencies (< 3 kHz), the components have to be considered separately, and this obviously includes electrostatic and magnetostatic fields—fields that do not vary in strength with time.[5]

Static fields

A static field of one kind does not generate a static field of the other kind unless there is some movement within the field. There often is. Just by walking, or turning around, you generate a time-varying electric field in your body because you are moving unevenly through the earth's magnetic field. The frequencies that have been measured by so doing are in the 0.1–800 Hz range; the effect is extremely weak though.

The flow of ions in the blood is a better example as it may be affected by the strong magnetostatic fields sometimes used in medical examinations.[6] [7]

Some cellular structures in the blood and other parts of the body are magnetically anisotropic and can be aligned by a magnetostatic field, but not at levels people are normally exposed to. Any effect of weaker fields is completely masked by Brownian motion.

Static and near-static fields occur naturally. They are generated by friction in hair and fabrics; changes in the ionosphere in response to solar activity; the movement of ions in the air especially, but not only, during thunderstorms; and by waterfalls, flames, and the earth during earthquakes. These fields can, at times, be very strong.

"Natural" waves

All stars, including the sun, emit radio waves, and the cosmos as a whole is bathed in weak microwave radiation that peaks at 160 GHz. Many marine organisms generate light (bioluminescence), a common and delightful phenomenon around Gabriola as you walk the beach on moonless nights in

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with an MRI machine; on the other hand, depression and suicide is sometimes listed as one possible outcome of exposure to electromagnetic radiation. Epidemiological studies have found little support for either contention.

4 Hz = hertz, one cycle per second. kHz = kilohertz, a thousand (10^3) hertz; MHz = megahertz, a million (10^6) hertz; GHz = gigahertz, a billion (10^9) hertz; THz = terahertz, a thousand -billion (10^{12}) hertz; PHz = petahertz, a million-billion (10^{15}) hertz.

5 The electromagnetic spectrum at low frequencies is classified by engineers as low frequency (LF, 30–300 kHz); very-low frequency (VLF, 3–30 kHz); ultra-low frequency (ULF, 300–3000 Hz); super-low frequency (SLF, 30–300 Hz); and extremely-low frequency (ELF, 3–30 Hz). Anything below 3 Hz is regarded as being static. ELF in health discussions often includes power supply frequencies (50/60 Hz).

6 According to the World Health Organization (WHO) at magnetic field strengths of more than 2 T (tesla) which are only commonly found in MRI units in hospitals. Around the home, fields are usually a million times weaker than this although the earth's magnetic field is around 60 μT (microtesla). A small, cheap, bar magnet has a field of around 10 mT (millitesla), which is hundreds of times too weak to have an effect. The International Commission on Non-Ionizing Radiation (ICNIRP) recommended limit is a very cautious 500 μT.

7 It is however a misconception that static magnets attract the iron in red blood cells resulting in increased circulation. The iron in blood cells is not ferromagnetic.

late summer. The human and other animals' brains and hearts generate electric and magnetic fields—extremely tiny though. They're used in clinical studies and electro- and magneto-encephalographical research.

Low-frequency fields

The strengths of the electric and magnetic fields at distances closer to the source than a small number of wavelengths are dependent on the source and its immediate surroundings. These strengths are not necessarily connected with the power of the source. A very-low-frequency, long-wavelength source may be generating fields that contain lots of energy, but not much of this energy propagates in the form of an electromagnetic wave. The source in these cases is continuously exchanging energy between itself and the space around it, but with relatively little loss. You couldn't transmit electric power over long-distance transmission lines if it were otherwise.[8]

Higher-frequency fields

At a few wavelengths distance from a source—in the far-field—electric and magnetic fields are intimately related by the electric and magnetic properties of free-space.[9] The energy exchange is then back and forth between the two types of field, and their relationship is completely independent of the nature of the source.[10]

Given the power density of a wave, it's a simple matter to calculate the strength of the component fields. The closeness of this relationship, in both time and space, makes it unnecessary to consider a propagating field—a wave—as anything other than what it is, a single entity—an electromagnetic wave.[11]

Properties

All electromagnetic waves are the same; there aren't different *kinds* of wave. Nor are there different *kinds* of electric and magnetic fields. That much is basic physics.

The properties of an electromagnetic wave that are of interest when it comes to health issues are how <u>strong</u> are the fields; what <u>frequency</u> is the radiation; what is its <u>power spectral density</u> (the distribution of power over bands of frequencies); and what is the nature of its <u>modulation</u> (its time-varying amplitude, phase, and frequency), particularly its peak-to-average power ratio. A few might also include its spatial <u>polarization</u>, but this is rarely the case.

Electromagnetic waves can produce currents in the body in the same way that touching a metallic conductor can. The fields have to be pretty strong however to produce "induced shocks", so we won't talk about them, even though for most people a "contact shock" is what first reveals the potential harm that electricity can do.[12]

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8 At 60 Hz, a wavelength is 5000 km, roughly the length of the Great Wall of China.

