Thermal Energy, Infrared Energy and Temperature

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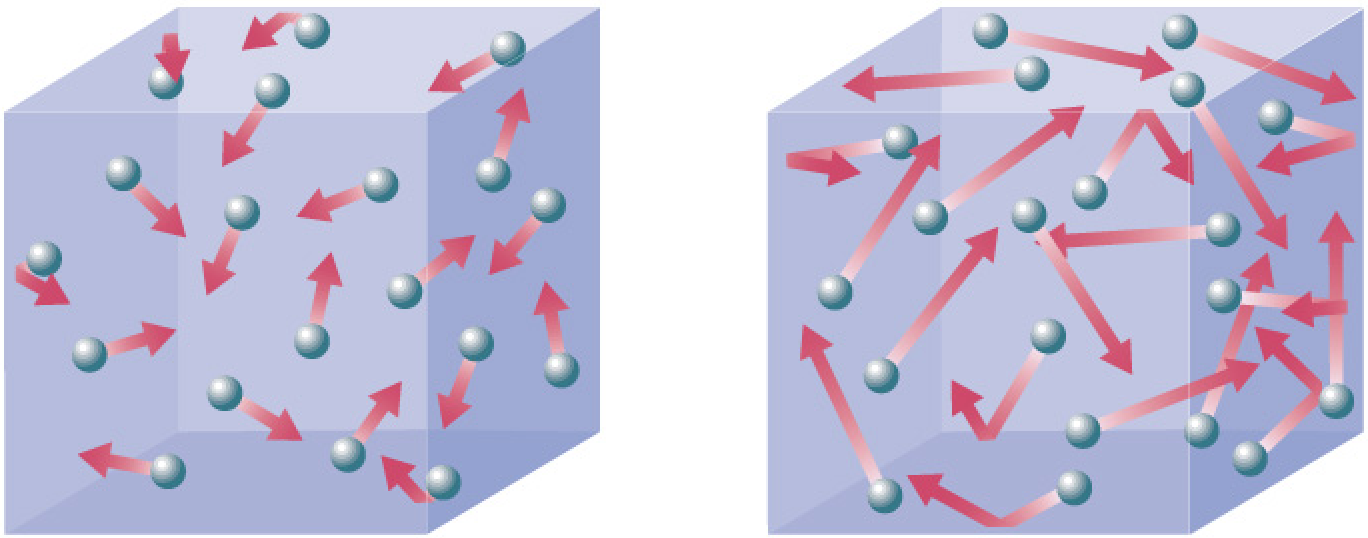
Thermal Energy



Longer arrows mean higher average speed.

