Explainer: what is the electromagnetic spectrum?

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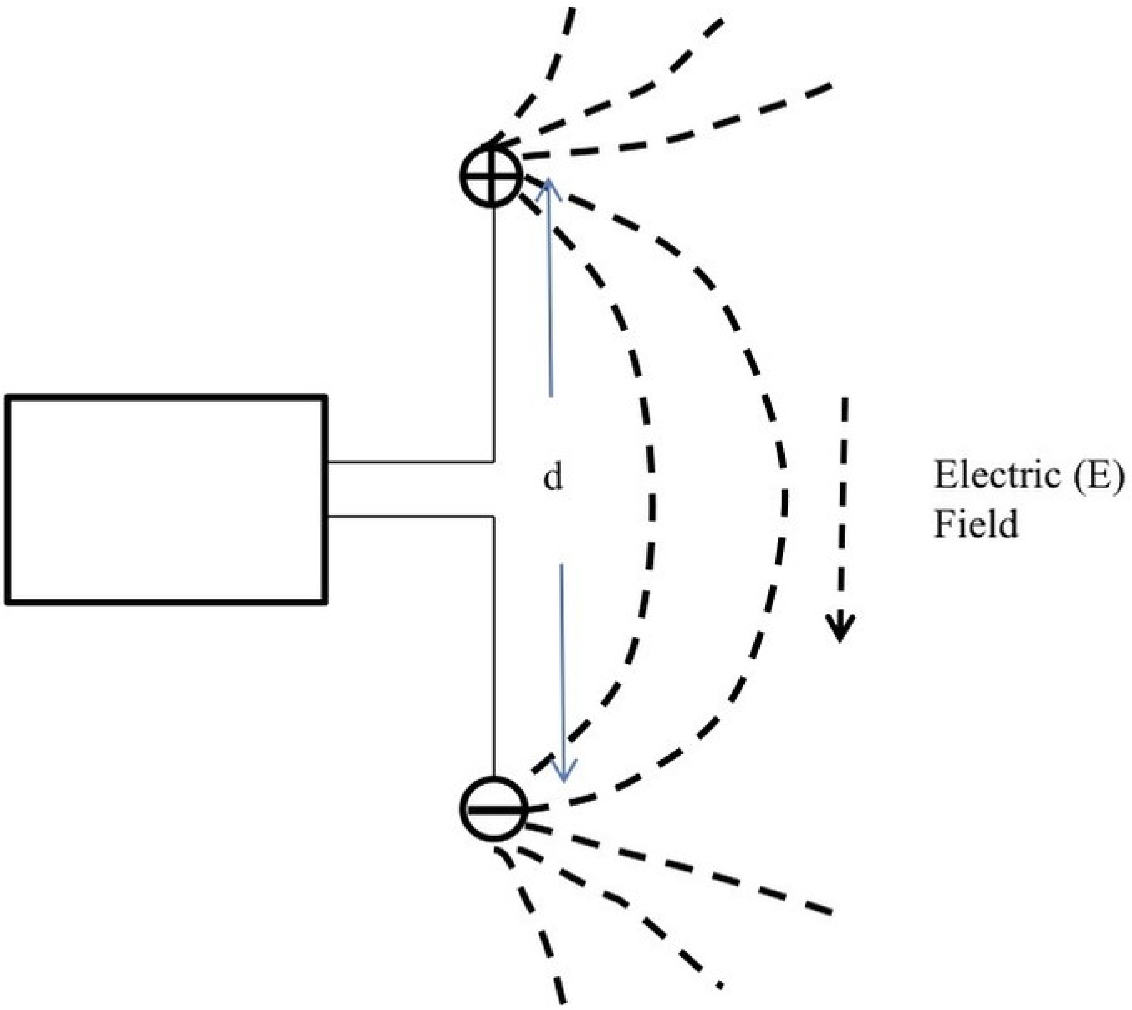
Visible light forms part of the electromagnetic spectrum. So do emissions from TV and radio transmitters, mobile phones and the energy inside microwave ovens.

The X-rays used in diagnostic imaging and the materials used in advanced positron emission tomography scanners (PET) also form part of this amazing range of radiations which share some features in common.

Why electromagnetic?