9 At 100 metres for example, we are talking about frequencies in the high-frequency (HF) short-wave radio band. These days, most communication devices operate at much shorter wavelengths (higher frequencies).

10 There are exceptions. A magnetron in an empty microwave oven for example is both emitting energy into and absorbing energy from the oven cavity much like a very low-frequency source in free space.

11 Physicists contend that electric and magnetic fields are just differing perspectives of the same phenomenon and that the fields are not "in space" but are a local property "of space". It is impossible to produce a space, even by perfect shielding, in which quantum electromagnetic effects do not occur. The Aharanov-Bohm effect that demonstrates this has been observed experimentally.

12 As kids, we used to stun fish in the river by connecting my dad's hand-cranked megger to a roll of immersed chicken wire. Playing daredevil by touching an electrified farm fence with a wet stick was also part of my childhood education.

Power

Power—or more precisely, *power density*—is obviously important because electromagnetic radiation of sufficient intensity burns. It's how microwave ovens work. You can melt metal with lasers.

You can feel the heat generated by electromagnetic radiation at power densities of around 300 W/m^2 (watts per square metre). Burning with prolonged exposure begins at around 1 kW/m^2 (kilowatt per square metre). Instant pain begins at around 10 kW/m^2. And you can cook dinner at around 50 kW/m^2.

Microwaves heat by causing electrically polarized molecules, like water, to rotate, thereby increasing their kinetic energy, which, after friction has very rapidly converted this angular momentum to linear momentum, is what defines their temperature. The effect is known as *dielectric heating*.[13]

All safety standards, no matter how inadequate one might consider them to be, mandate that at least the power in an electromagnetic wave to which human skin is exposed is well below the level at which it can burn, and thus necessarily, well below the power of sunlight. A typical standard is not more than, at most, 10 W/m^2,[14] which is about a hundred times weaker than sunlight on a clear day.

The human body emits and absorbs about 80 watts of infrared radiation, which is roughly 40 W/m^2, so I suppose strict observance of some safety standards would mean we couldn't hug each other. But don't worry—it's okay so long as you keep the radiation up above 300 GHz.

Cell phones differ in the power they transmit, but it's usually about a watt. Simple arithmetic says 10 W/m^2 is the density at about 90 mm (3½ inches) from such a source.

Distance

The power density of an electromagnetic wave is dependent on its distance from the source. In a few instances, the density falls only slowly with distance. Examples are laser beams, microwaves focussed by parabolic antennas,[15] and radio waves that are guided by the ionosphere.[16] In most instances however, the density falls fairly sharply with distance from the source.

There are two reasons for this. One is that as a wave moves away from its source, the area over which the wave is dispersed is increasing as the square of the distance. This is the basis of the rule-of-thumb that doubling the distance from an isotropic source reduces the "strength" by a factor of four (2^2). The second reason for a falling power density is that sources that are not intended to radiate are often a mixture of two equal and opposite sources—two wires

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[13] One might anticipate slight differences in the effects of dielectric heating and other forms of heating, and some meticulous chemical researchers have indeed found such differences in the laboratory. The differences though are very slight, are usually only apparent at high power levels, and do not occur in liquids. None of the differences have been linked to health issues. As a means of cooking from the health perspective, microwaving falls between boiling and baking with frying and grilling off the "bad" end of the scale. This is primarily because microwaving doesn't generate so many hot spots in the food (the ones that make the food taste better while creating potential carcinogens).

[14] The corresponding electric field is 62 V/m (volts per metres), which is about half the "natural" atmospheric background for electrostatic fields in fair weather. The corresponding magnetic field is 0.2 μT.

[15] There is almost no emission below a microwave dish antenna. They are carefully engineered not to waste power.

[16] The electric and magnetic field close to a source both follow the inverse square law, but in a propagating wave distant from the source, it's the power that does this, not its individual components.

in a power supply cable for example. The field generated by such sources is only a residual field due to imbalance, and it may fall off as much as the distance cubed.

The most effective protection against exposure from power appliances and house wiring, if that's a concern, is simply to move a few metres away.[17] Field strengths rapidly become small. Power transmission line fields become comparable with background levels at around a hundred metres, and staying at arm's length from a modern microwave oven will ensure your exposure is only a fraction of what is even conservatively considered unsafe.[18]

The new flat-screen LCD computer monitors produce significantly less radiation than the old CRT monitors. All you have to do to keep radiation exposure levels negligible is keep your nose off the screen.

To illustrate the strong dependence of power levels on distance from the source, someone (not me) has calculated that standing 50 metres away from a telephone tower exposes you to 5000 times less radiation than putting a cell phone an inch from your ear. That sounds just about right to me and is one of the reasons I don't own a cell phone.

Frequency

The frequency of an electromagnetic wave may be significant for several reasons, but by far the most important of these is that the energy of the individual photons (quanta) is directly proportional to the frequency. This energy of a photon does not depend on the power of the wave. A photon of light for example contains roughly a million times more energy than a photon of a typical radio wave.[19] And this is true no matter how weak the light, or how powerful the radio transmitter.

