VISUAL PHYSICS ONLINE

THERMODYNAMICS

METHODS OF HEAT TRANSFER

RADIATION

Radiation is the energy transferred by electromagnetic waves mainly infrared (IR), visible and ultraviolet (UV). All materials radiate energy in the form of electromagnetic waves in amounts determined by their temperature.

Thermal radiation wavelength ranges

IR ~ (100 - 0. 8) μm

Visible ~ (0.8 - 0.4) μm (800 – 400) nm

UV ~ (0.4 - 0.1) μm

micrometre 1 μm = $1\text{x}10^{-6}$ m

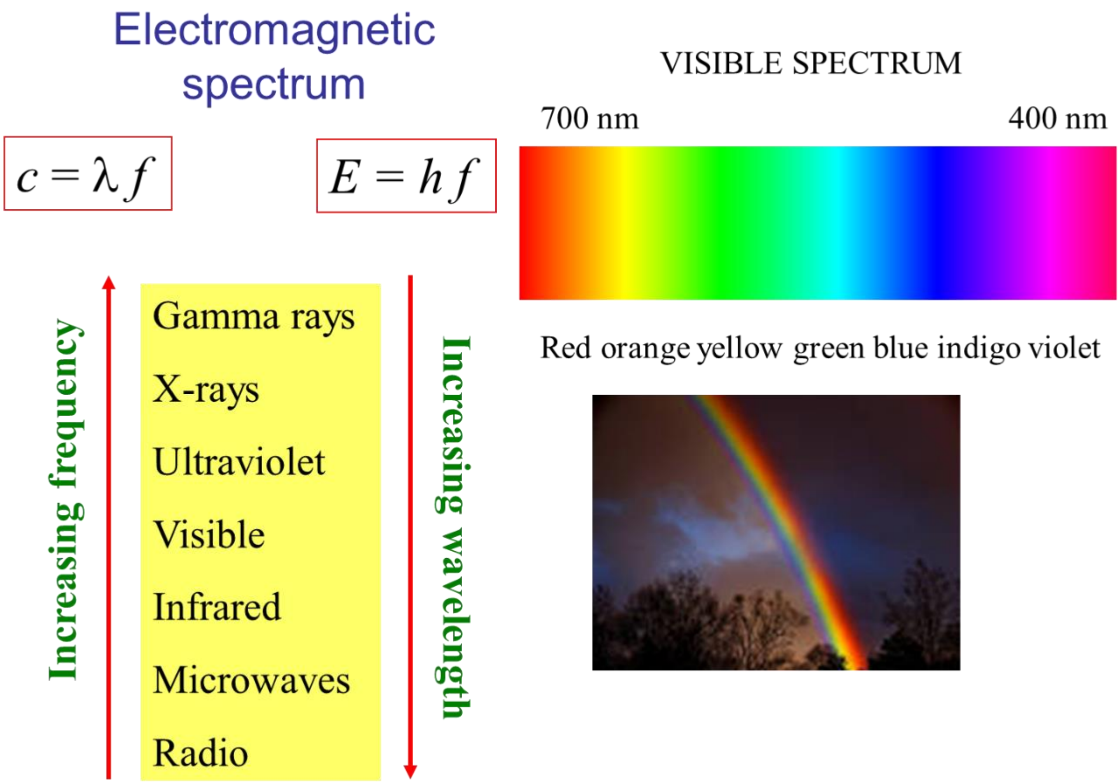
nanometre 1 nm = $1\text{x}10^{-9}$ m

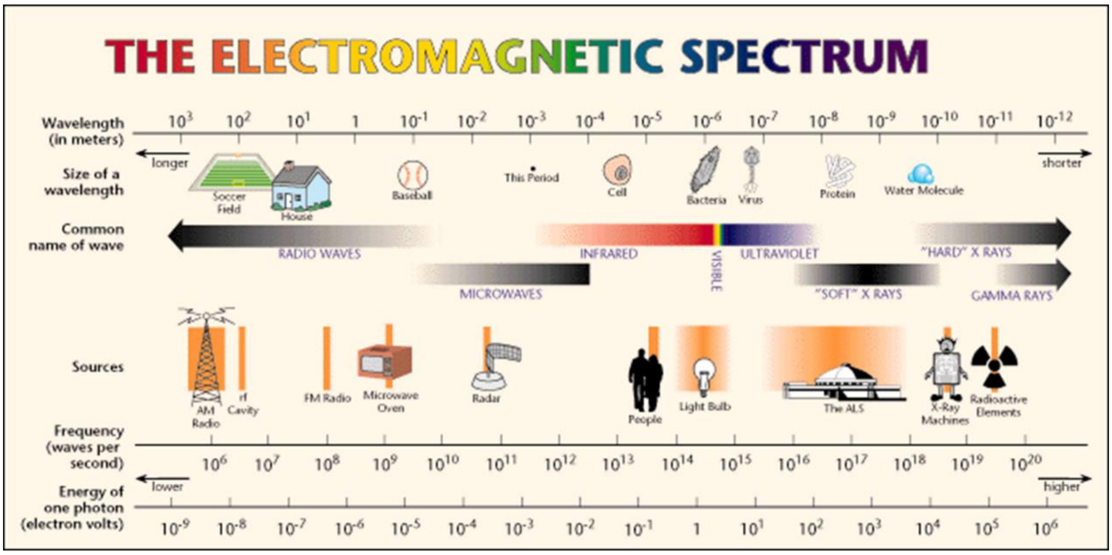
All objects above **absolute zero** emit radiant energy and the rate of emission increases and the peak wavelength decreases as the temperature of object increases.

Infrared thermography, thermal imaging, and thermal video are examples of infrared imaging science. Thermographic cameras usually detect radiation in the long-infrared range of the electromagnetic spectrum (9–14 µm or 9000–14000 nm) and produce images of that radiation, called **thermograms**.