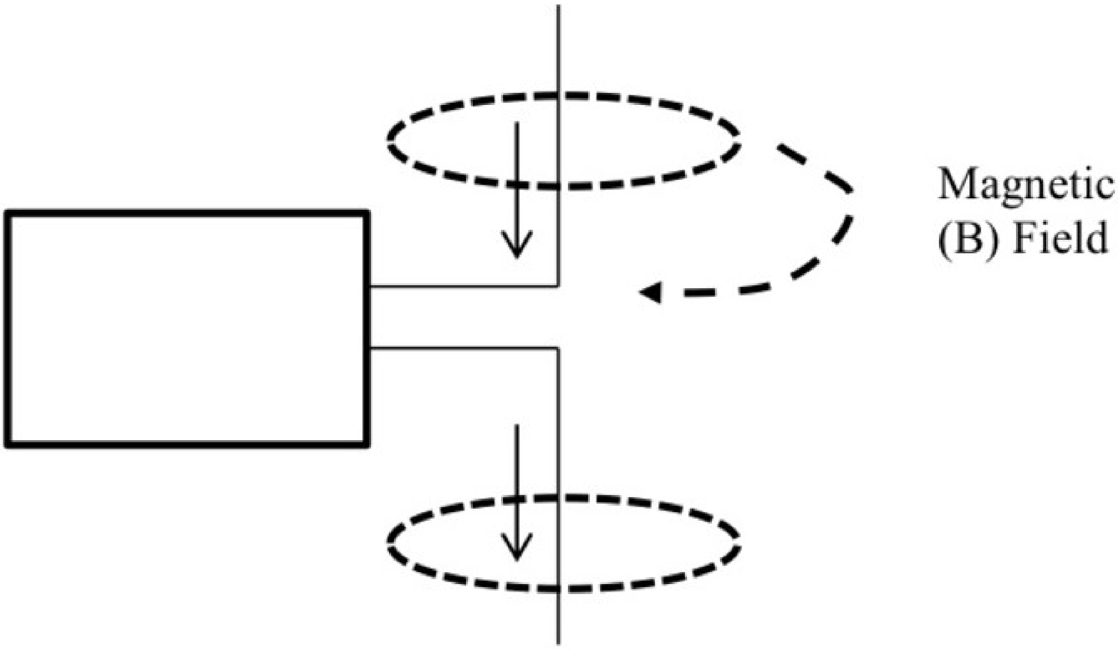
As the name implies, they have electric and magnetic fields associated with them. Although it is a bit complicated to demonstrate these fields in the case of light and X-rays, it is quite easy to picture with radio-waves.

Consider the wires shown below, in which an electric charge has been placed at the tips as shown (don't worry about the technicalities – it's a bit like the static charge that appears in dry hair when combed vigorously).



Electric field (E) due to positive and negative charge separated by a distance (d). Andrew Wood.

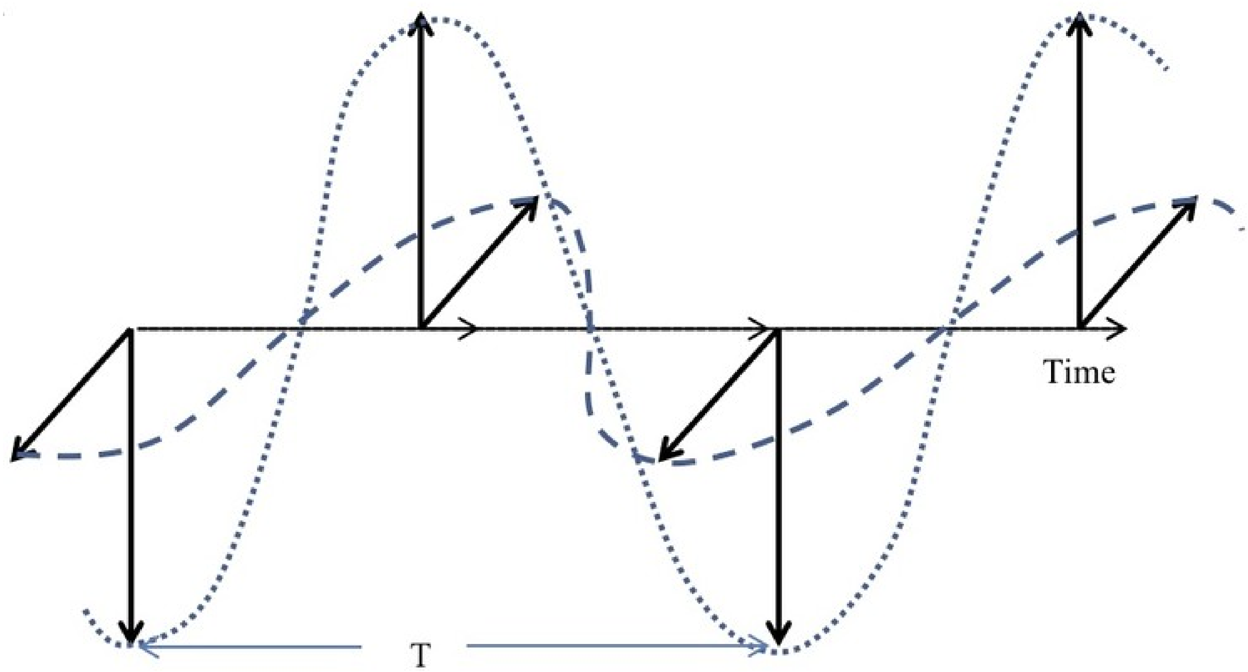
This pair of charges (plus and minus) sets up an electric field, with the imaginary field lines shown. If now the charge is allowed to flow along the wire, this will set up a magnetic field as shown by the concentric circles.