Severe damage to individual complex organic molecules begins in earnest at frequencies at the upper end of the ultraviolet-A spectrum, at roughly 950 THz. From the perspective of a complex molecule, being hit by a photon of blue light and by a photon of microwave radiation is the difference between being hit by a hefty SUV and being hit by a ping-pong ball.

Non-linearities (distortion) in exposed tissue always create harmonics of the incident radiation, albeit at lower power levels than the fundamental frequency. These always have to be considered when assessing potential hazards.

Penetration

Frequency determines how deep into the body waves penetrate. At very-low frequencies the body is transparent and the radiation reaches all parts of the body, but is only partially absorbed. At the upper end of radio frequencies (lower end of microwave frequencies) around 1 GHz, radiation penetrates a few centimetres. At the frequencies of visible light, the body is opaque. X-rays and gamma rays on the other hand pass right through us.

Limiting the rate of absorption of electromagnetic energy per unit mass of exposed tissue (the *specific absorption rate* or SAR measured in watts per kilogram) is the objective of most safety standards. In Canada, the limit is set for the public at approximately 50 times less than the rate that the scientific consensus contends that there is a possibility of an adverse health

[17] The highest magnetic fields are generated by ovens, ceiling heat, and refrigerators. Some brands of electric blankets generate high exposures when inadvisedly switched on in bed—but there has been no experimental evidence of increased health risk.

[18] With the proviso that the oven is in good working order with no damaged doors or door seals.

[19] Yellow light = 545 THz and a radio wave is, say, 545 MHz, a ratio of a million to one. Visible light ranges from 400 THz (red) to 750 THz (violet).

effect. Exposure limits are also defined by maximum field strengths.

Most electrical devices easily comply with this standard. A common cause of high field strengths in domestic environments is incorrect wiring.[20]

DNA effects

Because I'm not a bio- or organic-chemist, I had, before composing this piece, imagined that because a warm human body has a temperature of 37°C, photons of infrared light that are freely emitted and absorbed by anything at that temperature posed no threat to DNA. Just to check that this was true, I looked up the binding energy of a hydrogen bond, which is a common but relatively weak chemical bond in large organic molecules. The answer seems to be in the range 0.05-0.3 eV[21] (12–72 THz). This was a surprise, because if you work out the photon energy of the infrared radiation in which the body is naturally bathed by virtue of being alive, it works out to 0.08 eV (18 THz). This is not well below that of a hydrogen bond, but within its range.

A little more time spent revisiting my basic chemistry showed my alarm was unfounded. The myriad chemical reactions that go on in our bodies all the time wouldn't happen if the thermal photon energy were less than the reactants' activation energies. None of us dies merely as a consequence of being pleasantly warm, but cold can kill.

Covalent bonds are stronger than hydrogen bonds, being roughly in the range 2–5.6 eV for simple bonds involving carbon, oxygen, nitrogen, or hydrogen. For the more complicated bonds in DNA, I've seen figures in the 4.5-8.7eV range, which translates to photon frequencies, as one might expect, in the near ultraviolet (1-2PHz).[22]

DNA damage and repair

Googling Wikipedia once again, which is as far as my knowledge in this particular area goes, showed that my image of how strands of DNA pass their time is wrong. They don't quietly reside unmolested in the nucleus of a cell with only the occasional sub-atomic particle from outer space (cosmic ray) or from radioactive decay in the rocks of the earth to watch out for.[23]

DNA can be damaged by violet, and ultraviolet light; elevated temperatures; industrial chemicals, especially aromatic compounds; the plant toxins we talked about earlier; viruses; and some by-products of normal metabolic processes (electron acceptors or oxidants and free radicals). The good news is that at visible and near-visible light frequencies, the damage that a photon can inflict has been observed to fall off exponentially with decreasing frequency (moving from blue to red and on into the infrared).

While the amount of damage suffered in the "natural" world might be small in terms of

[20] Specifically, reversal of the polarity of single-phase wiring. One of the two wires is "neutral" meaning that it is grounded at a remote location by the utility; the other is "hot" meaning that it is at close to the full voltage (110V) above ground. Interrupting either of the two wires will switch the power off, but if the "hot" wire is not the wire being disconnected, as it should be, it will go on generating an electric (but not magnetic) field beyond the switch. I always have to be careful about this because in Canada, the hot wire is black, whereas in the UK where I first dabbled with electricity, it was the neutral wire that was black. Some sockets won't accept a polarized plug and a common remedy is to snip the larger plug pin down to size making it easy to plug it in either way, including of course the wrong way.

[21] eV, 1 electron-volt = 1.6. 10^{-19} joules.

[22] Extreme-UV begins at 3PHz and soft X-rays at 30 PHz.

[23] I don't suppose people wear radioactive glow-in-the-dark watches any more. It was fun waving these at Geiger counters in physics classes at school and listening to the click rate soar.

the number of DNA strands in a body, the damage is sufficiently significant for the process of natural selection to have favoured organisms that have evolved DNA repair mechanisms. These sophisticated mechanisms and their effectiveness are far from being completely understood, and so can complicate the results of experiments to determine what and how much damage to DNA radiation does.