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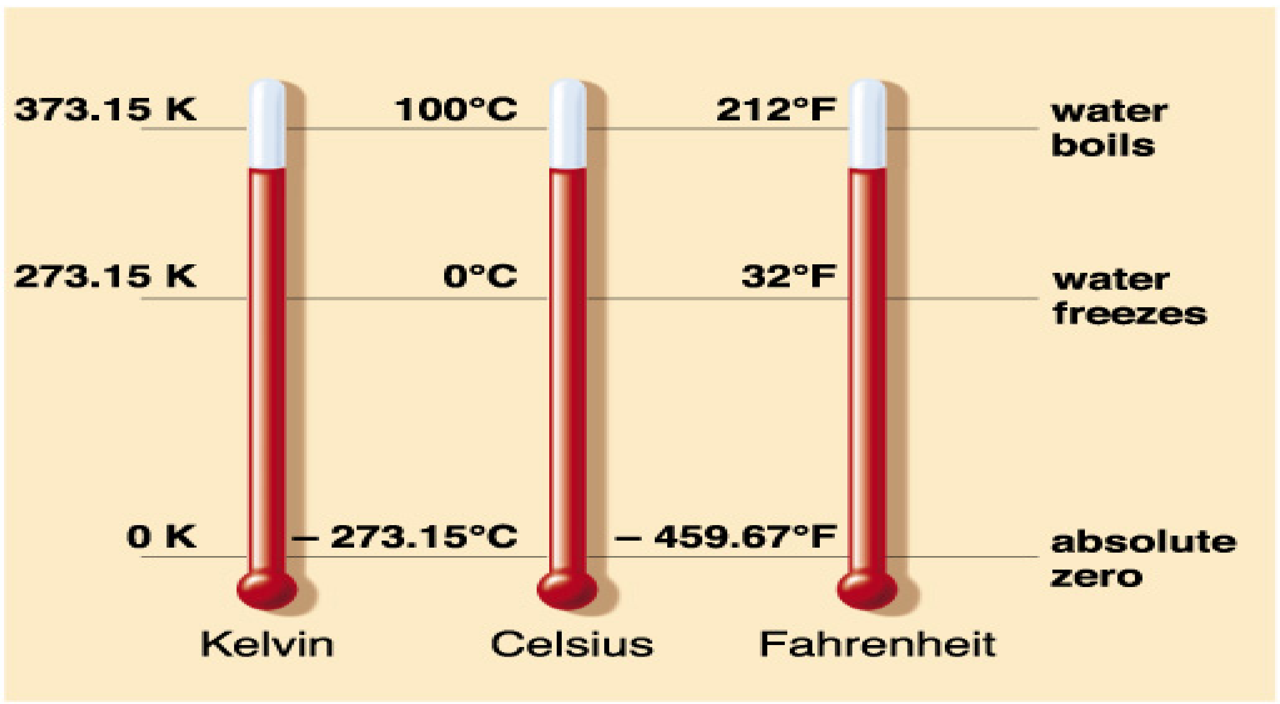
Thermal Energy and Temperature – Absolute Zero



