Workshop Tutorials for Physics

Solutions to TR8: **Blackbody Radiation**

A. Qualitative Questions:

1. Many objects such as hot metals, houses and even people behave at least partly like a black body, and this is useful when looking at the thermal properties of materials and ways to control heating and cooling.

a. A perfect blackbody is one which emits radiation characteristic of its temperature. More precisely, it is emitted at a rate given by $P = \varepsilon\sigma A(T^4 - T_o^4)$A graph of energy against dλ for a perfect blackbody has no absorption bands, $\alpha = \varepsilon$ for all wavelengths.

b. The emissivity, ε, of a perfect black body is 1 (where ε can have a value between 0 and 1). This means that it is an efficient radiator, radiating the maximum amount of energy possible for a given temperature.

c. The coefficient of absorption, α, of a perfect black body is also one, which means that it absorbs all radiation incident on it.

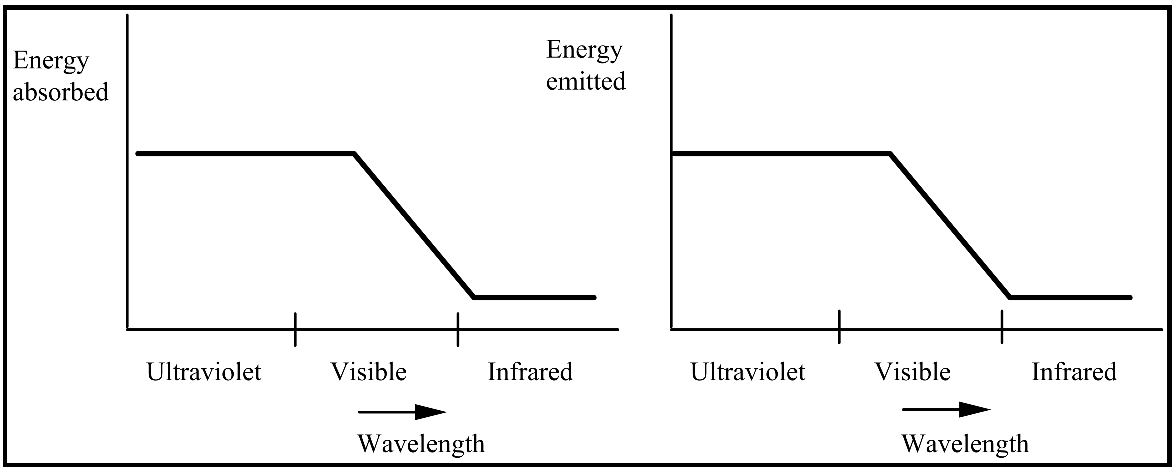
d. Black velvet is a good black body. A cavity with a small hole, such as a keyhole in a closet door is almost a perfect black body. Any radiation incident on the keyhole enters and is trapped and absorbed by the closet walls. Hence any radiation emitted is characteristic of the temperature of the closet.

e. Anything which reflects a lot of radiation, or has a low emissivity is a poor blackbody, for example a mirror or a white piece of paper.

2. Consider the design of solar water-heating systems. Visible light from the sun is absorbed by the solar collector.

a. The visible light absorbed by the solar collector causes the solar collector to heat up. It acts as a black body and emits infrared radiation to its surroundings. It cannot emit visible light because it does not get hot enough (unlike the sun), it emits at much higher wavelengths.

Solar collectors are specially coated to improve their performance. The amount of radiation absorbed or emitted by a collector depends on the wavelength. The properties of one recently discovered coating are shown below.



b. The solar radiation incident on the coating from the sun is mainly in the visible region. The coating absorbs well in that wavelength region, so it will absorb a lot of energy. The collector temperature is such that its radiation is in the infrared. The coating is a poor emitter in that wavelength region, so it cannot lose much energy compared to a perfect black body. Hence it will absorb energy well and radiate it poorly, and it will become very hot.

B. Activity Questions:

1. Thermal radiation – the Leslie Cube.

The greater the emissivity, ε, of the surface the more it will radiate for a given temperature. The quantity ε takes values between 0 and 1 depending on the nature of the surface radiating heat, a *perfect* radiator of heat has ε = 1 and is called a blackbody radiator. To a good approximation, all the sides (surfaces) of the cube are at the same temperature - the cube contains hot water and the cube's sides are made of thin sheet metal, a good conductor of heat. The surfaces with the greater emissivity – matt black, shiny black (in that order) will radiate the most and have $\varepsilon \approx 1$ whereas shiny, polished metal (like a new stainless steel kettle) may have $\varepsilon \approx 0$.

2. The Black Box

When you look into the hole you see blackness, even though the inside of the box is white. This is because the hole is very small, and no light can get out of it to your eye. Black is an absence of light, and as there is no light in the box it appears black, just as a window to an unlit room is black regardless of the colours of the room. When the box is open light is reflected and you can see that it is white inside. A cavity or box with a small hole is a good approximation to a black-body because all light entering the hole is trapped, so the absorption is very high.

3. Blackbody radiation.

As you turn up the power supply the voltage across the graphite gets greater. This gives a bigger current through the graphite, and more power dissipated in it, hence it gets hotter. As it gets hot it begins to glow. Initially it glows red, and as it heats up more it glows orange and yellowish. If you could get it hot enough without melting it, it would glow white hot and eventually blue and ultraviolet.

C. Quantitative questions:

1. Santa Claus is sitting naked in his sauna with the temperature of the sauna at 70°C. Assume that he has a surface area of 1.5 m^2 and his skin temperature is 37° C. The emissivity of the human body in the infrared radiation range is close to one.

a. The power transferred by radiation is given by:

$P = \varepsilon\sigma A(T^4 - T_o^4) = 1 \times 5.67\times 10^{-8}\ \mathrm{W.m^{-2}.K^{-4}} \times 1.5\ \mathrm{m^2} \times [(310\ \mathrm{K})^4 - (343\mathrm{K})^4] = -392\ \mathrm{W}$.

The negative sign indicates that the net flow of heat is into Santa Claus.

b. To stop him heating up too much, his body uses other mechanisms to get rid of the excess thermal energy. In particular the body perspires and the perspiration uses thermal energy from the body to evaporate. This is very effective for humans and other animals with sweat glands, but if he took his pet dog in with him it would be very dangerous for the dog as they are unable to sweat. His reindeer, however, could safely join him in the sauna.

2. Our sun's radiation output peaks at around 550 nm.

a. Estimating the surface temperature of the sun:

Using Wien's law, $\lambda_{max} = 2.90$ mm.K / T, and a λ_{max} of 550 nm, the surface temperature of the sun is

$T = 2.90$ mm.K / 550 nm $= 2.90 \times 10^{-3}$ m.K/ 550×10^{-9} m = 5270 K.

b. Again using Wien's law:

$\lambda_{max} = 2.90$ mm.K / $T = 2.90 \times 10^{-3}$ m.K/ 2.7 K $= 1.07 \times 10^{-3}$m or ~ 1.1 mm.