One of my favourite findings reported in the scientific literature was that exposing a cell to harmless red light before exposing it to ultraviolet light resulted in the DNA fragmentation being much lower than without pre-irradiation. The researchers' interpretation of this effect was that the pre-irradiation by red light, while doing no damage, pre-activates enzymes of the DNA repair machinery and these immediately repair the subsequent damage by the ultraviolet. This is typical of the surprises one gets when "doing science".[24] Perhaps getting up at dawn to watch the sun rise is healthier than sleeping in. This effect may also be behind the observation that cell phone radiation improves, not impairs, the cognitive performance of mice that are developing Alzheimer's-like symptoms.

Power spectral density

The coherence of the electromagnetic radiation may also be significant when it comes to non-thermal effects (which I'll be talking about soon). A coherent sound wave is a pure tone. The analogy in electromagnetic terms is a single-frequency signal, known as a carrier wave (CW), or a "pure" colour—the monochromatic orange light at 509 THz from a sodium lamp for example.

Although fields generated by domestic appliances are mostly single-frequency (60 Hz), some loads are non-linear and generate harmonics with frequencies of several kilocycles and these can become significant sources of induced currents.

The radiation produced by lasers is approximately single frequency, but again non-linear effects and multiphoton absorption can generate harmonics, though not significantly. The probability of an atom absorbing two or more photons at the same time, thereby doubling or more the received energy, falls precipitously with the number of quanta involved.

Analog and frequency modulated radio waves (AM and FM) are single-frequency CW sources whenever there is no sound being transmitted.

Single-frequency signals usually have a high spectral power density, even though they might be weak compared to the broadband background signals.[25]

Resonance

One of the concerns with single-frequency sources is the enhancing effect of resonance. Everyone is familiar with the resonance of sound in enclosed spaces. The human body as a whole resonates electrically at around 70 MHz in the very-high frequency (VHF) band. Smaller cavities, and of course smaller bodies when it comes to thinking

[24] Another aside—just to illustrate how difficult some biological experiments are—is that experimenters looked at the degree of DNA damage in the brains of rats that had been killed in different ways. The differences were substantial, and enough to mask their attempt to observe DNA damage in the animals' brains after exposure to microwave radiation.

[25] In general, to be useable for communication purposes, the power spectral density of a "manufactured" wave has to be greater than that of natural sources, but this is not always true. By exploiting the fact that a manufactured wave has known coherence and natural waves, being random, don't, it is possible to communicate using signals that are weaker than the natural background, but this is not usually the case.

about children or even individual cells, resonate at higher frequencies.

The "enhancement factor" of a resonance (known as the "Q" among engineers) is rarely more than ten in non-metallic enclosures because the stored energy turns to heat and is lost. The possibility of resonance has to be considered when setting standards, but there is no experimental evidence that significant resonance absorption occurs in biological tissue, nor would one expect there to be.[26]

Modulation

Modulation, with one exception, is perhaps the least important of all the properties of an electromagnetic wave. All modulation, and particularly digital modulation, spreads the spectrum of the signal and makes it more like random or thermal background noise. The exception is pulse modulation, as used for radar and some lasers. The energy in a short pulse may be very high, even though the average power is low.

Because of the non-linearity of the electrical properties of the body, modulation creates electrical signals in exposed tissue at the frequency of the modulation, so, for example, an amplitude-modulated microwave can also be a source of lower than low-frequency voltages and currents in addition to those at the microwave frequency.[27]

Non-thermal effects

As used in the literature on health issues and electromagnetic radiation, a *non-thermal effect* is any biological interaction with an electric or magnetic field that is not due to heating. It is also invariably understood to exclude ionization. The *microwave effect* is any conjectured non-thermal effect at obviously microwave frequencies.[28]

Although we tend to think of our bodies in biochemical terms—at least some of us sometimes do—they also have electrical attributes, the nervous system being the most obvious example of what's called *bioelectromagnetism*. One could even say that all biochemical reactions are essentially also electrical in that they involve the re-arrangement of electrons in the outer shells of atoms and molecules. Electro-osmosis is just one of several electrochemical effects in biological material.

The unanswerable question

Given that there are many ways that the application of an external electric or magnetic field, or electromagnetic wave *might* change what is going on inside us, the question is, are any of them harmful at levels below those set by safety standards based only on thermal effects?

This is unfortunately an unanswerable question. One can only frame the answer in terms of probabilities. Even if diligent researchers went through every bioelectromagnetic interaction they knew and assessed its danger level—a practically impossible task in itself because of the sheer number of interactions and the complexity of both biological systems and the properties of waves—there would always remain the

[26] Mechanical resonances would not be expected because biological tissue is immersed in viscous fluid that damps any motion. Resonance is however not the only factor involved; electric fields can become locally strengthened at dielectric boundaries.