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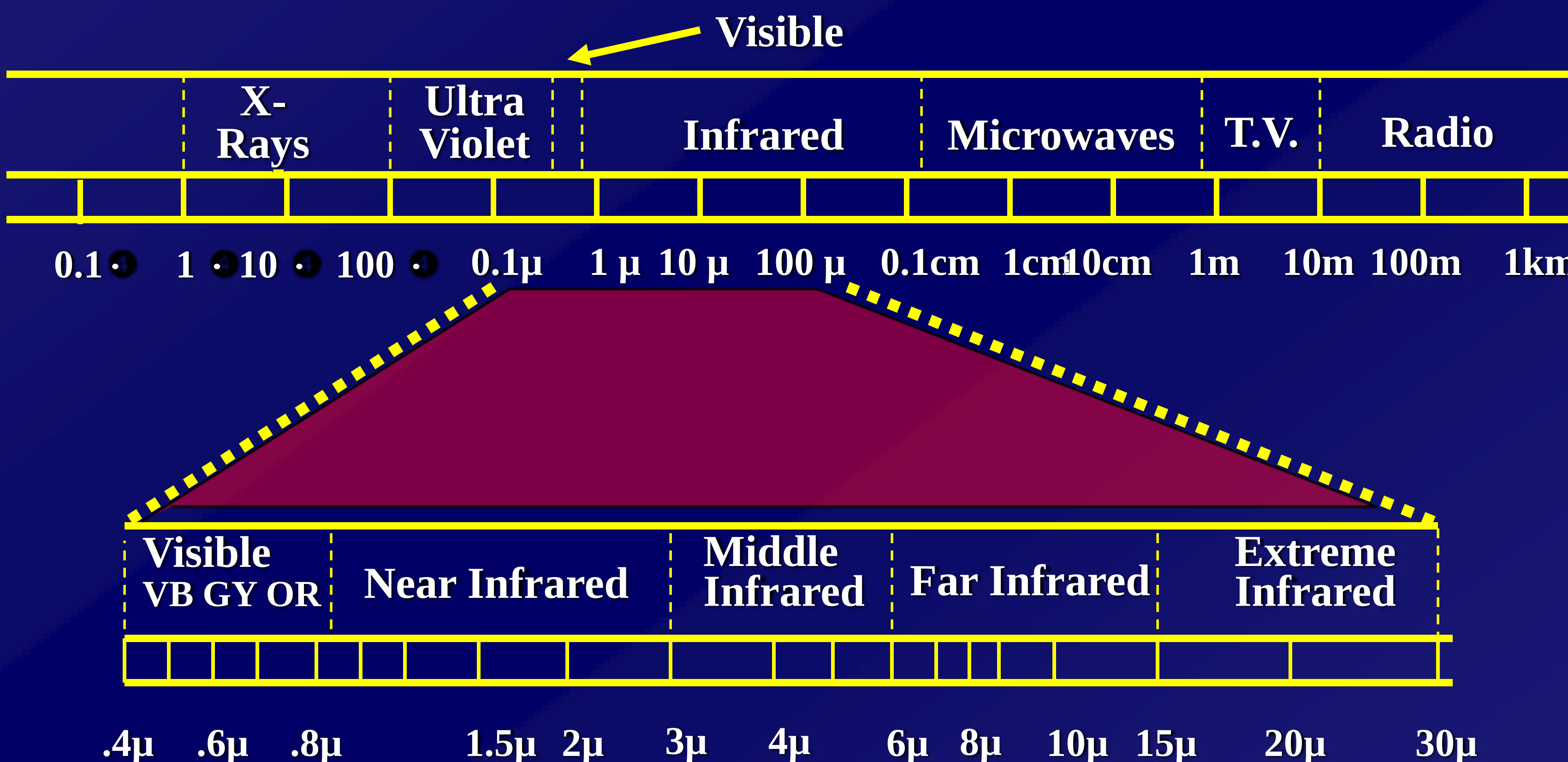
Electromagnetic Spectrum



