

THERMAL VS. NON-THERMAL BIOLOGICAL EFFECTS

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Short Summary

A physics approach to defining temperature as a convenient way of describing a distribution function is presented along with some limitations on the use of non-thermal as a way of describing the results of the exposure of biological systems to RF.

Abstract.

There has been extensive controversy on the existence non-thermal biological effects as a result of exposure to RF fields. Definitions of non-thermal effects vary with the users. Often it means that the temperature averaged over a given volume of material increased by less than either 0.1 or 0.5°C which is temperature change that is within the normal range of variability for humans. I believe it is important to define temperature before we can define a non-thermal effect.

A definition of temperature in physics is a convenient way of describing a distribution function. Two common distribution functions are a Maxwell Boltzmann and Fermi-Dirac Distributions. The Maxwell Boltzmann Distribution is given by

$$\frac{n_i}{N} = \frac{e^{-\frac{E_i}{kT}}}{\sum e^{-\frac{E_i}{kT}}}$$

Where n_i is the number of particles in energy level E_i and N is the total number of particles. k is Boltzmann's constant, and T is the constant we use to define this energy distribution of particles. With this distribution function we have an exponentially decaying number of particles with increasing energy. This distribution function applies to the distribution of kinetic energies associated with the velocities of particles in a gas and to a large number of other processes. It is to be noted that in plasma we may have different values of T to describe the distribution of energies for the motion of electrons, ions and molecules. Typically the electron temperature will be much larger than the ion or molecular temperatures. It is to be noted that the energy associated with a single photon at microwave frequencies, hf , where h is Planck's constant is small compared to kT . Thus at thermal equilibrium and room temperature for a frequency of 10^{10} Hz and $T=300$ K the ratio of the number of particles in $N_2/N_1 = 1.6 \times 10^{-3}$. where N_2 is the energy of the upper state and N_1 is the energy of the lower state.

In solids the most common distribution for the energies of electrons is a Fermi-Dirac distribution which is given by

$$N_2 = \frac{N_1}{e^{\frac{\Delta E}{kT}} + 1}$$

Where $\Delta E = E_2 - E_1$

In the case of semiconductors we often have different values of T for the electrons than the lattice. The lattice temperature is associated with the vibration energy of the atoms and is the temperature that you would measure by placing a thermal couple on a block of semiconductor with a current running through it. The electron temperature is associated with the kinetic energy of the electrons.

The absorption of RF energy changes these distribution functions so that in this sense the absorption of energy is a thermal process leading to a change in temperature. Thus almost every experiment that has been reported on the effects of RF energy on biological systems involves a change in temperature. Typical molecular relaxation times are very fast, in the range from 10^{-12} to 10^{-6} seconds. For volumes less than a cubic micron, so that this absorbed energy is distributed rapidly to the vibrational and rotational energies in the surrounding volume. It is very hard to get significant differential increase in temperature over small volumes because of the high thermal conductivity of water.

Temperature is not a way to describe the characteristics of single particle. Typically we do not want to use temperature for processes that are the direct effect of an electric or magnetic fields on a single atom or molecule. For example to describe the Stark or Zeeman effects for the shift in the energy levels of a molecule as a function of the electric or magnetic field. However, we could use it to describe the distribution of particles resulting from these fields. It is also not the way we would be likely to describe concentrations that vary in space.

There are states where the energies are the same, degenerate, but differ in other ways. My favorite example is a 2 by 4 with a nail driven through it. If the point is up and you step on it the reaction is very different than if it is pointed down.

In conclusion I believe that we should avoid using non-thermal as a way to describe many of the experiments resulting from exposures to low levels of electric and magnetic fields and be more precise in our descriptions where we can.