[27] How times have changed. The journal IEEE Transactions on Microwave Theory and Techniques was in my day something only engineers read with their mid-morning coffee. I see in a 2004 edition a paper, *Computational modeling evidence of a non-thermal electromagnetic interaction mechanism with living cells: microwave nonlinearity in the cellular sodium ion channel*.

[28] Rather conveniently, the cells of all living organisms, including bacteria, release heat-shock proteins in response to thermal stress so detection of these proteins is an indication, that the response being observed is likely, at least in part, thermal.

possibility of an interaction of which nobody was aware.[29]

In addition to this, there exists the possibility that an interaction exists that has no threshold, that is, no matter how low the exposure to electromagnetic radiation, there remains a non-zero probability of damage. Radioactive radiation and exposure to chemical carcinogens are examples of this. What's safe then becomes a matter of opinion, or is determined more objectively by computing the risk and comparing it with other types of risk, like breathing car exhaust fumes for example, or walking beneath the roof of the Malaspina Galleries.

And another problem—boy are there a lot of these—what if the interaction is cumulative? You can't observe the damage done by twenty years of exposure to technology that's less than twenty years old. You can of course draw inferences, an obvious one being that if ten years of exposure causes no damage, twenty years of exposure at less than half the intensity probably won't either, particularly if you can't identify any mechanism for "memorizing" the effects of previous exposure. Inferences as to what will happen in the future nevertheless can always be wrong, no matter how unlikely.

Science can prove probabilities, but not provide certainties; an unenviable position compared with that of some its critics who in an effort to control opinion happily provide certainties with no proof at all.

Compounding this already complicated question is the fact that practically all interactions between low-level electromagnetic fields and ourselves are unobservable without instrumentation. So—electric fields can make the hair on your skin stand up; charged doorknobs can create a tingle; but what else? It's very difficult to make a list of any length.[30]

Do non-thermal effects make radiation dangerous?

One thing one can say right off the bat is that although there may be hidden dangers in low-levels of exposure to electromagnetic radiation, they must be pretty weak. People have been using electricity for over a century, yet, in poorer regions like parts of Asia, Africa, and South America, there are populations who (even today) use no electricity at all. If normal levels of electromagnetic radiation were indeed harmful to the body, then we would see a readily observable correlation between electromagnetic-induced illness and geography. Despite what may be claimed by some sources on the Internet, the scientific consensus is that there is no such correlation, and clear evidence of physiological damage caused by electromagnetic radiation is lacking even in the most industrialized regions.

Telecommunications workers, people who work with radar as ferry and airport workers do, or work on high power transmission lines in the field or in power utility research and testing laboratories are not falling sick in any palpable way. If there were a significant interaction between the human body and a weak field, it would be easy to

[29] Some even make the task of researchers even harder by postulating non-thermal "window" effects. Window effects only occur in a narrow range of power levels, so they can actually get worse if the power of the radiation is reduced. No such bizarre effect has been reliably observed.

[30] Rats very interestingly appear to be able to "hear" microwaves, but only when pulsed. This has to be an example of demodulation by non-linearities. A plausible explanation is that "the microwave pulse, upon absorption by soft tissues in the head, launches a thermoelastic wave of acoustic pressure that travels by bone conduction to the inner ear. There it activates the cochlear receptors via the same process involved for normal hearing". The same effect occurs in humans but only at radiation levels above those allowed by safety standards.

demonstrate, and there would be no controversy over its existence.

Studying possible non-thermal effects

Studies of possible non-thermal or *athermal* effects can be broadly categorized as:

- *physiological*—the study of the mechanical, physical, and biochemical functions of animals or;
- *epidemiological*—the study of factors affecting the health and illness of animal populations.

Physiological studies include studies at the cellular or even sub-cellular level, *in vitro* studies of biological tissue, and some *in vivo* experiments with live animals and volunteers. It's rare that a physiological study can say what effect on general health, if any, an observed effect may have, but it may be the source of explanation of the results of an epidemiological study.

Epidemiological studies are observational and are aimed at identifying statistical relationships between exposure and illness, particularly cancer—they lie at the "effect" end of the cause-and-effect spectrum.

It is difficult to draw definitive conclusions about causality based on statistics. Exposure levels are not easy to assess as people go about their daily business, and it's not possible to rule out completely every last confounder, particularly if a relevant variable cannot be measured. Illnesses that are hypothesized as being a consequence of exposure to radiation practically always have other possible causes, not all of which are known.

