

31 Thermal radiation

Subject:

We comment on three statements about thermal radiation, that can be found in textbooks. They are partly contradictory and partly incorrect. They appear not necessarily in the same textbook.

(1) Heat transfer takes place as heat conduction, convection and thermal radiation.

(2) At the red end of the spectrum of the visible light begins the domain of infrared or thermal radiation.

(3) With the light of the Sun heat comes to the Earth. It manifests itself by a temperature increase of the body that absorbs the light.

Deficiencies:

Our subject is that electromagnetic radiation, which is called *heat radiation* or *thermal radiation*. With these names one characterizes a particular method of creating electromagnetic radiation: A body emits electromagnetic radiation because its absolute temperature is greater than zero. There are other procedures for the production of electromagnetic radiation. The corresponding radiation is called non-thermal radiation. An example for non-thermal radiation are the microwaves produced by means of a klystron, the luminescence radiation from a semiconductor diode or the light from a laser.

First a somewhat trivial objection against one of the above-cited statements: Thermal radiation is not limited to the infrared domain. Sunlight is thermal radiation but most of its energy corresponds to the visible part of the spectrum. The cosmic background radiation is thermal, and its spectral maximum is situated in the microwave domain. The plasma of a fusion reactor emits thermal radiation in the X-ray domain.

A more serious and more subtle deficiency has to do with the statement that thermal radiation transfers heat. To analyze this statement we first have to clarify what is meant when saying that in a process heat or “energy in the form of heat” is transmitted. A heat transfer is an energy transfer that is accompanied by an entropy transport. The energy current P and the entropy current I_S are proportional to one another:

$$P = T \cdot I_S .$$

In general an energy flow has various contributions: heat, work, electric and chemical energy. Only that part is called heat, that corresponds to above equation.

To decide if or which part of a given electromagnetic radiation is heat we have to consider the energy flow and we have to know the temperature. If the radiation has a Planck spectrum, there is no problem. But the more selective the spectrum is, the more difficult it is to attribute a temperature to the radiation. The situation gets simple again when the radiation comes from a non-thermal radiator, as the microwaves from a Klystron or the electromagnetic waves from a radio emitter. In these cases that entropy flow is nearly zero and one will not call the emitted waves thermal radiation. When only considering the effect of the electromagnetic waves on an absorber, i.e. the fact that the absorber heats up, these difficulties are easily ignored.

We now come to an incorrectness in one of our citations. The heating effect of the absorber is not an indicator of the heat that may be transported by the radiation. The heating effect is due to the fact that the radiation transfers energy and that this energy is dissipated in the absorber. The “form” of the energy does not matter. A radiation that is completely entropy-free causes the same heating effect as thermal radiation, if both radiations carry the same energy and if both are completely absorbed.

Summing up: From the heating of an absorber we cannot conclude that the heat has been transported by the incident radiation.

Indeed, in those cases where the argument is most often used, i.e. in the case of the sunlight or the infrared radiation coming from a glowing body, the entropy production rate in the absorption process is much higher than the entropy inflow by the radiation.

We have seen that the heating of an absorber does not prove that the radiation transfers entropy. There is, however, a clear indicator for the entropy transferred by a given radiation. Instead of looking at the absorber, look at the emitter. If the temperature of a body, which has no material contact with its surroundings, decreases, i.e. if its entropy decreases, we can conclude that the radiation emitted by the body must have carried the entropy away, since the Second law tells us, that entropy cannot be annihilated.

Origin:

Heat radiation has been observed and studied long before it was possible to recognize that the nature of the radiation is the same as that of light, and long before the relationship between energy and heat was understood. The name radiating heat (strahlende Wärme) is probably due to Scheele [1]. In 1790 Pictet [2] believed that light and heat exist separately. In particular, he believed to have shown that moonlight is not accompanied by heat, whereas sunlight is. In the first decades of the 19th century the conviction was growing that light and heat radiation are of the same nature. However, for a definite clarification the appearance of two great theories had to be awaited: Maxwell’s electrodynamics and Planck’s statistical thermodynamics of radiation [3].

Disposal:

Do not identify infrared radiation and radiative heat transfer.

Regarding the electromagnetic radiation from the Sun, do say that it transfers energy. The heating of the absorber is mainly due to the dissipation of this energy. As an argument for the fact that radiation also transfers entropy consider the cooling of the emitter instead the heating of the absorber.

Instead of giving a name to the radiation – thermal radiation or heat radiation – attribute the name to the emitter: thermal emitter.

[1] Mach, E.: Die Principien der Wärmelehre. – Verlag von Johann Ambrosius Barth, Leipzig 1919. – S. 126

[2] Pictet, M. A.: Essai sur le feu. – Genève 1790

[3] Planck, M.: Vorlesungen über die Theorie der Wärmestrahlung. – Verlag von Johann Ambrosius Barth, Leipzig 1913