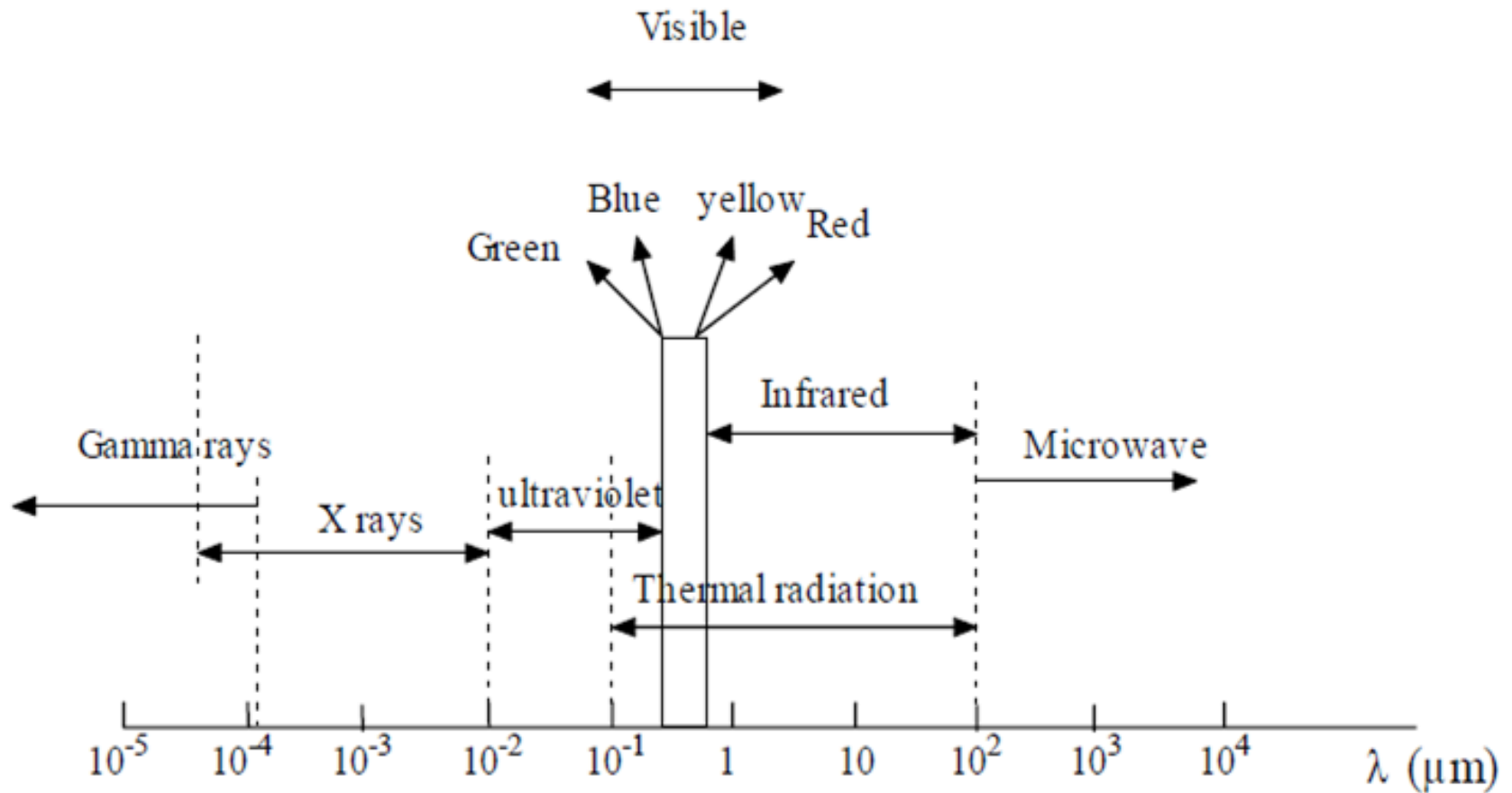


Infra-red (IR) Thermography

MSc in NDT

Optical and IR Methods

Infra-red (IR) Thermography



Infra-red (IR) Thermography

- One or two dimensional, noncontact technique of temperature measurement.
- An infrared scanning radiometer (IRSR) detects the electromagnetic energy radiated in **one infrared spectral band** by an object (whose surface temperature is to be measured and which should be **fully opaque to the detected band**) and converts it into an electronic video signal.
- Introduced in the early 1960s, infrared thermography was regarded as an exciting scientific breakthrough. The produced two-dimensional images, which **qualitatively** allowed for seeing the invisible, were considered astonishing.
- Fully computerized infrared imaging system of the new generation can provide both **qualitative** and **quantitative** measurements which are of utmost importance in a vast variety of industrial as well as research fields.