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Properties of Infrared Energy

- All objects emit infrared energy
- Infrared Energy Exhibits the Same Properties as Visible Light
  - Travels in straight lines at the speed of light
  - Bounces off reflective surfaces
  - Transmits through IR windows

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The Relationship of Energy to Temperature

- Emitted infrared energy is proportional to the object's temperature
  - As objects get hotter, they emit more energy
  - As objects get cooler, they emit less energy
- The amount of energy emitted is a function of temperature & emissivity
- Opaque objects emit energy at all wavelengths
  - Energy is visible to the eye at temperatures above about 1200°F (650°C)

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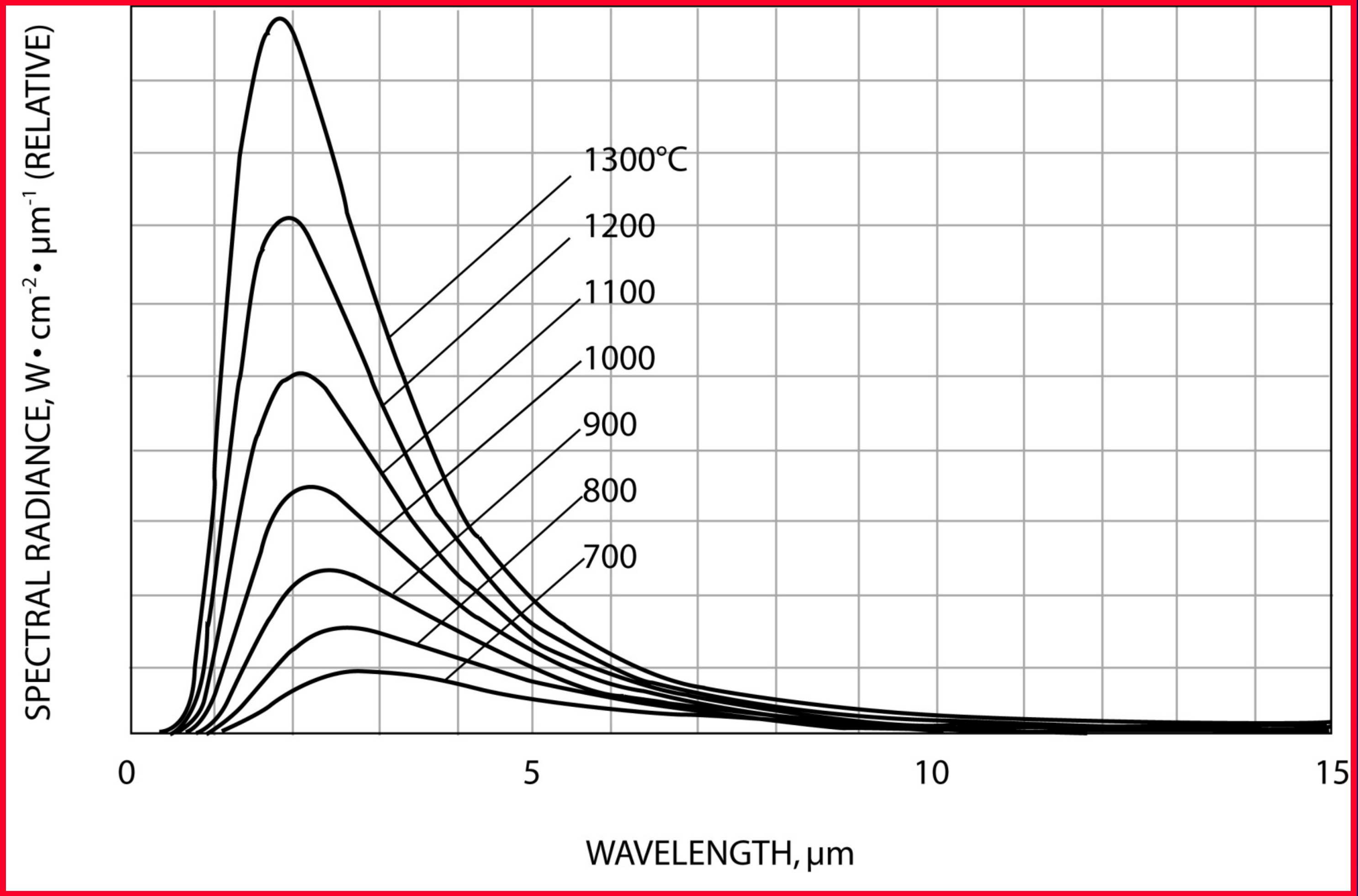
Blackbody Emissions