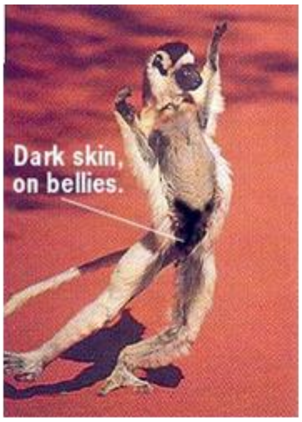
Since infrared radiation is emitted by all objects with a temperature above absolute zero (**blackbody radiation law**), thermography makes it possible to see one's environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature, therefore, thermography allows one to see variations in temperature. When viewed through a thermal imaging camera, warm objects stand out well against cooler backgrounds; humans and other warm-blooded animals become easily visible against the environment, day or night. Thus, thermography is particularly useful to the military and other users of surveillance cameras.

Electromagnetic Spectrum





RADIATION



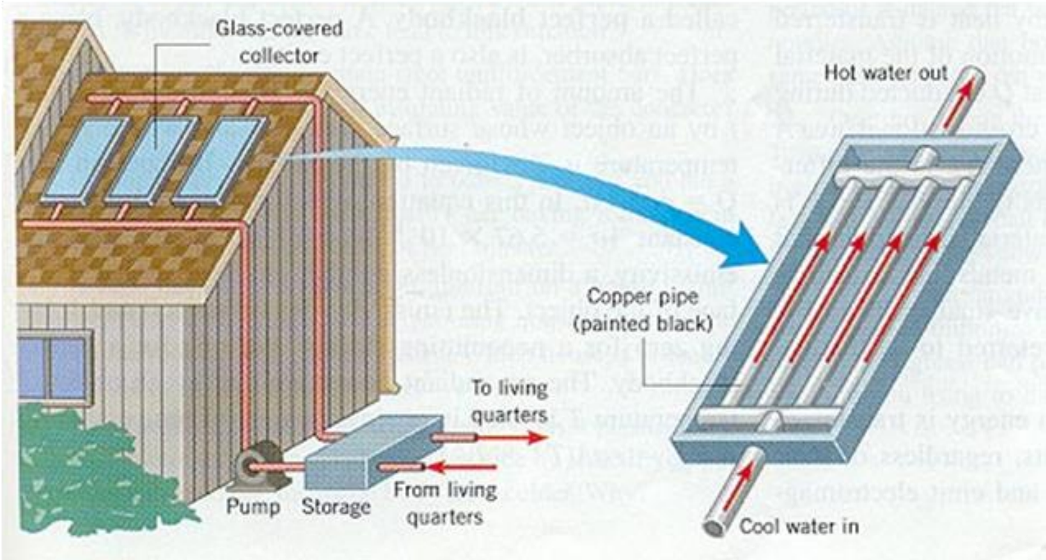
Lemur at left is nocturnal, so the dark fur poses no disadvantage in absorbing excessive sunlight.

