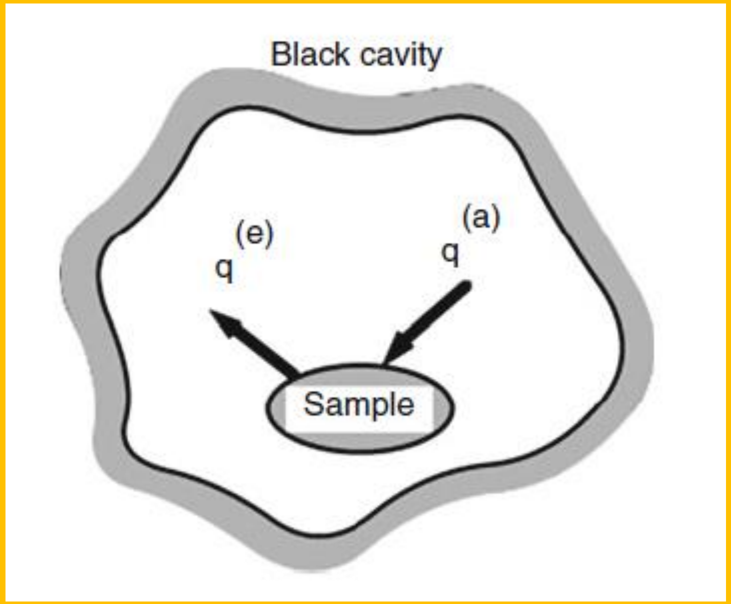
lecture (2)

Thermal radiation

❑ Research topic (1)

❖ **The emissivity and absorptivity of a surface**

❖ **Planck's distribution law in radiations**



Absorptivity

Radiation incident on an opaque surface is either absorbed or reflected. The fraction absorbed is called the absorptivity

$$a = \frac{E_a}{E_i} \qquad a_\lambda = \frac{E_{a(\lambda)}}{E_{i(\lambda)}}$$

For a real body, absorptivity varies with frequency and less of unity. For a hypothetical black body, absorptivity is unity.

❑ <u>The emissivity</u>

The emissivity of a surface is the amount of energy that a surface will emit compared to a black body at the same temperature

$$\varepsilon = \frac{E_e}{E_b}$$

In a system in <u>thermal equilibrium</u> and at constant temperature, the energy leaving any surface must equal that coming to the surface

$$\varepsilon = a$$

❑ Thermal radiation

- ❖ **Any object emits some amount of electromagnetic radiation of thermal nature, which is called thermal radiation or sometimes heat radiation. This means that some of the thermal energy is converted into electromagnetic radiation energy. At absolute zero temperature, which can never be exactly reached, that thermal radiation would vanish.**

- ❖ **Thermal radiation is well known from light bulbs and from the sun, for example. Even if the temperature is not high enough to generate visible thermal radiation, there may be strong infrared radiation which can be felt on the skin, for example.**

❑ Stefan–Boltzmann law

The rate P_{rad} at which an object emits energy via electromagnetic radiation depends on the object's surface area A and the temperature T of that area in kelvins and is given by

$$P_{\text{rad}} = \sigma \varepsilon A T^4.$$

Here $\sigma = 5.6704 \times 10^{-8}$ W/m^2 .The symbol ε represents the emissivity of the object's surface, which has a value between 0 and 1, depending on the composition of the surface. A surface with the maximum emissivity of 1 is said to be a blackbody

- The rate P_{abs} at which an object absorbs energy via thermal radiation from its environment, which we take to be at uniform temperature T_{env} (in kelvins), is

$$P_{abs} = \sigma \varepsilon A T_{env}^4.$$

- Because an object both emits and absorbs thermal radiation, its net rate P_{net} of energy exchange due to thermal radiation is

$$P_{net} = P_{abs} - P_{rad} = \sigma \varepsilon A (T_{env}^4 - T^4).$$

Example :

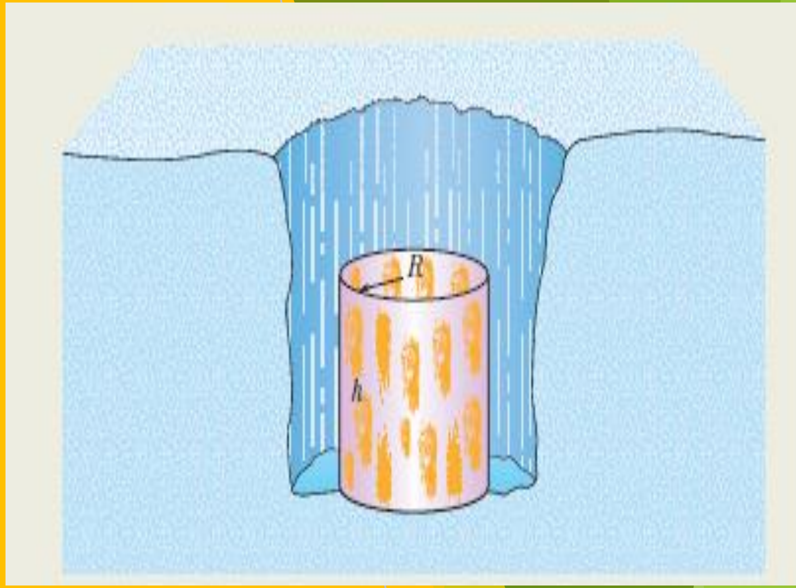
Two identical bodies radiate heat to other. One body is at 30 C and the other at 250 C. Teach he emissivity of both is 0.7. Calculate the net heat transfer per square meter.