Magnetic field (B) due to the flow of electric charge along the wires. Andrew Wood

A long way away from this arrangement (which is called a dipole antenna) the electric and magnetic fields are at right angles. If the charge generator alternates between having plus and minus at the top, the field direction will also alternate, as shown, with a time period T between positive-going peaks (1 cycle).

Since the generator has to do work to alternately put charge one way and then the other, this work (energy) is constantly streaming from the wires, out into the surrounds.



As the charge alternates between positive to negative at the upper wire in Figure 1, the direction of the E and B fields alternate with a smooth transition ("sinusoid") between the positive and negative peaks. The distance in time between two successive similar peaks is called the "period" T. Andrew Wood

This is why it is called "radiation", because it is radiating outwards. In fact, at a particular point, the fields will appear to be moving past at a particular speed.

This speed is the velocity of light (which in vacuum is 3×10^8 m/s, or 300,000 km/s). Even if the electromagnetic waves are invisible radio-waves or X-rays, for example, they still go at this speed. The energy spreads out over a larger and larger area as it moves away from the source, often the same in all directions.

In this case, the area it spreads over is the area of a sphere ($4 r^2$), thus there is an "inverse square law" of energy density, since for a particular area (1 cm^2, say) the energy falls by a factor of $1/r^2$.

The other thing to notice is that if the wave is travelling at the speed of light (c) and the time for 1 cycle is T, then the length of 1 cycle (wavelength) is c x T. The table below shows the wavelengths of typical forms of radiation.

Why spectrum?

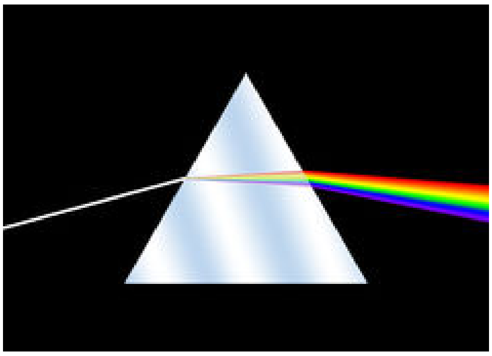


Diagram of a dispersion prism. Wikicommons

A spectrum is what you get by passing light through a glass prism – the white light is split into its component colours.

Imagine a magic prism which could do this for the entire range of electromagnetic waves. Such a device does not exist, but if it did, wavelengths ranging from thousands of kilometres (Extremely Low Frequency or ELF) through to sizes smaller than an atom would be produced.

For the radio-frequencies, there is a device, called a spectrum analyser, which does this for particular ranges. Modern mobile telephony uses "spread spectrum" technology, so a network analyser can be used to measure the amount of radio frequency (RF) energy spread out over a range of frequencies, much in the same way a glass prism does for light.

Why ionising and non-ionising?