Lemur at the right is active during the day; it points its belly toward the sun on cold mornings.

Solar collector

Highly reflecting metal foil keeps inside temperature low

Why are pipes in solar panels painted black ?



From the colour of the iron rod taken from a hot fire, what can you conclude about the temperature of different parts of the rod?

Radiation Laws

The Syllabus does not give any equations for the transfer of heat by radiation. So, you don't need to know the following mathematics, but without this knowledge, you would have a very limited view of fundamental and important ideas related to thermal phenomena.

Every object because of its temperature emits electromagnetic waves. The emission from the surface of an object depends upon the surface area A over which the radiation occurs, the nature of the surface described by the surface emissivity e and the temperature T of the surface. The power P_{rad} (energy / time) radiated is described by the **Stefan-Boltzmann Law**

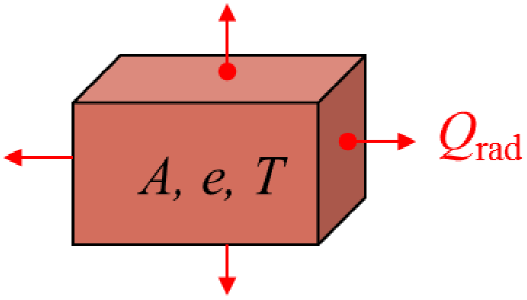
$$P_{rad} = \frac{dQ_{rad}}{dt} = e\,\sigma A T^4$$ temperature must be in kelvin K

The constant is known as the **Stefan-Boltzmann constant**

$$\sigma = 5.67 \times 10^{-8}\ \text{W.m}^{-2}\text{.K}^{-4}$$

Note that the power radiated is proportional to the **fourth** power of the temperature – a small change in temperature leads to a larger change in the power radiated.

The nature of the surface described by the surface emissivity e which is a dimensionless number between 0 and 1 and its value indicates how effective the surface is in radiating energy (or absorbing energy). A value of $e = 1$ is a perfect radiator and the object radiating is called a **blackbody**. Generally, a dark coloured surface has an emissivity near 1, whereas a light-coloured surface has an emissivity must less than 1.



Radiation falling on a surface absorbs that radiation. Therefore, all surfaces are emitting radiation and absorbing it. Thus, if the temperature of a System is T_S and its surrounding temperature is T_{env} the net power P_{net} radiated by the object is

$$P_{net} = e\sigma A\left(T_S^{\ 4} - T_{env}^{\ 4}\right)$$

If the surface temperature is greater than the surroundings $\left(T_S > T_{env}\right)$, it radiates more energy that it absorbs, hence, $P_{net} > 0$.

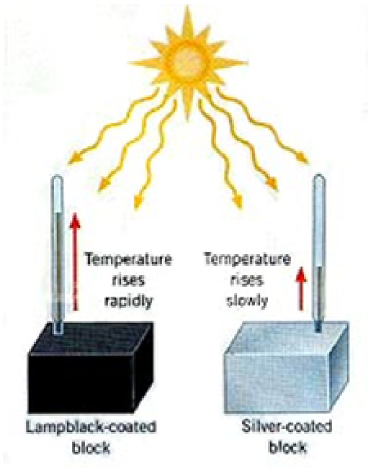
If the surface temperature is less than the surroundings $\left(T_S < T_{env}\right)$, it radiates less energy that it absorbs, hence, $P_{net} < 0$.

