Everything radiates and absorbs electro-magnetic radiation. Many important radiation laws are based on the performance of a perfect steady state emitter called a blackbody or full radiator. These have smoothly varying spectra that follow a set of laws relating the spectral distribution and total output to the temperature of the blackbody. Sources like the sun, tungsten filaments, or our Infrared Emitters, have blackbody-like emission spectra. However, the spectral distributions of these differ from those of true blackbodies; they have slightly different spectral shapes and in the case of the sun, fine spectral detail. See Fig. 1.

Any conventional source emits less than a blackbody with the same surface temperature. However, the blackbody laws show the important relationship between source output spectra and temperature.

**STEFAN-BOLTZMAN LAW**

Integrating the spectral radiant exitance over all wavelengths gives:

\[
\int M_\lambda (\lambda, T) \lambda d\lambda = M_\infty (T) = \sigma T^4
\]

\(\sigma\) is called the Stefan-Boltzmann constant

This is the Stefan-Boltzmann law relating the total output to temperature.

If \(M_\infty (T)\) is in W m\(^{-2}\), and \(T\) in kelvins, then \(\sigma\) is \(5.67 \times 10^{-8}\) W m\(^{-2}\) K\(^{-4}\).

At room temperature a 1 mm\(^2\) blackbody emits about 0.5 mW into a hemisphere. At 3200 K, the temperature of the hottest tungsten filaments, the 1 mm\(^2\), emits 6 W.

**WIEN DISPLACEMENT LAW**

This law relates the wavelength of peak exitance, \(\lambda_m\), and blackbody temperature, \(T\):

\[\lambda_m T = 2898\]

where \(T\) is in kelvins and \(\lambda_m\) is in micrometers.

The peak of the spectral distribution curve is at 9.8 \(\mu\)m for a blackbody at room temperature. As the source temperature gets higher, the wavelength of peak exitance moves towards shorter wavelengths. The temperature of the sun’s surface is around 5800K. The peak of a 6000 blackbody curve is at 0.48 \(\mu\)m, as shown in Fig. 3.

**EMISSIVITY**

The radiation from real sources is always less than that from a blackbody. Emissivity (\(\varepsilon\)) is a measure of how a real source compares with a blackbody. It is defined as the ratio of the radiant power emitted per area to the radiant power emitted by a blackbody per area. (A more rigorous definition defines directional spectral emissivity \(\varepsilon(\theta, \phi, \lambda, T)\). Emissivity can be wavelength and temperature dependent (Fig. 2). As the emissivity of tungsten is less than 0.4 where a 3200 K blackbody curve peaks, the 1 mm\(^2\) tungsten surface at 3200 K will only emit 2.5 W into the hemisphere.

If the emissivity does not vary with wavelength then the source is a “graybody”.

**PLANCK’S LAW**

This law gives the spectral distribution of radiant energy inside a blackbody.

\[W_{\lambda}(\lambda, T) = \frac{8\pi hc}{\lambda^5} \cdot e^{hc/kT} - 1 \cdot \lambda^{-1}\]

Where:

- \(T\) = Absolute temperature of the blackbody
- \(h\) = Planck’s constant \((6.626 \times 10^{-34} \text{Js})\)
- \(c\) = Speed of light \((2.998 \times 10^8 \text{m s}^{-1})\)
- \(k\) = Boltzmann’s constant \((1.381 \times 10^{-23} \text{JK}^{-1})\)
- \(\lambda\) = Wavelength in m

The spectral radiant exitance from a non perturbing aperture in the blackbody cavity, \(M_{\lambda}(\lambda, T)\), is given by:

\[M_{\lambda}(\lambda, T) = \frac{c}{4\pi} W_{\lambda}(\lambda, T)\]

\(L_{\lambda}(\lambda, T)\), the spectral radiance at the aperture is given by:

\[L_{\lambda}(\lambda, T) = \frac{c}{4\pi} W_{\lambda}(\lambda, T)\]

The curves in Fig. 3 show \(M_{\lambda}\) plotted for blackbodies at various temperatures. The output increases and the peak shifts to shorter wavelengths as the temperature, \(T\), increases.
KIRCHOFF’S LAW

Kirchoff’s Law states that the emissivity of a surface is equal to its absorptance, where the absorptance ($\alpha$) of a surface is the ratio of the radiant power absorbed to the radiant power incident on the surface.

$$\int_{\lambda} \alpha(\lambda, T) d\lambda = \int_{\lambda} \varepsilon(\lambda, T) d\lambda$$

$$\alpha = \varepsilon$$

LAMBERT’S LAW

Lambert’s Cosine Law holds that the radiation per unit solid angle (the radiant intensity) from a flat surface varies with the cosine of the angle to the surface normal (Fig. 4). Some Oriel Sources, such as arcs, are basically spherical. These appear like a uniform flat disk as a result of the cosine law. Another consequence of this law is that flat sources, such as some of our low power quartz tungsten halogen filaments, must be properly oriented for maximum irradiance of a target. Flat diffusing surfaces are said to be ideal diffusers or Lambertian if the geometrical distribution of radiation from the surfaces obeys Lambert’s Law. Lambert’s Law has important consequences in the measurement of light. Cosine receptors on detectors are needed to make meaningful measurements of radiation with large or uncertain angular distribution.

Fig. 3 Spectral exitance for various blackbodies

Fig. 4 Lambert's cosine law indicates how the intensity, I, depends on angle.