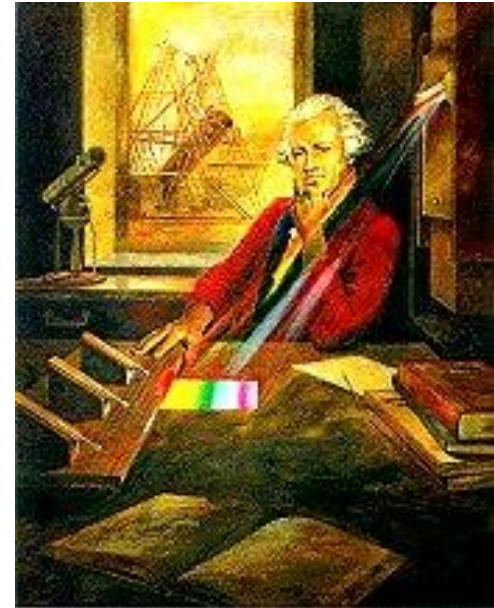
Infra-red (IR) Thermography

Origins

- The origin of infrared thermography comes from the early 1800s when the English physicist William Herschel discovered thermal radiation outside the deep red in the visible spectrum, the invisible light later called infrared.

Refer to the Herschel Experiment sheets for more information.

- In the succeeding years, many physicists, amongst them Macedonio Melloni, Gustav Kirchhoff, Clark Maxwell, Joseph Stefan, Ludwig Boltzmann and Max Planck, addressed the problem of fully understanding the energy distribution in the spectrum of thermal radiation.



Infra-red (IR) Thermography

Planck's Radiation Law

- In 1900, Planck derived the law of radiation (experimentally at first), which precisely describes the spectral distribution of the radiation intensity from a blackbody:

$$W_{\lambda b} = \frac{C_1}{\lambda^5 (e^{C_2 / \lambda T} - 1)}$$

where, $W_{\lambda b}$ is the blackbody monochromatic radiation intensity (W cm^{-2}), C_1 (=37,418) and C_2 (= 14,388) are the first and second radiation constants, respectively, λ is the wavelength of the radiation being considered (μm) and T is the absolute temperature of the blackbody ($^\circ\text{K}$).

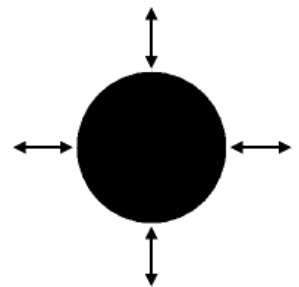
Infra-red (IR) Thermography

Radiation Heat Transfer Definition

- Heat transfer through radiation takes place in form of electromagnetic waves mainly in the infrared region.
- Radiation emitted by a body is a consequence of thermal agitation of its composing molecules.
- Radiation heat transfer can be described by a reference to the so-called '**black body**'.

Black Body Definition

- A black body is defined as a body that absorbs all radiation that falls on its surface. Actual black bodies don't exist in nature - though its characteristics are approximated by a hole in a box filled with highly absorptive material.
- A black body is a hypothetical body that completely absorbs all wavelengths of thermal radiation incident on it. Such bodies do not reflect light, and therefore appear black if their temperatures are low enough so as not to be self-luminous.
- All blackbodies heated to a given temperature emit thermal radiation.