At equilibrium, where the surface and surroundings are at the same temperature, hence, $P_{net} = 0$.

A **blackbody** $e = 1$ is both a perfect radiator and absorber of electromagnetic radiation.

The opposite of a blackbody is an **ideal reflector**, which absorbs zero radiation. This is why the inside of a Thermos bottle is highly reflective, very little heat energy is absorbed from the hot contents.

Emissivity, e – the nature of the surface

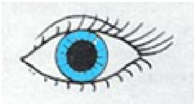


$e \sim 0.8$ $e \sim 0.4$

Summer clothing: white reflects radiant energy better than black.

Wrap an ice-cube in black cloth and another in aluminium foil and place both in the sunshine. What will happen?

Why is the pupil of the eye black?



http://sol.sci.uop.edu/~jfalward/heattransfer/heattransfer.html

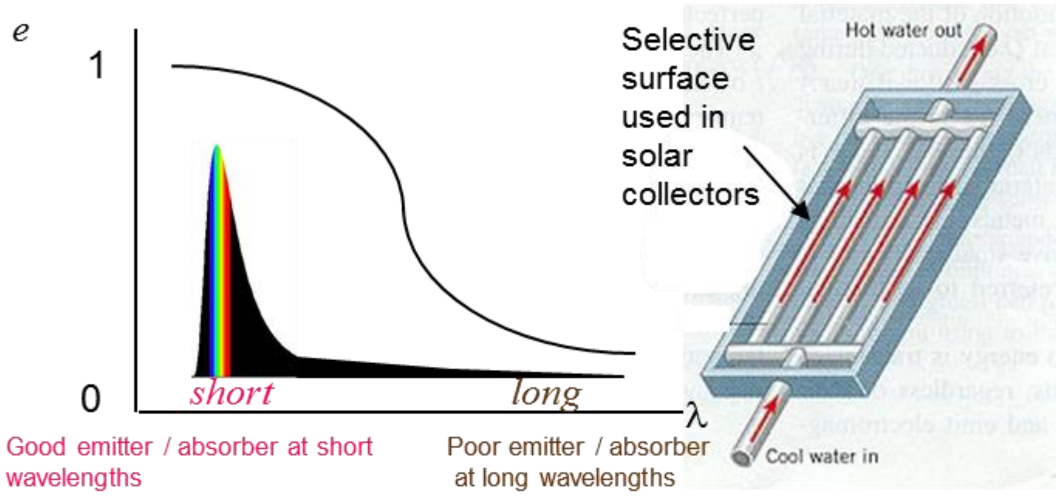
Thinking question

Explain the role of the surface of the thermal collector.

To make a solar collector efficient, materials are designed to have a selective surface for the absorption and emission of radiation. The selective surfaces are good absorbers of shortwave radiation (sunlight) and good emitters at longer wavelengths to heat water.

Selective surfaces
Emissivity, *e* – the nature of the surface

Value of *e* is temperature and wavelength dependent



Good emitters of radiation are also good absorbers of radiation and poor emitters are poor absorbers. A good radio antenna is a good transmitters and receiver. A poorly designed antenna is a poor receiver. Absorption and reflection are opposite processes. A good absorber of radiant energy reflects very little energy (including light) and so looks dark. Good reflectors are poor absorbers.

Clean snow is a good reflector and does not melt quickly in sunlight. Dirty snow melts faster because of the greater absorption of sunlight.

Most oil type heaters warm the room by convection and not radiation, so colour should not make any difference. However, for optimum efficiency, a light coloured radiator will radiate less and remain hotter longer and do a better job in keeping the air warm.