$$Q = \varepsilon\sigma A\left(T_1^4 - T_2^4\right)$$
$$= 0.7 \times 56.7 \times 10^{-9} \times 1 \times \left(523^4 - 303^4\right)$$
$$= 2635\ \mathrm{W}.$$

Example

Unlike most other plants, a skunk cabbage can regulate its internal temperature (set at T =22C) by altering the rate at which it produces energy. If it becomes covered with snow, it can increase that production so that its thermal radiation melts the snow in order to re-expose the plant to sunlight. Let's model a skunk cabbage with a cylinder of height h = 5.0 cm and radius R =1.5 cm and assume it is surrounded by a snow wall at temperature T_{env} = 3.0C. If the emissivity ε is 0.80, what is the net rate of energy exchange via thermal radiation between the plant's curved side and the snow?

$$P_{net} = P_{abs} - P_{rad} = \sigma \varepsilon A (T_{env}^4 - T^4).$$



We need the area of the curved surface of the cylinder, which is $A = h\,(2\pi R)$. We also need the temperatures in kelvins:

T_{env} = 273 K+(-3)K = 270 K and T = 273 K +22 K = 295 K.

$$P_{net} = (5.67 \times 10^{-8})(0.80)(0.050)(2\pi)(0.015)(270^4 - 295^4) = -0.48\ \text{W}. \qquad \text{(Answer)}$$

Thus, the plant has a net <u>loss</u> of energy via thermal radiation of 0.48 W.

❑ Blackbody radiation

- ❖ All objects with a temperature above absolute zero (0 K, -273.15 ºC) emit energy in the form of electromagnetic radiation. A blackbody is a theoretical or model body which absorbs all radiation falling on it, reflecting or transmitting none. It is a hypothetical object which is a “perfect” absorber and a “perfect” emitter of radiation over all wavelengths.
- ❖ **This radiation, which depends on the temperature and other properties of an object, typically consists of a continuous distribution of wavelengths from the infrared, visible, and ultraviolet portions of the spectrum.**

Planck's Law of blackbody radiation

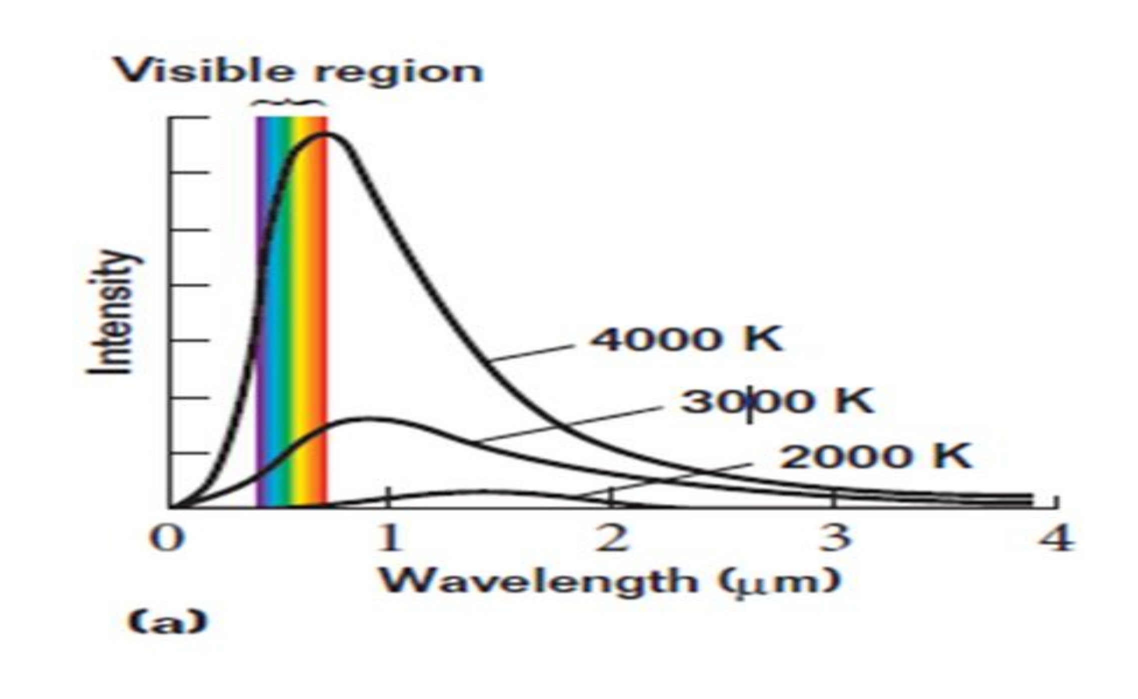
Planck's Law of blackbody radiation, a formula to determine the spectral energy density of the emission at each wavelength (E_λ) at a particular absolute temperature (T)