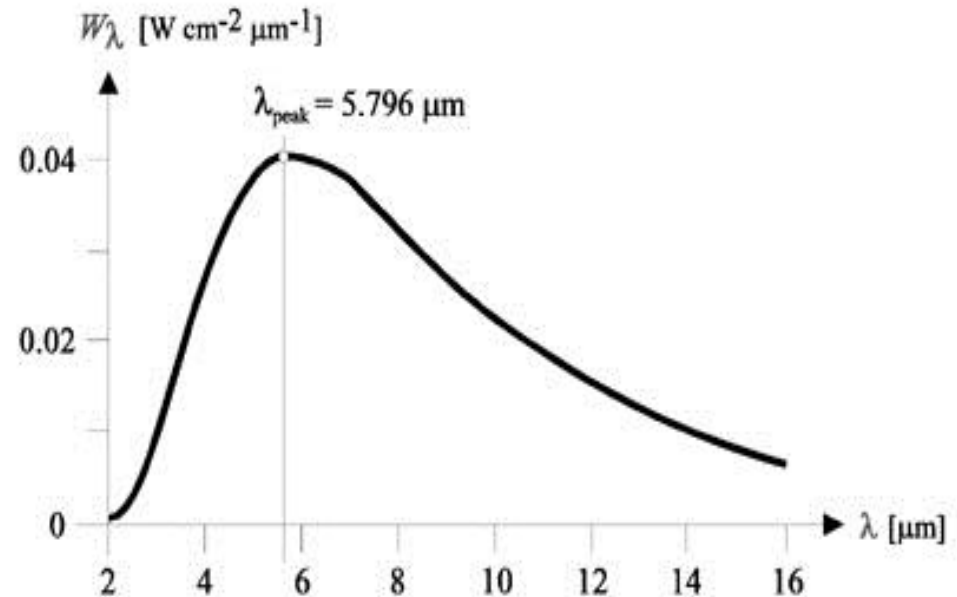


Infra-red (IR) Thermography

Planck's Radiation Law

In the equation there is a strong dependence on the wavelength and that $W_{\lambda b}$ goes to zero when $\lambda = 0$ and ∞ .

Planck's curve for a 500 K blackbody is shown in the figure (Note: $W_{\lambda} = W_{\lambda b}$ in this figure)



Problem 1.

Set up an Excel Spreadsheet to determine the intensity radiation curve for a specified temperature (use a fixed reference cell for this).

Note the effects that varying temperature has on the curve, both in terms of energy levels and wavelength.

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Wien's Displacement Law

By differentiating Planck's law with respect to λ and looking for the maximum radiation intensity, the Wien's displacement law is obtained:

$$\lambda_{\max} = \frac{2898}{T}$$

which mathematically expresses the common observation that colours vary from red to orange to yellow, as the temperature of a thermal radiator increases.

So, the sun (about 6000 K) emits yellow light peaking at about 0.5 μm in the visible light spectrum. At ambient temperature (300 K) the peak of radiation lies in the far infrared at about 10 μm , while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant radiation intensity occurs at 38 μm in the extreme infrared wavelength.

Infra-red (IR) Thermography

Stefan-Boltzmann Law

By integrating Planck's law over the entire spectrum ($\lambda=0-\infty$), *the total radiation intensity can* be obtained which is expressed by the Stefan-Boltzmann law:

$$W_b = \sigma T^4$$

Where $\sigma = 5.67 \times 10^{-12}$ (W.cm⁻².K⁴) is the Stefan-Boltzmann constant.

Problem 2.

- a) Extend your Excel Spreadsheet to include both Wien's Displacement and Stefan-Boltzmann equations.
- b) By numerically integrating the radiation law derived curve along with the curves maximum (Problem 1.), compare the computed values with those obtained using the equations implemented in part a.

Infra-red (IR) Thermography

Spectral Bands

The electromagnetic spectrum is roughly divided into a number of wavelength regions called bands. The infrared spectral band is generally subdivided into 3 or 4 lesser bands (with arbitrarily chosen boundaries):