Snow lying on grass melts much more slowly than the snow of the road. Grass is a good insulator and little energy is conducted from the ground through the grass to the snow. However, the road surface conductors more energy, so the snow melts more quickly.

snow melts quickly of the road surface

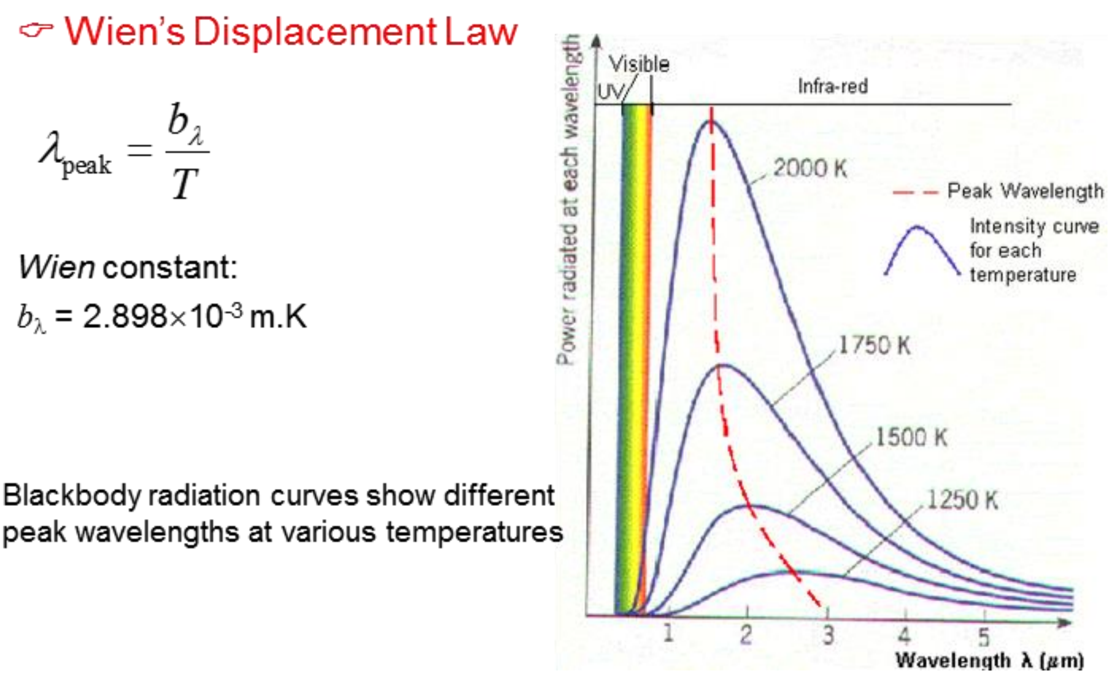
snow melts slowly over the grass

Wien’s Displacement Law

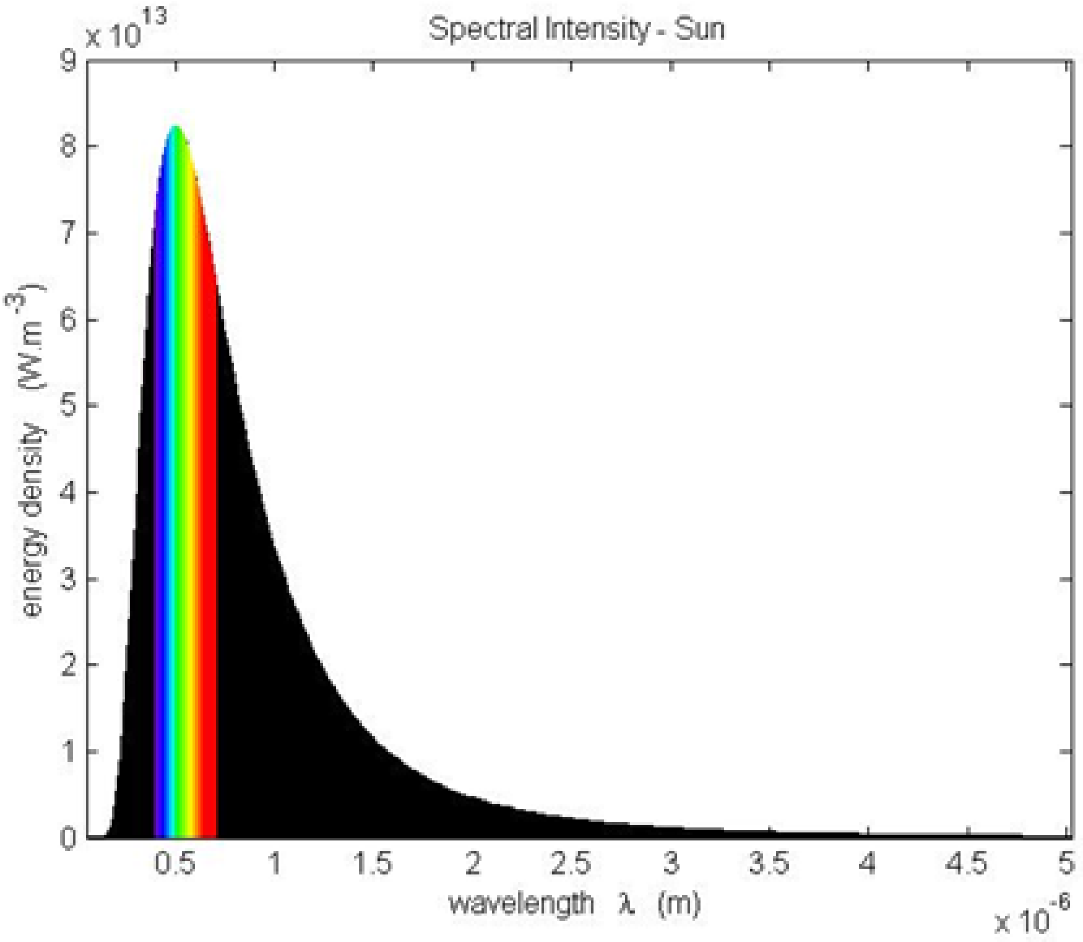
A useful law for understanding the radiation emitted from a hot object is **Wien's Displacement Law**. It states that peak wavelength of the radiation emitted from a hot body is λ_{peak} inversely proportional to the temperature T.

$$\lambda_{peak} = \frac{b_\lambda}{T} \qquad \text{Wien's constant } b_\lambda = 2.898\times10^{-3} \text{ m.K}$$