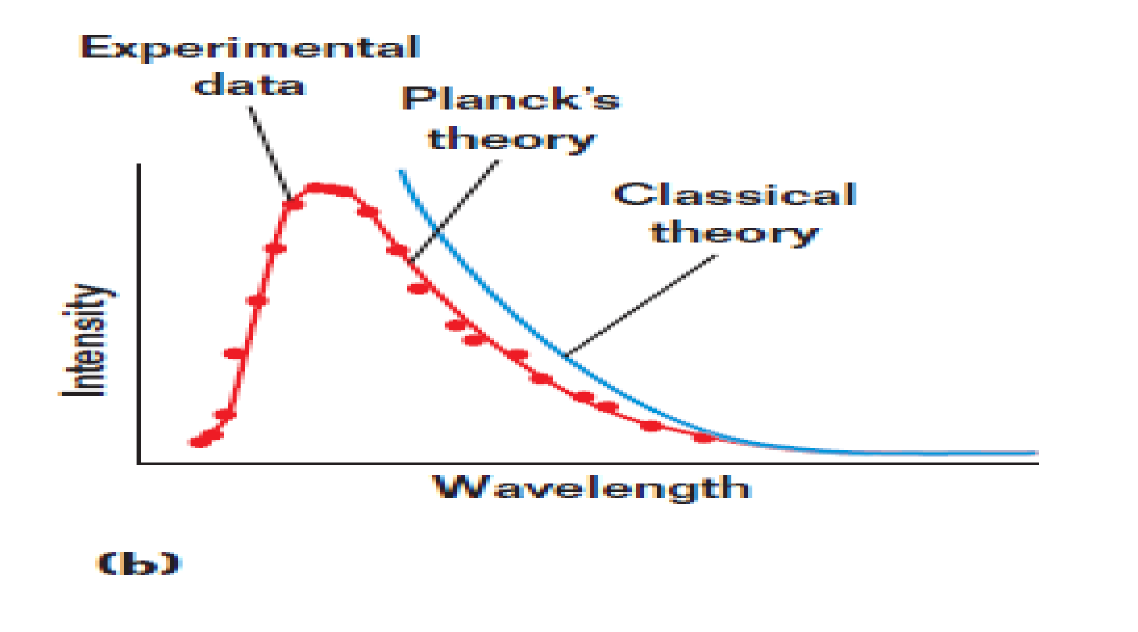
$$E(\lambda, T) = \frac{2hc^2}{\lambda^5} * \frac{1}{e^{\left(\frac{hc}{\lambda kT}\right)} - 1}$$

$\mathrm{h} = \text{Planck's constant} = 6.626 * 10^{-34}\, J * s$
$\mathrm{c} = \text{speed of light} = 2.997925 * 10^{8}\, m / sec$
$\lambda = \text{wavelength (m)}$
$\mathrm{k} = \text{Boltzmann's constant} = 1.381 * 10^{-23}\, J/K$
$\mathrm{T} = \text{temperature (K)}$

❖ As the temperature of an object increases, the range of wavelengths given off shifts into the visible region of the electromagnetic spectrum

❖ Classical theory predicts that as the wavelength approaches zero, the amount of energy being radiated should become infinite. This prediction is contrary to the experimental data, which show that as the wavelength approaches zero, the amount of energy being radiated also approaches zero. This contradiction is often called ultraviolet-catastrophe, because the disagreement occurs at the ultraviolet end of the spectrum





❑ Wien's law,

❖ **Wien's law, also called Wien's displacement law, relationship between the temperature of a blackbody (an ideal substance that emits and absorbs all frequencies of light) and the wavelength at which it emits the most light .**

$$\lambda_m T = b = 0.2898 \; (\mathrm{Cm\,.\,K})$$

Wien's law of the shift of the radiative power maximum to higher frequencies as the temperature is raised expresses in a quantitative form commonplace observations.

Example:

A disc has radii 2 m is coated with carbon black on their outer surfaces. The wavelengths corresponding to maximum intensity are 300 nm. Calculate the power radiated a disc.

$$\lambda_m T = 0.2898 = b$$

For a thin disc of radius r emitting from both surfaces

$$A = 2\pi r^2.$$

$$P = \sigma\varepsilon A T^4.$$

$$P = 2\pi\sigma\,\varepsilon\, b^4 (r^2/\lambda^4)$$

Finish …

Thank you