Infrared Energy vs Wavelength



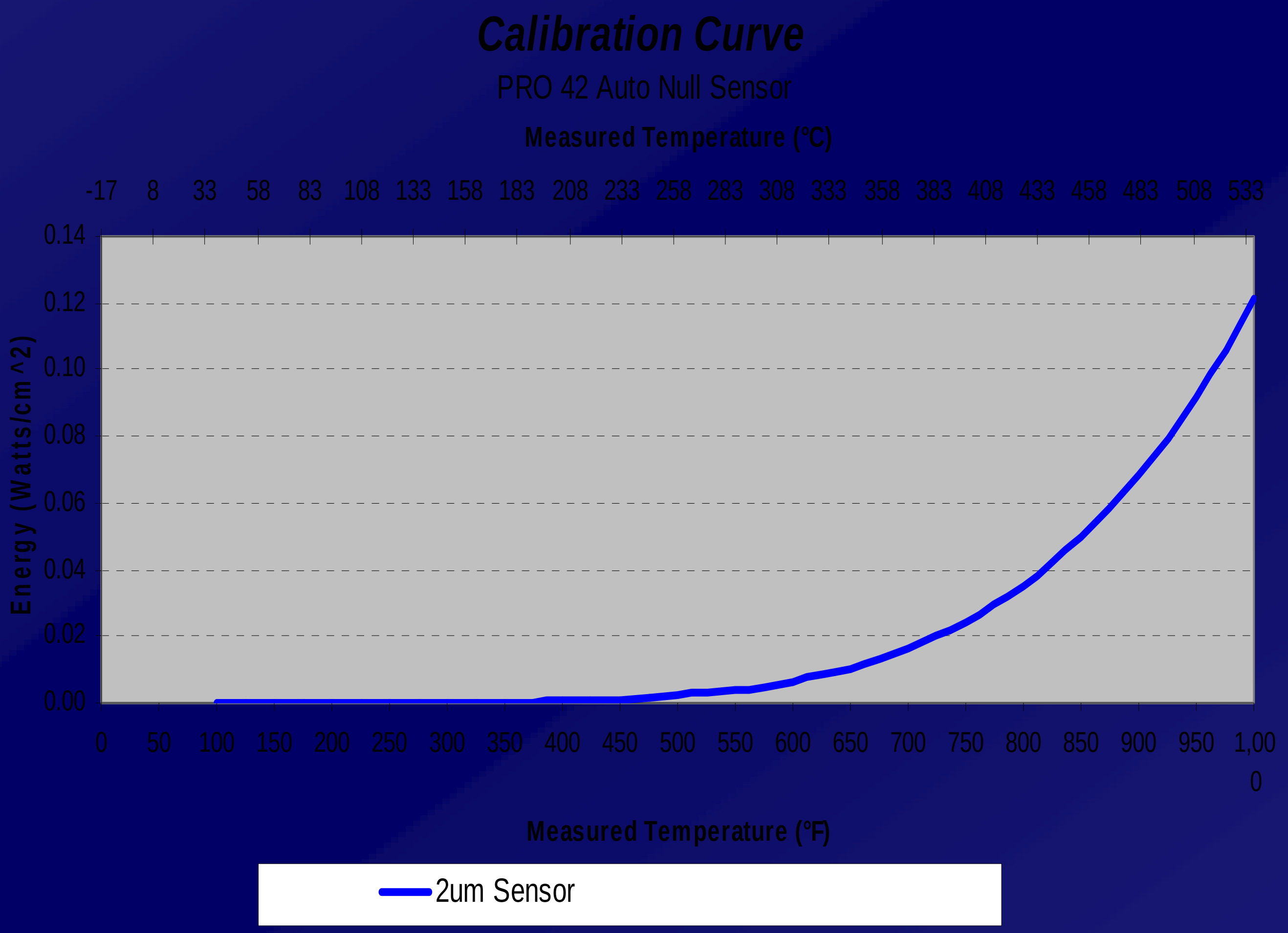
Plank's Equation

$$E_{b\lambda}(\lambda,T) = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda T}\right)-1\right]}$$

Stefan-Boltzman Law

$$E_b(T) = \sigma T^4$$

Infrared Energy vs. Temperature



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Emissivity, Reflectivity and Transmission

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Definition of a Blackbody

1. A blackbody absorbs all incident radiation
2. For a given temperature and wavelength, no surface can emit more energy than a blackbody
3. All blackbody radiation is independent of direction

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Scientific Definition of Emissivity

Emissivity (ε) is:

The ratio of infrared energy emitted by an object compared to the amount of infrared energy emitted by a perfect emitter (blackbody) at the same temperature.

ε = (Measured IR Energy)/(Blackbody Value)

