\[ E_{e^-} = \frac{hc}{\lambda} - W_0 \]

Where \( W_0 \) = characteristic escape energy for the metal
\( E_{e^-} \) = the kinetic energy of an escaping electron
\( hc/\lambda \) = the energy of the photon of wavelength \( \lambda \)
SUPERPOSITION
(INTERFERENCE)
When can we ignore polarization?
• Imaging problems
• Interference/direction for beams at small angles
When is it important?
• Transmittance/reflectance calcs
• Superposing beams at large angles
• Detailed interactions with matter:
  – Birefringent materials, surface effects,
  – atomic/molecular transitions, nonlinear optics, magneto-optical effects, electro-optical effects, . . .
$y = \text{vibration direction of light (direction of E vector)}$
If this wave were approaching an observer, its electric vector would appear to be rotating clockwise. This is called right-circular polarization.
The electric field is made up of an x-component and a y-component.

If the x and y-components are equal in magnitude and differ in phase by 90-degrees circular polarization will result. The figures below show a representation of the resulting polarization.

Figure 3. CIRCULAR POLARIZATION - E FIELD
Sinc function
• Max Planck (1900)
  – first major result of quantum mechanics
  – Planck curves describe variation of energy flux as a function of temperature and wavelength

• Wien’s law
  – describes wavelength of peak energy flux

• Stefan-Boltzmann law
  – describes total energy output
Blackbody

- Above absolute zero (= -273.15 C = 0 K) all objects radiate at all wavelengths
- Blackbody is an idealized system that absorbs incident radiation of all wavelengths
- A blackbody is an ideal emitter; it absorbs energy completely at all wavelengths and emits a radiation field that is proportional to its temperature. Cavity is a good real-life approximation to a blackbody
• A blackbody
  – is a perfect emitter of electromagnetic radiation at all wavelengths
    • no ‘stored’ energy
  – is a perfect absorber of electromagnetic radiation
    • no reflection of incident radiation
Planck Law

\[
\frac{8\pi\nu^2}{c^3} \frac{h\nu}{\nu^3} \frac{1}{e^{h\nu/kT} - 1}
\]

Quantum

Classical

\[
\frac{8\pi\nu^2}{c^3} \frac{kT}{c^3}
\]

Rayleigh-Jeans Law

\[e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots\]

\[
\frac{h\nu}{e^{h\nu/kT} - 1} \approx 1 + \frac{h\nu}{kT} \quad \text{for} \quad h\nu \ll kT \quad \text{Low frequencies}
\]

For low frequencies the Planck Law agrees with the classical Rayleigh-Jeans Law

\[
\frac{8\pi\nu^2}{c^3} \frac{h\nu}{1 + \frac{h\nu}{kT} - 1} = \frac{8\pi\nu^2}{c^3} \frac{kT}{c^3}
\]

The "Ultraviolet Catastrophe"

Visible

Planck Radiation Formula

Rayleigh-Jeans Law

Wavelength of radiation in nm
Planck Curve and Blackbody (Thermal) Radiation
A key result:

A BB at temperature $T_1$ will emit more energy, at all wavelengths, than a BB at temperature $T_2$ provided, $T_2 < T_1$

The ‘shape’ of the BB curve is described by the Planck Function

$$I(\lambda, T) = \left(\frac{2 \pi h c^2}{\lambda^5}\right) \left(\frac{1}{\exp(hc/kT) - 1}\right)$$
A backbody radiates proportional to its temperature. Spectral radiance, $I(\lambda, T)$, is determined by Planck’s Radiation Law:

$$I(\lambda, T) = \left(\frac{2 \pi h c^2}{\lambda^5}\right) \left(\frac{1}{\exp(hc/\kappa T)-1}\right)$$

$h = \text{Planck’s constant} = 6.6260755 \times 10^{-34} \text{ joule-second}$

$k = \text{Boltzmann’s constant} = 1.3807 \times 10^{-23} \text{ joule-kevins}$
Blackbody Radiators

• Most hot objects can be approximated (to some degree) as blackbody radiators - stars certainly can.

• BB theory describes amount of electromagnetic energy radiated as a function of wavelength.

• BB’s have well defined characteristics
  – all described by their temperature $T$. 
Planck’s law defines the nature of blackbody radiation. Real objects are not blackbodies so a correction for emissivity should be made.

\[
\text{Emissivity} = \frac{\text{Radiant energy of an object}}{\text{Radiant energy of a black body with the same temperature as the object}}
\]

Emissivity ranges between 0 and 1 depending on the dielectric constant of the object, surface roughness, temperature, wavelength, look angle. The temperature of the black body which radiates the same radiant energy as an observed object is called the brightness temperature of the object.

Many natural surface materials are well approximated by blackbodies in the infrared region. For instance, water has a thermal infrared emissivity of .98.
The spectral emissivity and spectral radiant flux for three objects that are a black body, a gray body and a selective radiator.
Alunite as seen by three systems

~65-250 nm

10-50 nm

5-10 nm

FWHM

TM

MODIS

LAB
Wien’s Law

- The wavelength ($\lambda_{\text{max}}$) at which a BB emits the maximum amount of energy decreases with increasing temperature

$$\lambda_{\text{max}} T = 2.8977 \times 10^{-3}$$

- units: $\lambda$ in meters, $T$ in Kelvin
Wien’s law: $\lambda_{\text{max}}$ varies according to temperature.
Planck curve for BB of temperature $T_1$

Line connecting ‘peaks’ of BB’s of different temperature
Wien’s Displacement Law:

\[ \lambda_{\text{max}} = \frac{k}{T} \]

\( k = 2898 \, \mu m \, K \), and \( T \) is the absolute temperature in degrees Kelvin.

It is obtained by differentiating the spectral radiance.

It shows that the product of wavelength (corresponding to the maximum peak of spectral radiance) and temperature, is approximately 3,000 (\( \mu mK \) is the best for measurement of objects with a temperature of 300K).

This law is useful for determining the optimum (peak) wavelength for temperature measurement of objects with a temperature of \( T \). For example, about 10\( \mu m \) is the best for measurement of objects with a temperature of 300K.
The Stefan-Boltzmann law

- The energy emitted per second per $m^2$ (the energy flux $F$) increases with temperature:

$$F = \sigma T^4$$

- **Units:** Flux in Watts/m$^2$, $T$ in Kelvin
- **Stefan-Boltzmann constant ($\sigma$) = 5.67 x $10^{-8}$
BB of temperature $T$

Area under curve $= F = \sigma T^4$
Stefan-Boltzmann Law:

\[ M_{\lambda} = \sigma T^4 \]

Where \( \sigma \) is the Stefan-Boltzmann constant, \( 5.6697 \times 10^{-8} \text{ W}^{-2}\text{K}^{-4} \)

Gives the total amount of emitted radiation from a blackbody

Units: (Same as radiant emittance) \( \text{W m}^{-2} \)

Proportional to \( T^4 \)

Obtained by integrating the area under the Planck Curve.