One of the pages of my (electronic) notebook is devoted to a list of all the diseases that have at one time or another been attributed to electromagnetic radiation. The list is now over 50 items long and begins: "Alzheimer's disease, anxiety, asthma, birth defects, blood pressure increases, brain cancers and tumours, burning sensations, chemical sensitivity, chronic fatigue……" and so on, concluding with "…..sleep disorders, suicide, testosterone reductions, thyroid cancer, and tinnitus".[31] According to a register kept by the Australian Government, the most frequent complaints at the time of writing were headaches, body pain, dizziness, burning sensations, and quote "lethargy", probably meaning chronic fatigue.[32]

Statistical techniques for multivariate analysis have improved greatly in recent years; however, economists who use them have found only recently that establishing causality using what they call *the method of instrumental variables* can easily mislead. It has been demonstrated that depending on what seemingly reasonable, but different, choices of variables you include in your analysis, you can reach no conclusion, or

[31] With surprise, I read in the July 31, 2009, Flying Shingle that Dr. Magda Havas in her talk on the island had added no less than seven more, namely, "…difficulty concentrating, irritability, visual disturbances, dizziness, loss of appetite, nausea, and movement difficulties". This is interesting because when somebody with these symptoms recently put a post on the Internet as to what the cause might be, the answers were lactose intolerance, arsenic poisoning, fibromyalgia, mononucleosis, haemochromatosis, sinus infection, chronic fatigue, cancer, and others, but not exposure to radiation. I finally traced her list to a health survey carried out in Spain in 2004. This survey has since been heavily criticized on the basis that the participants were self-selected and so could be expected to include an unrepresentative number that were biased in their perceptions.

[32] Chronic-fatigue syndrome, or myalgic encephalomyelitis (ME), sometimes appears to be malingering, but some recent research suggests it does have a biological basis. Its roots appear to be genetic, but what triggers it is usually a mystery; there appear to be many causes including exposure to certain viruses and other infectious diseases. Sufferers are often in their 20s and 30s, and more women are affected than men. There are no studies supporting a causal relationship with radiation.

you can reach two different conclusions that contradict each other. Also, advances in the study and identification of carcinogens have shown that older epidemiological studies were sometimes flawed by an inadequate accounting of the possible correlates involved.

One, at the time much cited, study in the late 1970s, purported to demonstrate that electric utility workers were three times as likely to suffer from leukemia as the general population, with the implication that exposure to electromagnetic fields might be the cause. A subsequent follow-up study found that these same workers were also being exposed to *benzene* solvents, a variable not considered in the original work. *Benzene*, unlike electromagnetic radiation, is a confirmed cause of leukemia.

This is, however, I hasten to add, far from being the end of investigations into electric utility workers' occupational health, but it indicates that the conclusions of older studies need to be read with care, and older citations need to be checked and not unthinkingly promulgated as they often are.

Information

Apart from scientists and experts working on, interested in, and able to read the technical stuff, the most comprehensive sources of information—"disinformation" if you believe in conspiracies—is mostly from government and professional institutions.

For me—and I'm not a lifelong avid researcher of this topic—sources include the World Health Organization (WHO) and the various national health and other authorities who contribute to their reports; in the UK, the Health Protection Agency, National Radiation Laboratory; in the US, the National Institutes of Health and the National Institute of Environmental Health Sciences; in Canada, Health Canada and the Royal Society of Canada; and others.[33]

Adding to these sources are independent groups such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[34] and the Bioelectromagnetics Society (BEMS).

Sources of information that are particularly critical of "mainstream" sources tend to be, in my limited experience, from groups of independent scientists such as the Bio-Electromagnetic Research Initiative (BEMRI); and from outspoken contrarians with scientific qualifications such as the late-Dr. Neil Cherry and Canada's Dr. Magda Havas; and from various interest groups, the California Council on Wireless Technology Impacts, to give a randomly chosen example. Numerous references to these and other individuals and groups with similar views are to be found echoed on the Internet.[35]

Mainstream views

The vast majority of institutional sources currently take the position that: "years of research have not produced convincing scientific evidence to suggest that exposure

[33] Including the American Cancer Society; British Medical Association; Director General of Health of France; Electric Power Research Institute; European Commission's Scientific Committee on Toxicity, Ecotoxicity, and the Environment; Health Council of the Netherlands; Institute of Electrical Engineers; International Agency for Research on Cancer; Swedish Radiation Protection Authority; and Australian Government.

[34] ICNIRP is a non-profit making organization registered in Germany. It is a body of independent scientific experts, not employed by industry, covering epidemiology, biology, dosimetry, and optical radiation. It also uses consulting experts in other specialities.

[35] "Gabriolans for Environmental Awareness" is a group that only promulgates the views of critics of mainstream opinion.

to low-level electromagnetic fields causes any short- or long-term health effects".

The WHO for example has concluded:

> In the area of biological effects and medical applications of non-ionizing radiation approximately twenty-five thousand articles have been published over the past thirty years.
>
> Despite the feeling of some people that more research needs to be done, scientific knowledge in this area is now more extensive than for most chemicals. Based on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low-level electromagnetic fields. However, some gaps in knowledge about biological effects exist and need further research.

The Royal Society of Canada's Expert Panel[36] reaches similar conclusions, but perhaps put a bit more emphasis on those "gaps":

> All of the authoritative reviews completed within the last two years [2003] have concluded that there is no clear evidence of adverse health effects associated with radio-frequency (RF) fields.
>
> At the same time, these same reviews support the need for further research to clarify the possible associations between RF fields and adverse health outcomes that have appeared in some reports.

These extracts are a bit dated now [September 2009], but most recent reports and research simply reinforce these conclusions.

