Workshop Tutorials for Introductory Physics

Solutions to TI7: **Blackbody Radiation**

A. Review of ideas in basic physics.

Blackbody Radiation

Try holding your hands close to but not touching a mug of hot coffee – you can feel the **warmth**. This warmth is actually **electromagnetic** radiation emitted from the mug. The amount and wavelength of radiation will depend on certain characteristics of the mug including its temperature. As you already know a hot body will radiate more than a cold one. The surface of the body will also affect the amount of radiation leaving the body. In fact each object has a characteristic **spectrum** of emitted radiation.

To provide a standard for the amount of radiation emitted from a body we define an ideal object called a blackbody. A blackbody is one where all the radiation hitting the body is **absorbed,** a perfect absorber. It is also a perfect emitter, emitting the maximum amount of radiation possible for a body at a given temperature.

The Stefan-Boltzmann law tells us that the rate at which energy is radiated from a body is $\boldsymbol{P = \sigma A T^4}$ for a perfect blackbody, where σ = Stefan-Boltzmann constant and A = surface area. For any other body, the power is $P = \varepsilon\sigma A T^4$, where ε is the **emissivity** of the body – a characteristic of the surface.

Wien's Law relates the wavelength λ_m at which emitted radiation is a maximum to the temperature of the body. It states that $\lambda_m \times T$ = constant. A body with a lower temperature will emit more radiation of longer wavelength. This provides a useful way of measuring the **temperature** of things without having to get close enough to them to reach thermal equilibrium with them. This is particularly useful for astronomers as it gives them a means of measuring the surface temperatures of distant **stars**. It can also provide a warning not to touch something – if it is hot enough to be glowing, like an electric hot plate, then it is much too hot to touch.

Discussion Question

All bodies emit and absorb radiation but, as we have seen, rates will vary. A white car parked in the sun does not get as hot as a dark coloured one because it will absorb less radiation than a dark coloured car, and reflect more. Sometimes people say that dark colours attract heat – this is not true, you cannot attract heat. The amount of incident heat depends on the surface area of the object and the intensity of radiation only.

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 $\varepsilon = 1$ 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.

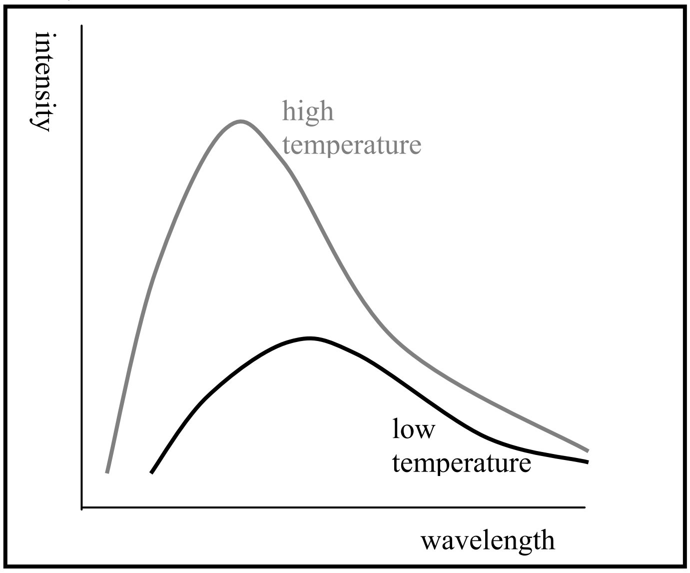
3. Blackbody radiation.
As you turn up the power supply the voltage across the graphite gets greater. This gives a bigger current through the graphite, and more power dissipated in it, hence it gets hotter. As it gets hot it begins to glow. Initially it glows red, and as it heats up more it glows orange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

C. Qualitative Questions.

1. Max Planck came up with an explanation of Black body radiation.

a. A black body is a perfect absorber, one which absorbs all incident radiation. A black body is also a perfect emitter, emitting the maximum amount of radiation for a body at that temperature. Such radiation is called black body radiation.

b. See diagram opposite. The higher the temperature, the lower the wavelength of peak intensity, and the greater the peak intensity.



If the temperature of the sun were suddenly to *increase* (but its size were to stay the same) :

c. The total radiant power received by the Earth would increase.

d. The wavelength for maximum spectral intensity of received radiation would decrease.

e. The radiant power received in the visible range would increase.

2. A thermos bottle consists of an inner bottle and an outer bottle, usually with the space between them evacuated. This prevents heat loss by conduction. There is a vacuum between the walls and this limits transfer of thermal energy by both conduction and convection. The inner wall is often made of glass, and is very shiny so that it reflects heat back into a hot drink. To reduce loss of thermal energy by radiation we want the walls of the container to *not* be a good absorber of radiation nor to be a good emitter, they should have both a low coefficient of absorption, and a low emissivity. So the walls should *not* behave like a black body radiator.

D. Quantitative question:

In the movie "2001: a space odyssey" an astronaut walks briefly in space with no space suit. Would he have felt the cold of space? If you did this you would radiate thermal energy, but absorb almost none from your environment.

a. Estimating the average human body to have a surface area of 1.5 m^2, and a skin temperature of around 30^oC = 303 K (a bit less than core temperature of 37^oC).

The heat radiated is then $P = \sigma\varepsilon AT^4 = 5.67 \times 10^{-8}$ $W.m^{-2}.K^{-4} \times 0.90 \times 1.5$ $m^2 \times (303\ K)^4 = 0.7$ kW.

This is about the same as a small fan heater.

b. The energy you would lose in 30 s is $E = t \times P = 30\ s \times 0.7\ kW = 21$ kJ.