Thermal radiation

Radiation of e/m waves of all wavelength is the result of oscillations of all charged particles that are in media, i.e. electrons, ions.

Radiation of the body requires energy losses. Hence, to provide plolonged radiation, one need to supply energy to the system. There can be various sources of energy for different radiations.

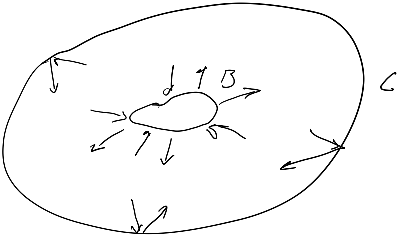
Types of radiation

1) thermal from internal energy of the body
2) luminescence
    a) chemiluminescence
    b) triboluminescence
    c) electroluminescence
    d) cathodoluminescence
    e) photoluminescence

Demonstrations

Why all types of radiation are divided into two ?

Thermal radiation is in equilibrium with surrounding bodies.



Study of thermal radiation played crucial role in our understanding of quantum nature of light.

① Kirchhoff's law

Let's introduce couple of new physical parameters:

1) Radiant emittance $R_T \left[\frac{W}{m^2} \right]$

Energy radiated in all directions, i.e. whole 4π steradian

Energy flux in small spectral range $d\omega$:

$$dR_{\omega,T} = r_{\omega,T}\, d\omega$$

2) $r_{\omega,T}$ - spectral excitance or spectral emittance

$$r_{\omega,T} = f(\omega, T)$$

☺

$$R_T = \int dR_{\omega,T} = \int_0^\infty r_{\omega,T}\, d\omega$$

In case we want to convert units:

$\lambda = \frac{2\pi c}{\omega}$ $\qquad d\lambda = \frac{\lambda^2}{2\pi c} d\omega$

$$r_{\omega,T}\, d\omega = r_{\lambda,T}\, d\lambda$$

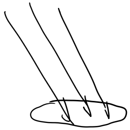
$$r_{\omega,T} = r_{\lambda,T} \frac{\lambda^2}{2\pi c}$$

3) $a_{\omega,T} = \frac{d\Phi'_{\omega,T}}{d\Phi_{\omega}}$ - absorbtive power

absorptive capacity

absorptivity

$d\Phi_{\omega}$ ~ light flux

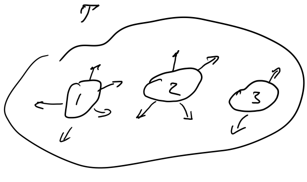


$d\Phi'_{\omega,T}$ — absorbed flux

$d\Phi_{\omega,T}$ - incoming flux

If $a_{\omega,T} = 1 \rightarrow$ absolute black body

Let's imagine we have three bodies in volume V at temperature T



Let's imagine

$r_1 > r_2 > r_3$

$a_1 > a_2 > a_3$

Since we need to be in equilibrium

$$\left(\frac{r_{\omega,T}}{a_{\omega,T}}\right)_1 = \left(\frac{r_{\omega,T}}{a_{\omega,T}}\right)_2 = \left(\frac{r_{\omega,T}}{a_{\omega,T}}\right)_3 = \ldots = f(\omega, T)$$

$f(\omega,T)$ – radiating capacity of ABB, when $a_{\omega,T} = 1$

$$\boxed{\frac{r_{\omega,T}}{a_{\omega,T}} = f(\omega, T)}$$ Kirchhoff function

Demonstration

Leslie's cube

Let's study the radiation itself.

Equilibrated radiation energy density

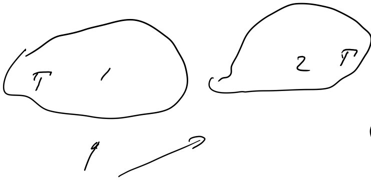
$u(T)$ – energy of radiation confined in elementary volume

$u(\omega,T)$ – spectral energy density

$$u(T) = \int_0^\infty u(\omega,T)\,d\omega$$

$u(\omega,T)$ – energy density in elementary volume and elementary spectral range

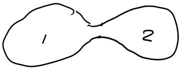
1) Let's proof now, that $u(T)$ depends only on temperature and do not depend on material properties of body walls.



different materials

If we assume

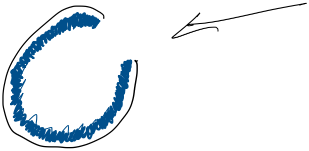
$u_1 > u_2$



1 will start to cool and 2 will start to heat up.

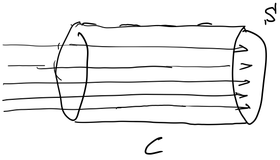
However, this process is forbidden by II law of thermodynamics.

2) Let's connect $u(T)$ with radiation capacity of ABB



We will consider the body with absolute black walls. In equilibrium, through every point inside the body there will be flux in all direction of equal density.

If all radiation would go in one single direction



$j = cu$

↑ density of radiation energy flux in every point

j is energy confined in this cylinder

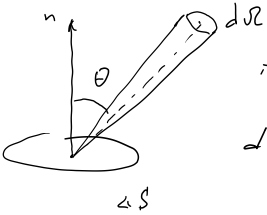
However, the flux is homogeneously distributed over 4π steradian body angle.

Hence,

$$dj = \frac{cu}{4\pi}\, d\Omega$$

In spherical coordinates:

$$d\Omega = \sin\theta\, d\theta\, d\varphi$$



The surface ΔS will send in $d\Omega$ energy flux

$$d\Phi = dj\,\Delta S\cos\theta = \frac{cu}{4\pi}\Delta\Omega\,\Delta S\cos\theta =$$

$$= \frac{cu}{4\pi}\Delta S\cos\theta\sin\theta\, d\theta\, d\varphi$$

Hence, energy flux that is radiated into whole half space:

$$\Delta\Phi = \int d\Phi = \frac{cu}{4\pi}\int_0^{\frac{\pi}{2}}\int_0^{2\pi}\cos\theta\sin\theta\, d\theta\, d\varphi = \frac{cu}{4}\Delta S$$

At the same time

$$\Delta\Phi = f(\omega, T)\,\Delta S$$

$f(\omega, T)$ - energy emissivity of ABB

$$f(\omega, T) = \frac{c\,u(\omega, T)}{4}$$

The main question of thermal radiation studies is experimental determination and theoretical understanding of $f(\omega, T)$ and $u(\omega, T)$ functions.