> [WHO Fact Sheet 304, 2006] Considering the very low exposure levels and research results collected to date, there is no convincing scientific evidence that the weak RF signals from base stations and wireless networks cause adverse health effects.
>
> [WHO Fact Sheet 322, 2007] A number of other adverse health effects [other than childhood leukemia] have been studied for possible association with ELF magnetic field exposure.[37] These include other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioral effects, and neurodegenerative disease. The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukemia. In some instances (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them.
>
> [Institution of Engineering and Technology, Biological Effects Advisory Group, 2008] BEPAG has concluded that the balance of scientific evidence to date does not indicate that harmful effects occur in humans due to low-level exposure to EMFs. This conclusion remains the same to that reached in its previous position statements, the last being in May 2006, and has not been substantially altered by the peer-reviewed literature published in the past two years.
>
> [Health Canada, May 2009] Health Canada has conducted its own research to determine whether RF energy could cause damage to DNA or changes to certain genes. The exposure levels used in these studies included those that were well above the limits specified in Health Canada's RF exposure guidelines. Based on Health Canada's research, no effects from RF exposure were seen.

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[36] Their Expert Panel is made up of independent experts from the fields of biomedics, biochemistry, biology, medicine, behavioural science, environmental and occupational health, epidemiology, physics, and pharmaceuticals.

[37] Extremely-low frequency (ELF, 3–30 Hz) is commonly used in health discussions to mean 1-300 Hz thereby including power supply frequencies (50/60 Hz).

[SCENIHR, Feb. 2009] Today, the European Commission's independent Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) publishes its opinion on possible health effects of electromagnetic fields (EMF). Due to rapid technological advances and new scientific research, the Commission asked the Committee to update its opinion from March 2007. The update considered more than 200 new scientific papers yet the conclusions differ little from the earlier opinion. Based on current evidence the main conclusions remain that radio frequency fields used in wireless communication technologies are unlikely to lead to an increase in cancer in the human population at large. However, further studies are needed to clarify if long-term exposure to mobile phones (well beyond 10 years) increases cancer risk for an individual using a mobile phone frequently and to examine the effects on children.

Childhood leukemia

Possible health effects of exposure to electric and magnetic fields has been going on for decades, and while the great majority of studies have shown no link between radiation exposure and a variety of maladies, several key epidemiologic studies have caused expert scientific panels to conclude that there is indeed a worrying statistically significant association between power-frequency magnetic fields and the development of childhood leukemia.[38]

[38] To be more precise, the US National Cancer Institute says: "A study in 1979 pointed to a possible association between living near electric power lines and childhood leukemia. Among more recent studies, findings have been mixed. Some have found an association; others have not. …Currently, researchers conclude that there is limited evidence that magnetic fields from power lines cause childhood leukemia, and that there is inadequate evidence that these magnetic fields cause other cancers in children. Researchers have not found a consistent relationship between magnetic fields from power lines or appliances and childhood brain tumors."

This epidemiological evidence has however not been supported by laboratory studies. Researchers have found no link between development of leukemia and exposure of animals to magnetic fields well above that permitted by the usual standards, and cellular *in vitro* studies have not provided a convincing explanation of the nature of any link. Despite this, the statistics appear to be sound.

Some years ago, University researchers in the UK came up with the rather ingenious hypothesis that perhaps power transmission lines were attracting aerosols carrying chemical pollution or perhaps radioactive decay products from naturally occurring cosmic rays and radon gas, but experiments failed to back this up. At the time of writing, the hypothesis is considered an unlikely contributor to the increased risk ratios encountered in the epidemiological studies.

A second hypothesis, I believe still being researched, is that it is not magnetic fields that are doing the damage, but the weak currents that they induce in household plumbing, and hence flowing through a child using, say, a bathroom tap. It remains a challenge to researchers and health theorists to sort this out. Childhood leukemia is thankfully not common.

Electrosensitivity

Some people report hypersensitivity to weak electromagnetic fields, but extensive research has shown that it is unlikely that any such effect exists.[39] The symptoms described by "electromagnetic hypersensitivity" sufferers can be severe and debilitating; however, despite well-performed trials with many hundreds of

[39] No new studies support a causal relationship between ELF fields and self-reported symptoms such as headache, fatigue, dizziness, concentration difficulties, or well-being. [SCENIHR, Feb. 2009].

individuals, nobody has managed to show in double-blind experiments that exposure to electromagnetic radiation, as opposed to sham exposure, triggers these symptoms, nor has anyone been found who demonstrated an extraordinary ability to detect weak radiation.

Given that the symptoms are the same as, or very similar to, those caused by stress, practically all the scientific researchers conclude that they are triggered by the perception that radiation is present rather than by its actual presence. The claimed sensitivity seems to be a *nocebo* effect, which, like its opposite the *placebo* effect,[40] remains a phenomenon that eludes explanation by neuroscientists and philosophers of mind alike. Finding someone who *was* hypersensitive and consistently showed physiological symptoms would be an enormous step forward in research into the links between health and exposure, and it may happen, but it hasn't happened yet.

