ENERGY IN THE HUMAN EYE

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It's interesting to compare the energy received by the eye from a light source with the background radiation in the eye itself. For the purposes of this, suppose we look at a 100 watt light bulb from a distance of $r=1$ metre. The intensity of the light bulb at the distance of the eye is then

$$I=\frac{100\text{ W}}{4\pi r^{2}}=\frac{100}{4\pi}\text{W m}^{-2} \tag{1}$$

If we take the area of the pupil in the eye to be $0.1\text{ cm}^{-2}=10^{-5}\text{ m}^{2}$ then the wattage entering the eye is

$$P=\frac{100}{4\pi}\times10^{-5}=\frac{10^{-3}}{4\pi}\text{ W} \tag{2}$$

The power is the rate at which energy enters the eye. To find the energy at any given instant within the eye due to this power, we need to estimate how long the photons remain in the eye. We suppose that the light travels from the cornea to the retina, where it is absorbed and detected. Taking the diameter of the eye to be 3 cm = 0.03 m, this time is the diameter divided by the speed of light. Thus the energy within the eye due to the light bulb is

$$E_{\ell}=P\frac{0.03}{c} \tag{3}$$

$$=\frac{10^{-3}\times0.03}{4\pi\times3\times10^{8}} \tag{4}$$

$$=7.96\times10^{-15}\text{ J} \tag{5}$$

To get an estimate of the background radiation within the eye, we can take the eye to be a blackbody cavity with a temperature of $37^{\circ}\text{ C}=310\text{ K}$. Carroll & Ostlie show that the energy density for a blackbody is

$$u=aT^{4} \tag{6}$$

where $a=7.565767\times10^{-16}\text{J m}^{-3}\text{K}^{-4}$ is the radiation constant. Taking $T=310$ K, we have the total energy in a sphere of radius 0.015 m

$$E_b = \frac{4\pi}{3}(0.015)^3 \times 7.565767 \times 10^{-16}(310)^4 \tag{7}$$
$$= 9.88 \times 10^{-11} \text{ J} \tag{8}$$

Thus the energy from blackbody radiation is considerably larger than that due to the light bulb. Given this fact, we might wonder why our vision is not swamped with light, even when our eyes are closed.

The answer lies in the fact that the blackbody radiation generated by our own body heat at 310 K is almost entirely in the infrared, while the radiation due to the light bulb lies largely in the visible region of the spectrum. We can see this by plotting the energy density curves for the two temperatures. The energy density due to a blackbody is given in Carroll & Ostlie's Chapter 3, and is

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)} \tag{9}$$

where h is Planck's constant $h = 6.626 \times 10^{-34}$, k is Boltzmann's constant $k = 1.38 \times 10^{-23}$ and c is the speed of light $c = 3 \times 10^8$, all in SI units. Fig. 1 shows the spectrum for $T = 310$ K and Fig. 2 for $T = 4000$ K, typical of old fashioned light bulbs. The vertical scale in each case is $B(\lambda, T)$ and the horizontal scale is the wave length in metres. The visible spectrum lies roughly between 4×10^{-7} and 7×10^{-7} m. We see from Fig. 1 that the spectrum becomes appreciable only around 5×10^{-6} m and is essentially zero for shorter wavelengths. Thus a blackbody at $T = 310$ K doesn't radiate in the visible region.

From Fig. 2 we see that a blackbody at $T = 4000$ K peaks at or near the visible region (and also has a much higher intensity; note the vertical scales. The $T = 310$ curve in Fig. 1 would be invisible if plotted alongside Fig. 2).

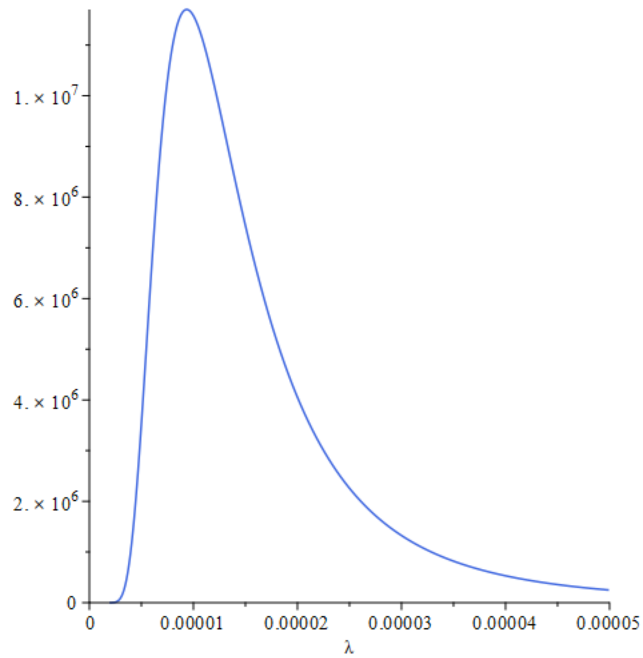

FIGURE 1. Blackbody spectrum for $T = 310$ K.

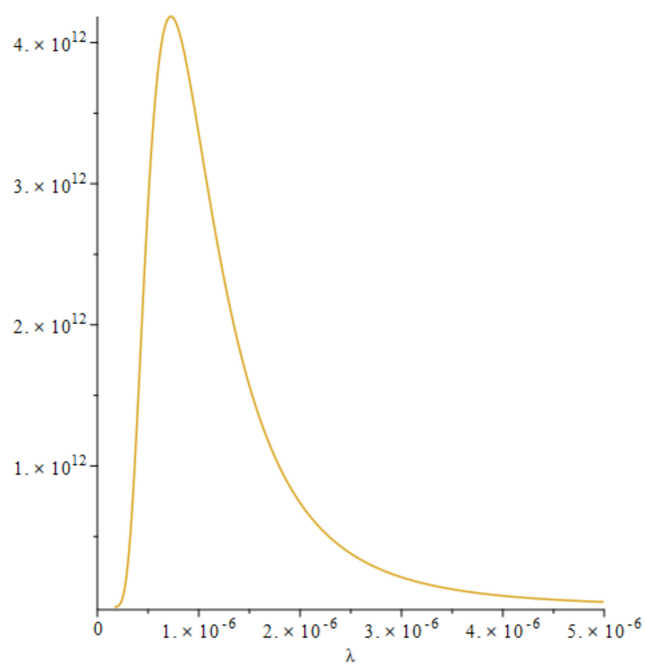

FIGURE 2. Blackbody spectrum for $T = 4000$ K.