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Definition of Emissivity

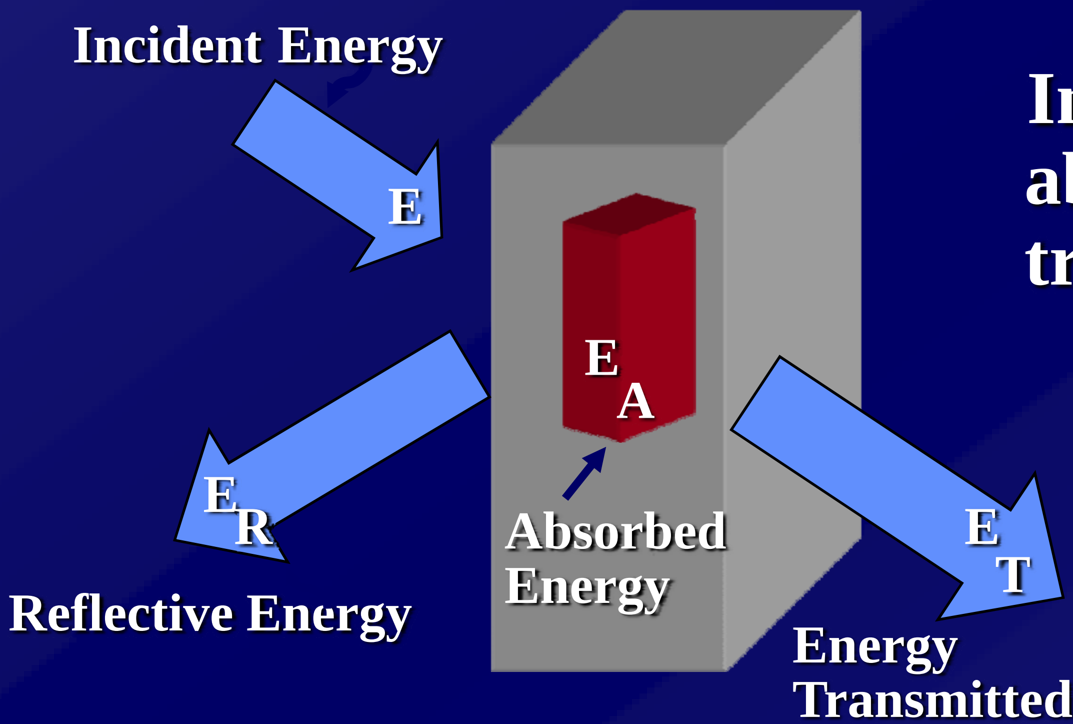
Emissivity is:

The ability of an object to emit infrared energy is equal to the ability of an object to absorb infrared energy.

Emissivity = Absorption.

Emissivity = 100% - Reflectivity - Transmission

Energy Transmission, Absorption, & Reflection



Incident Energy is either absorbed, reflected, or transmitted

$$E = E_R + E_T + E_A$$

$$\text{Emissivity} = E_A \,/\, E$$

Simple Definition of Emissivity

Emissivity is:

For an opaque material, emissivity is the opposite of reflectivity.

E = 100% - Reflectivity.

Surface Emissivity Characteristics

- Emissivity is:
  - A property of the target material & surface
  - Between 0.000 and 1.000 (1 = perfect emitter)
  - Independent of color
- For some materials, emissivity is relatively high & constant.
- For some materials emissivity is less than 1 and variable due to changes in material, surface oxidation, surface roughness, microstructure or coating.

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Surface Emissivity Characteristics

Emissivity Varies With Changes in ...

- Material or Alloy,
- Surface Oxidation,
- Surface Roughness,
- Microstructure, or
- Surface Contamination.
- Direction (angle)
- <u>Wavelength</u>

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Emissivity of Select Materials*

- Metallics and their Oxides
  - Polished Aluminum .04
  - Anodized Aluminum .82
  - Polished Stainless Steel .23
  - Lightly Oxidized SS .33
  - Highly Oxidized SS .67
- Non Metallics
  - Concrete .88-.93
  - Paint, white zinc oxide .92
  - Alumina Brick .40
  - Kaolin Brick .70
  - Water .92

* Incropera, F.P. and DeWitt, D.P. Fundamentals of Heat and Mass Transfer, 3rd Edition, pp. A27-A29