Risk

Risk is a well-defined quantitive term used by engineers particularly. The risk ascribed to an event is the product of the probability of it occurring and the severity of the consequences should it occur. The more unlikely an event, and the lower the severity of its consequences, the less risk it poses. Conversely, the more likely an event, and the higher the severity of its consequences, the more risk it entails.

Risk, so measured, has to be balanced with benefits. Life's like that. If one didn't run the risk of breaking a leg, or exposing oneself to ultraviolet radiation, one would never experience the joy of skiing down a high mountain on a sunny day in spring.

The most difficult cases of risk assessment are those where one or other of the terms is very large and the other is very small. Multiplying a very large number by a very small one inevitably produces a number that is ill defined. For example, the probability of the earth being hit by an asteroid or comet is extremely small, but the consequences would be catastrophic, making it difficult to arrive at a numerical estimate of the risk that everyone can agree with.

Some of the risk associated with exposure to electromagnetic radiation is in the same category. Even though it appears improbable that long-term exposure to low-level radiation eventually causes, say, cancer, the consequences would be, if it did, as some commentators point out, disastrous. Applying the "precautionary principle" however isn't necessarily the answer if the risks are outweighed by the benefits. Driving a car is risky, but few are willing to give up driving for that reason alone. Turning left at an intersection is far more dangerous than three turns to the right, but we don't all drive round the block all the time. There's also not many people I know who worry about their increased exposure to ionizing radiation when boarding a plane.

It is of course well known and accepted that people's perception of a risk is often different, sometimes wildly different, from what the statistics say, and research into this turns up some fascinating facts. One study, for example, showed that people will accept risks a thousand times greater if they are voluntary than if they are involuntary—personal control of the risk-taking is a big issue. Another showed that, as one might

[40] One anecdote going the rounds is that when a cell tower went up near Humboldt State University, the local newspaper asked people what they thought of it. Some said cell phone reception was better, others that the tower was affecting their health. It was only later learnt that the tower was not yet operational. Such "jokes" exploit the stigma attached to not-understood mental and psychiatric disorders that dates back to at least medieval times. Poking fun may sometimes be at the expense of people who suffer, but then some claims are truly ridiculous.

anticipate, risks that are understood are judged less serious than those that aren't. Also, people assess risks to be lower when they are in a positive emotional state.

In 2001, the WHO rated electromagnetic radiation as a Class 2B risk, "Possibly Carcinogenic to Humans", the lowest level of risk in the International Agency for Research on Cancer (IARC) scheme. This was based on the small but statistically significant association between radiation and childhood leukemia discussed earlier.

Examples of the IARC's risk rating system are:

Class 1—Carcinogenic to humans: tobacco, asbestos, X-rays, soot, alcoholic beverages, arsenic, benzene, silica (as fine dust)

Class 2A—Probably carcinogenic to humans: formaldehyde, diesel exhaust, UV radiation, high-temperature frying, wood smoke

Class 2B—Possibly carcinogenic to humans: coffee, potassium bromate (used in bread-making but banned in Canada), pickled vegetables, gasoline engine exhaust, welding fumes, and electromagnetic fields.

Bottom lines

First off, it is silly, I think, to be at either end of the spectrum of opinion on the effect of radiation on health. To maintain that all "manufactured" radiation is safe, and that, despite the electrical complexity of biological organisms, there are no biologically "significant" interactions between it and weak fields is unscientific. Until we look we don't know and looking can take a lot of time. Nature is full of surprises, and what is "significant" may turn out to be something one can only assess statistically and hence subjectively. Not only that, we cannot even be sure that the assumption that any "significant" interaction will be harmful is true. There might be benefits to exposure for all we know.

On the other hand, to maintain that all "manufactured" radiation is unconditionally dangerous simply is not what has been observed. Given the time and number of researchers that have looked at this, an "educated hunch" is that this is unlikely to change in the future. It makes sense though that if measures for reducing exposure can be taken at reasonable expense, an effort should be made to do so.

In my view, one aspect of the controversy frequently remains unrecognized and unaddressed, and that is the issue of control over one's personal environment. My neighbour cannot impinge with impunity upon my right to an environment free of noise, smell, unsightliness, or smoke; yet, there is nothing to stop one person flooding another with electromagnetic radiation. That it is probably harmless is beside the point. When somebody wants to put electric and magnetic fields inside my head, I'd like to be consulted.

And finally, rather than poking fun at the sometimes absurd claims of self-proclaimed electrosensitive individuals, we should chide the scientific community for lack of neurophysiological research that might also shed light on this and other stress conditions, posttraumatic stress disorder for example, and that might even contribute to the solution of the perplexing philosophical question as to the relationship between states of mind and physiological health.

I'll shut up now. Much has already been written on this topic. I'm inclined to the view that we should be more concerned about the many new and exotic chemicals that are migrating deeper and deeper into our environment, perhaps more insidiously than electromagnetic radiation from computers, toasters, and the spark plugs in the car ever did. ◊