An interesting graph for the radiation emitted by a blackbody is known as the **blackbody radiation curve** in which the energy radiated is plotted against the wavelength.



The Sun to a good approximation radiates as a blackbody and its blackbody radiation curve is



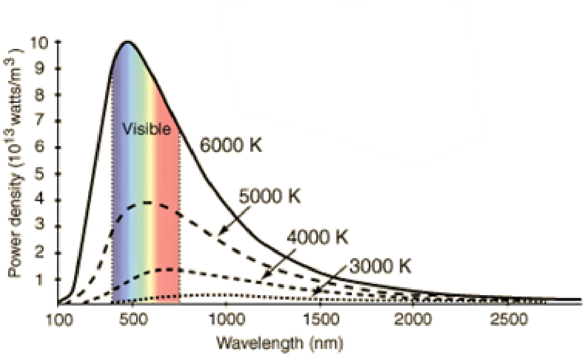
The peak wavelength for the radiation from the Sun is about

$$\lambda_{peak} = 5 \times 10^{-7}\ \text{m}$$ **green light**

From Wien's Displacement Law, the surface temperature of the Sun is

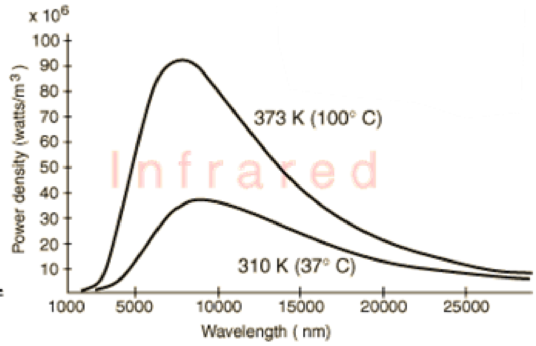
$$T = b / \lambda_{peak} = \left(2.898 \times 10^{-3} / 5 \times 10^{-7}\right)\ \text{K} = 6000\ \text{K}$$

Sun (6000 K - hot!)



