PhyzGuide: Thermal Radiation

When the term *radiation* is brought up in a physics class, you might think of atom bombs or nuclear power plants. The radiation associated with those things—nuclear radiation—is a topic for another day. The topic for this day is **thermal radiation:** energy given off by an object due to its temperature.

WHAT RADIATES AND WHAT IS RADIATION?

Examples of objects that give off such energy include the sun, hot lava from volcanoes, and glowing-hot metal. But other examples include you, this paper, and everything around you. While it may be true that "everybody hurts," it's certainly true that "everything radiates." (Hey, you could make a song out of that!)

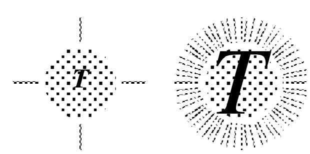
Radiation is energy emitted in the form of electromagnetic waves by any object with a temperature above absolute zero.

The electromagnetic wave is a topic for many days later in the year (stay tuned). The spectrum of electromagnetic waves includes radio waves, microwaves, infrared waves, visible light waves, ultraviolet waves, X-rays, and gamma rays. Electromagnetic waves vary in energy (which is determined by frequency), but are identical in their fundamental nature.

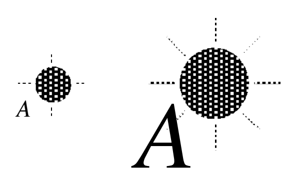
WHAT'S THE FREQUENCY, KENNETH?

We'll get to that when we study electromagnetic waves in more detail. For now we'll deal with a related question: "What's the radiation rate, Kenneth?" (No, you couldn't make a song out of that.) Radiation rate is the rate at which energy is emitted in the form of electromagnetic waves. The following variables drive the radiation rate Q/t.

1. Temperature *T*. The rate of energy emission depends on the temperature: the higher the temperature, the greater the radiation rate. In fact, radiation depends on the fourth power of the absolute temperature: $Q/t \propto T^4$. So with every doubling of the temperature, the radiation rate increases *sixteen* times!



2. Surface Area *A*. A large object emits more radiation per unit of time than a small one at the same temperature. Radiation is given off by electrons jiggling at the surface. The larger the surface area, the greater the number of electrons that can participate in radiation. $Q/t \propto A$.



3. Emissivity *e*. This is a measure of a surface's ability to radiate. Emissivity values range from 0 to 1. Generally speaking, light, shiny surfaces radiate poorly and have low emissivities and dark, rough surfaces radiate well and have high emissivities. $Q/t \propto e$.

STEFAN-BOLTZMANN RADIATION LAW

The factors listed above—along with a constant of proportionality—give the Stefan-Boltzmann Radiation Law. The constant is $\sigma = 5.67\times10^{-8} \text{W/m}^2\cdot\text{K}^4$. So the equation that relates radiation rate to temperature, surface area, and emissivity is

$$Q/t = \sigma eAT^4$$

ABSORPTION: RADIATION IN REVERSE

You might think that objects might radiate all their energy away and cool to absolute zero. This does not happen. That's because objects also *absorb* electromagnetic radiation. The rate at which an object absorbs electromagnetic radiation depends on the temperature of the environment (objects absorb more when in a hotter environment), the surface area (more area means more absorption), emissivity (high emissivity is also high absorptivity). Sound familiar? Check the absorption rate equation for *déjà vu* content:

$$Q/t = \sigma eAT^4$$

THE NET EFFECT

Radiation sends energy out; absorption takes energy in. The net radiation out is

$$(Q/t)_{out} = (Q/t)_{rad} - (Q/t)_{abs} = \sigma eAT^4_{object} - \sigma eAT^4_{environment} = \sigma eA(T^4_{object} - T^4_{environment})$$

ABSORBERS, EMITTERS, REFLECTORS, AND PERFECTION

The Perfect Blackbody. The reason an object appears to be black is because it absorbs most of the radiation that falls upon it. If it absorbed *all* the radiation incident upon it, it would be a perfect blackbody. A perfect blackbody has an emissivity of 1. It is a perfect absorber and a perfect emitter of radiation. Surfaces like black velvet have emissivities very close to 1 (around 0.95 or so). *Good emitters are good absorbers and poor reflectors.*

Shiny Happy Metal Surfaces. The reason an object appears to be bright is because it reflects most of the radiation that falls upon it. If it reflected *all* the radiation incident upon it, it would be a perfect reflector. A perfect reflector has an emissivity of 0. It is the worst possible absorber and the worst possible emitter of radiation. Surfaces like shiny, polished metal have emissivities very close to 0 (around 0.3 or so). *Poor emitters are poor absorbers and good reflectors.*

But Why? Why are good emitters good emitters, etc.? What does emissivity really tell us? It tells us about how well the electrons on a surface are coupled (connected somehow) to the atoms beneath them. If a surface electron is strongly coupled to an atom below it, it absorbs incident radiation (and sends the energy to the atom it's coupled to). And when the atom below has an abundance of energy, it jiggles the well-coupled electron which subsequently sends out radiation. Such a surface has a high emissivity. If a surface electron is poorly coupled to inner atoms, incident radiation forces the electron into oscillations. These oscillations re-emit the incident radiation without sending energy to the inner atoms. Similarly, when the inner atoms possess an abundance of energy, they can't send it up to the surface electrons which could send it out as radiation. Such a surface has a low emissivity.

Oh man, I should have called this guide "Radiation of Electro Magnetism." Dang!