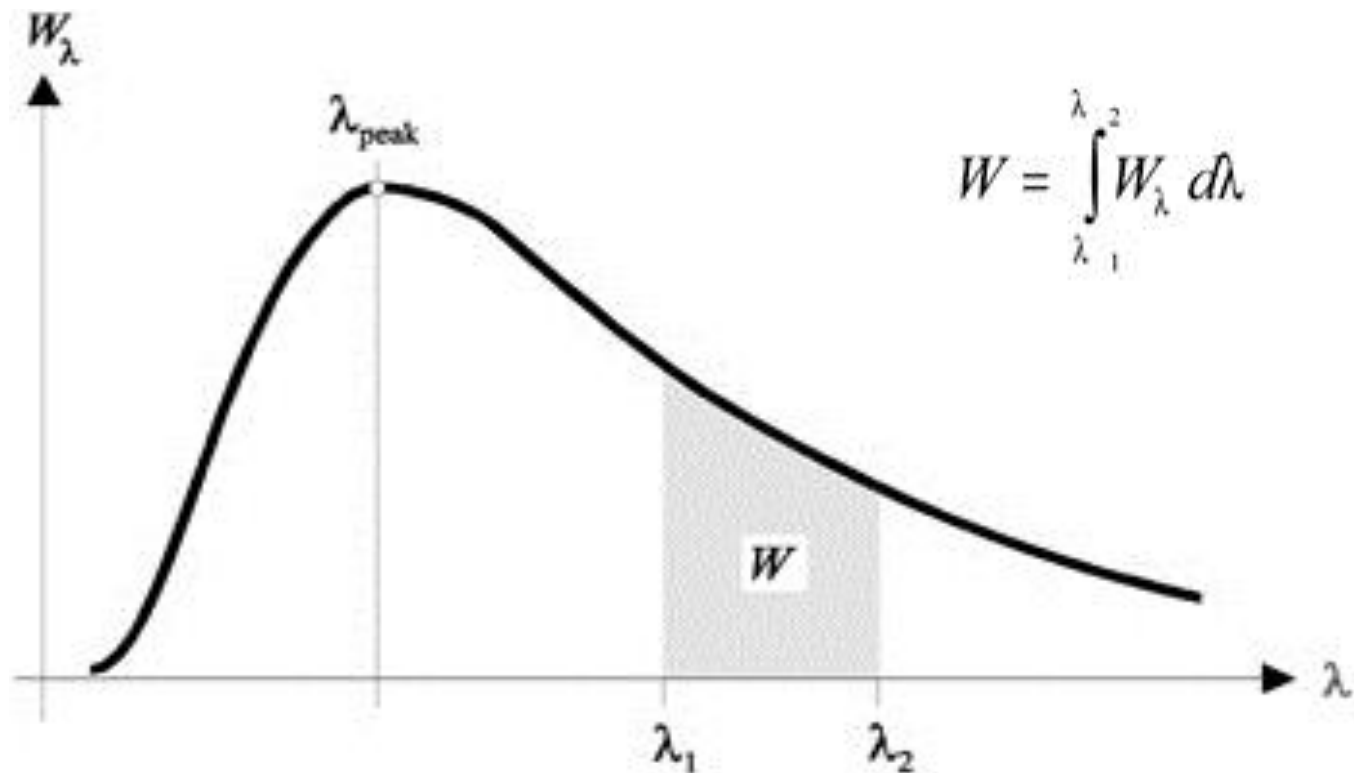
Designation	Abbreviation	Wavelength
Near Infrared	NIR	0.75 - 3 μm
Mid Infrared	MIR	3 - 6 μm
Far Infrared	FIR	6 - 15 μm
Ultra Far Infrared	UFIR	15 - 1000 μm

These divisions are not precise and can vary depending on the application and publication. The regions are used for observation of different temperature ranges, and hence different environments.

Infra-red (IR) Thermography

Spectral Bands (cont.)

To determine the radiant emittance over a spectral band, we integrate under the Planck curve between the limiting wavelengths λ_1 and λ_2 .



Infra-red (IR) Thermography

Spectral Bands (cont.)

A very convenient way is to apply Simpson's rule with the aid of a calculator.

$$W \cong \sum_{\lambda_1}^{\lambda_2} W_{\lambda} \Delta\lambda$$

Using a $\Delta\lambda$ of 0.05 or even 0.1 μm is sufficient for summations over the midwavelength (MWIR) and long-wavelength (LWIR) infrared regions (3–5, and 8–12 μm).

Note: If the spectral band is relatively narrow, $W \approx W_{\lambda} \Delta\lambda$.

Note: Rectangular or Trapezoidal Methods could also be used!

Infra-red (IR) Thermography

Spectral Bands (cont.)

Problem 3.

An infrared temperature sensor is operating in the *far infrared* region with a spectral bandwidth of (8 -14 μm) . The sensor is used to monitor the temperature variation of a component that resembles a **blackbody** in its behaviour.

Using Planck's electromagnetic radiation law and relevant numerical techniques determine the radiant intensity as a function of temperature. Use a temperature range of 20 - 100°C. Use increments of 10 C.

Infra-red (IR) Thermography

Emissivity

- It has to be pointed out that Planck's radiation law describes the radiation emitted from a blackbody which is the maximum value radiated by a body at a given temperature.
- Real objects almost never comply with this law although they may approach the behaviour of a blackbody in certain spectral intervals.
- A real object generally emits only a part $E_{\lambda} \leq E_{\lambda b}$ of the radiation emitted by a blackbody at the same temperature and at the same wavelength.
- By introducing the quantity:

$$\varepsilon_{\lambda} = \frac{W_{\lambda}}{W_{\lambda b}}$$

which is called spectral emissivity coefficient.
Planck's equation can be rewritten for real bodies by simply multiplying its right hand term by ε_{λ} .

Infra-red (IR) Thermography

Gray Bodies and Emissivity Coefficients

For the gray body the incident radiation (also called irradiation) is partly reflected, absorbed or transmitted.

Problem 4.

Assume for problem 3 that the component had a true surface emissivity of 0.73 over the spectral range of the sensor.

Determine the theoretical temperature measurement error through the initial assumption that the component behaved like a blackbody.