Visible radiation

Earth (300 K - cold!)

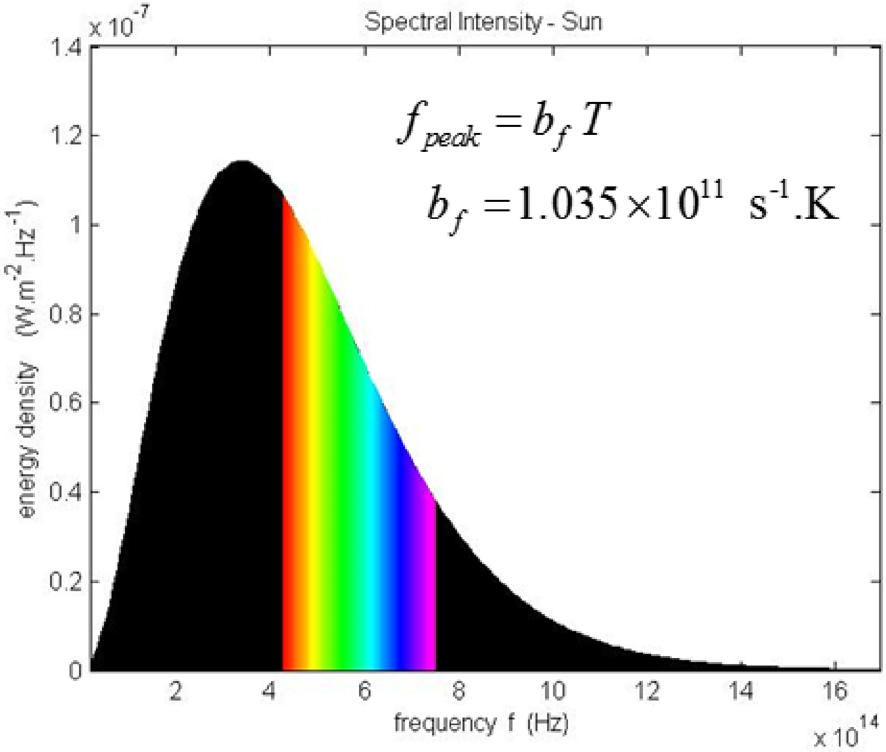


Infrared radiation

We can state the Wien Displacement law in terms of the peak frequency of the radiant energy

$$f_{peak} = \frac{c}{\lambda_{peak}} = b_f \, T \qquad b_f = 1.035 \times 10^{11} \ \mathrm{s^{-1}.K}$$

The peak frequency f_{peak} of the radiant energy emitted from an object is proportional to its surface temperature T.



The Sun has a high temperature (~ 6000 K) and most of the radiation emitted from the Sun is in the visible part of the EMR spectrum (**solar radiation**). The surface of the Earth is relatively cool and emits mostly infrared radiation which is called **terrestrial radiation**. The interior of the Earth is warmed by nuclear reactions (radioactive decay). Energy is conducted to the surface from the interior to become terrestrial radiation.

Everyday objects mainly emit infrared radiation. When your skin absorbs this infrared radiation, you have a warming sensation, for example, when standing in front of a fire.

Death in a hot tub: The physics of heat stroke

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High environmental temperature and/or vigorous physical work will tend to cause a person's body temperature to rise. In an attempt to maintain a normal body temperature of 37°C the body then increases its rate of dissipation of heat by mechanisms that involve large increases in the blood flow to the skin. When there is an increase in the fraction of the blood that flows to the skin, the fraction available to other organs will decrease. A decreased flow to the brain can cause unconsciousness or death. The basic elements of this competition can be represented in terms of a simple dc circuit. Here is an example where the elements of dc circuit theory can be coupled with basic concepts of thermodynamics to help demonstrate the complimentarity of different branches of physics and to help students in elementary physics courses to gain an improved understanding of an important physiological situation. Examples of this type seem to be absent from many of our texts for introductory courses in physics.

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