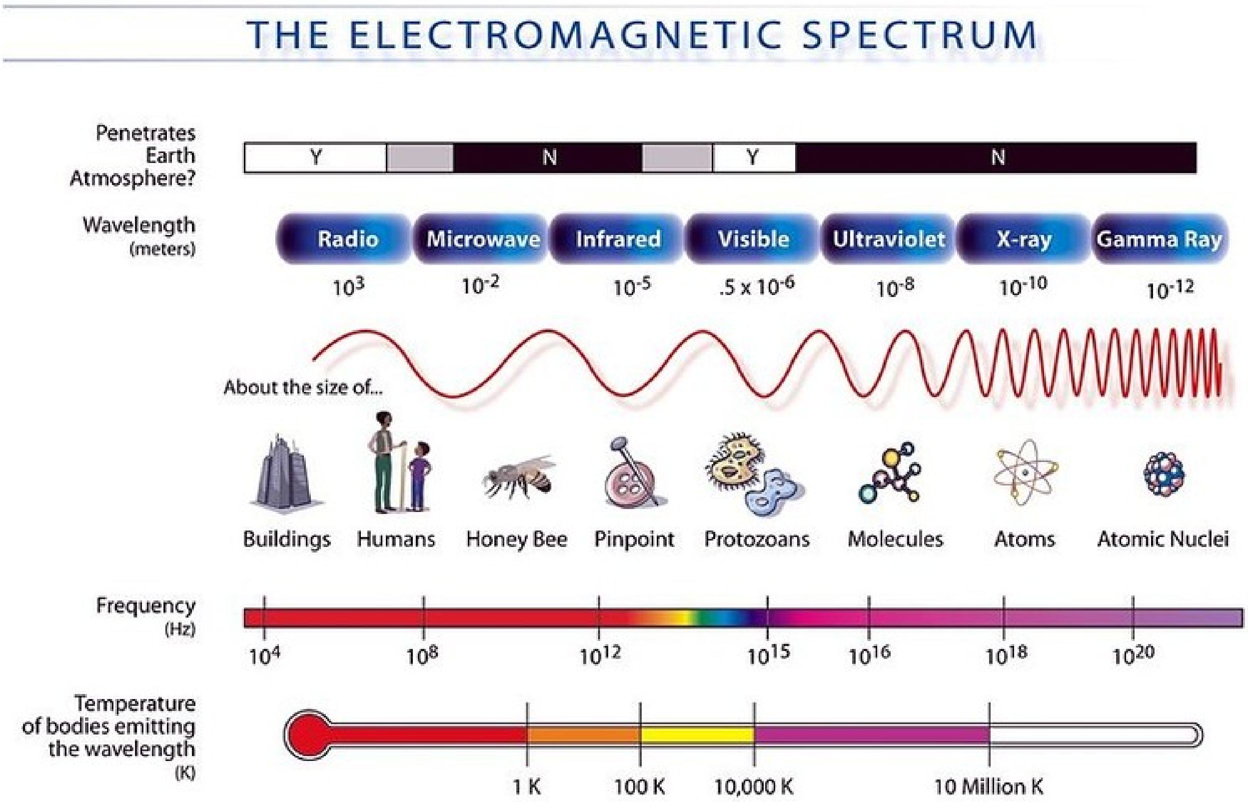
Although both RF and X-rays are referred to as radiation, they interact with the body in a fundamentally different way: X-rays can remove electrons from atoms (turning them into ions, hence ionising), whereas RF cannot (hence non-ionising).

The reason that exposure to high intensities of X-rays (and other rays, such as gamma rays and X-rays) is linked to cancer, is that the ionisation can lead to changes in genetic material which cannot be repaired.

Non-ionising radiation has not been shown to do this. The main effect of RF radiation is to cause heating (as in a microwave oven). Lower frequencies (such as ELF) can lead to the direct stimulation of nerves and muscles, rather than heating.

Using computer models of the human body (consisting of elements as small as 1mm cubes, and with the electrical properties of different types of tissue represented appropriately) it is possible to compute how much increase in temperature there will be in the parts of the head next to a mobile phone handset, when in operation.

With blood-flow properly included, the increase in temperature is much less than 1ºC, in fact much less than the natural variation in temperature over a 24-hour cycle.



The electromagnetic spectrum. NASA

Natural vs "unnatural"

There are now many who are concerned about "electrosmog" – the soup of emissions from consumer electronics that, to a greater or lesser extent, we are all exposed to (such as wireless routers, Bluetooth connections, smart meters).

It is perhaps comforting that, even before the advent of modern technologies, we were still exposed to various forms of electromagnetic radiation, principally from the sun (ranging from ultraviolet, through visible to infra-red), but also from natural (ionising) radioactivity, from various rocks such as granite and uranium ores.

In addition to the relatively strong magnetic field of Earth, various atmospheric phenomena, such as lightning, produce ELF and RF fields.

Remember also that the heart, brain, muscles and nerves all have electrical currents associated with them: diagnostic systems such as the well-known electroencephalogram measure body-generated electric fields and more advanced systems also measure the magnetic fields generated by the brain and other organs.

There is no evidence that the introduction of radio broadcasting at the start of the 20th century was associated with an increased incidence of disease. Life expectancies in general have increased significantly over the last 100 years, with a contribution from superior diagnostic procedures (computed tomography – which uses X-rays; and magnetic resonance imaging – which uses RF and strong magnetic fields) that exploitation of the electromagnetic spectrum has allowed.

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