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Wavelength Issues

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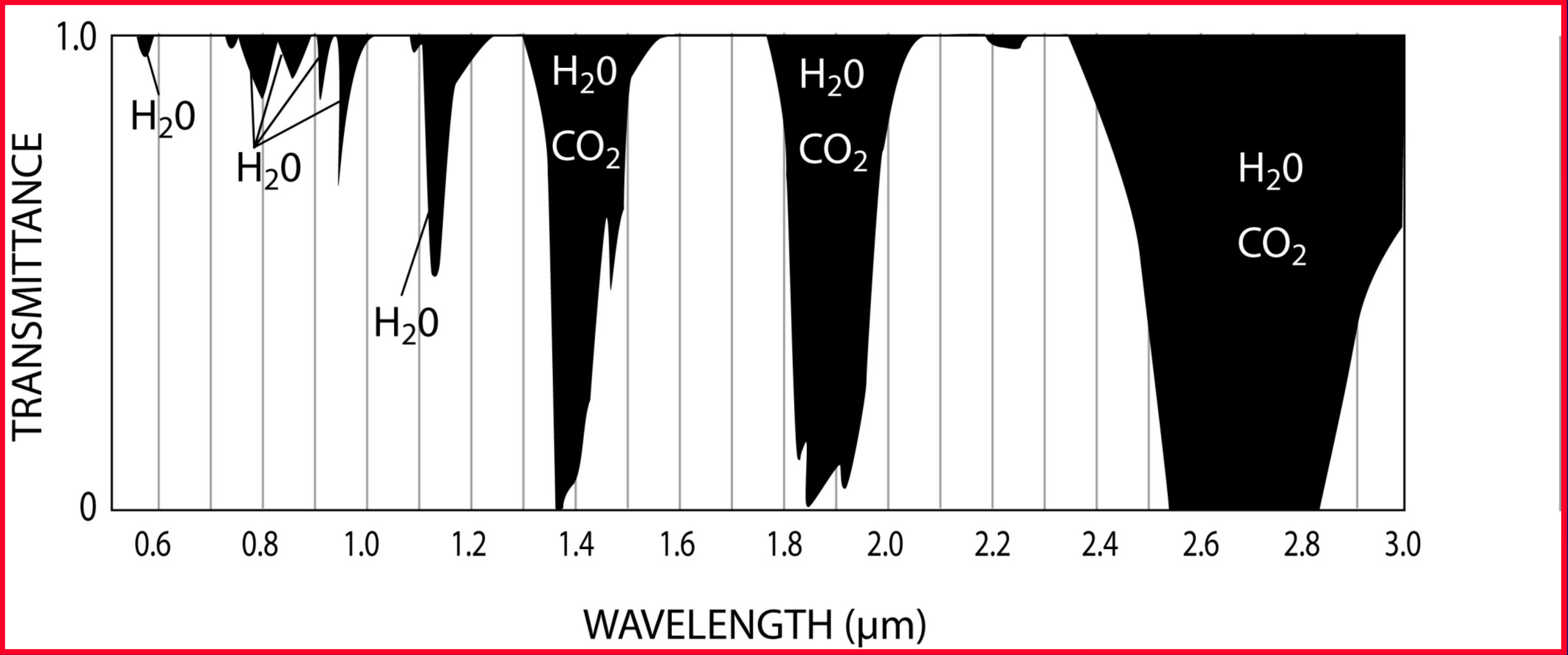
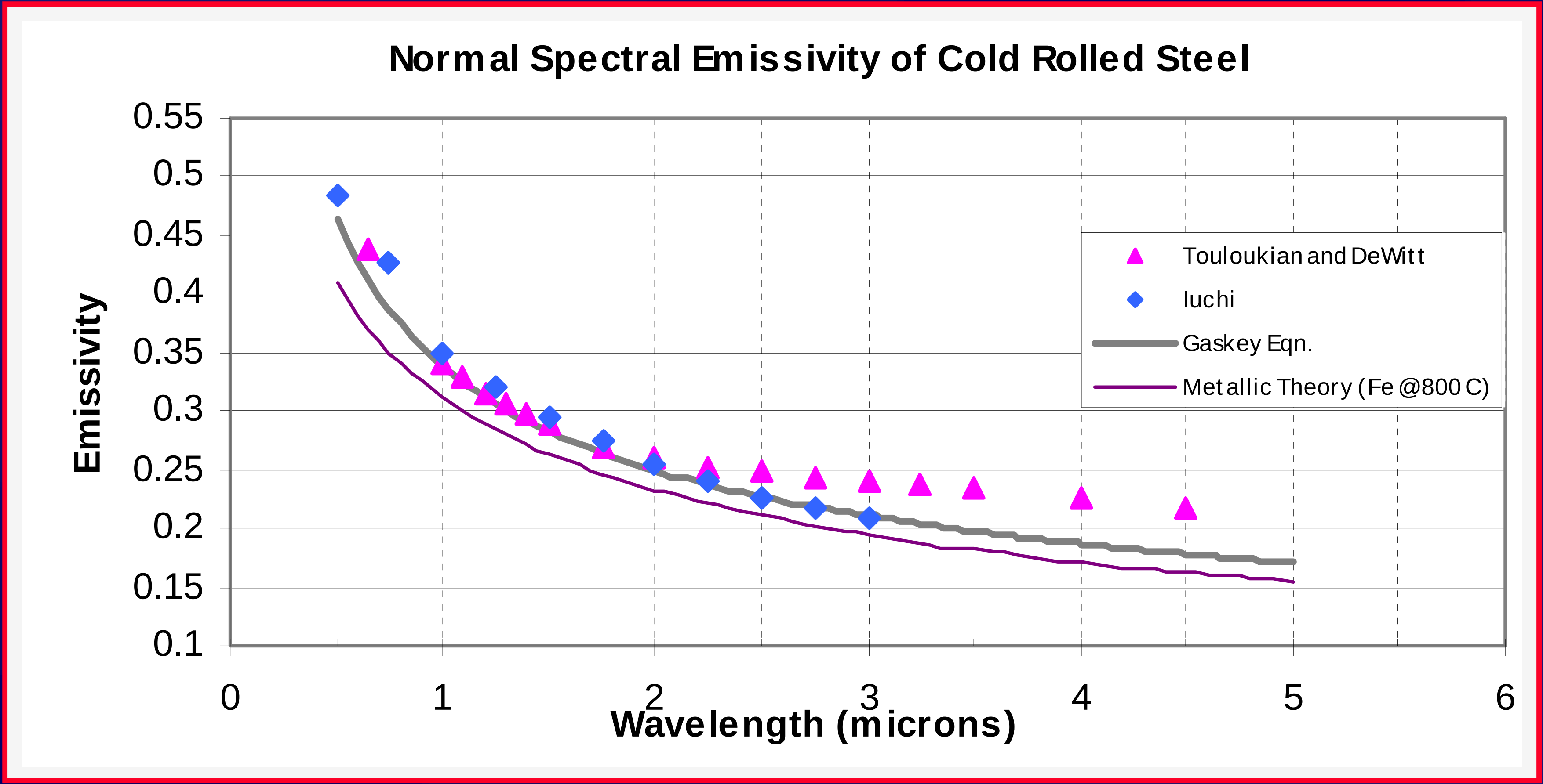
Atmospheric Absorption



Emissivity of Cold Rolled Steel



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Error due to Emissivity Variation – Brightness Sensor

$$\frac{\Delta T}{T} \approx \frac{\lambda \cdot T}{C_2}\left(\frac{\Delta \varepsilon}{\varepsilon}\right)$$

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Definition of e-slope

For a dual-wavelength pyrometer operating at wavelengths λ_1 and λ_2

$$eslope = \left(\frac{\varepsilon_{\lambda_1}}{\varepsilon_{\lambda_2}}\right) - 1$$

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Error due to Emissivity Variation – Ratio Sensor

$$\frac{\Delta T}{T} \approx \frac{\Lambda T}{C_2} \frac{\Delta r}{r}$$

$$\Lambda = \frac{\lambda_1 \cdot \lambda_2}{(\lambda_2 - \lambda_1)}$$

$$r = \frac{\varepsilon_1}{\varepsilon_2}$$

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Grey vs. Non-Grey Surface

- Grey Surface - Emissivity is independent of wavelength
  – Most ceramics and other non-metallics
- Non-Grey Surface - emissivity depends on wavelength
  – Most metallics, including steel

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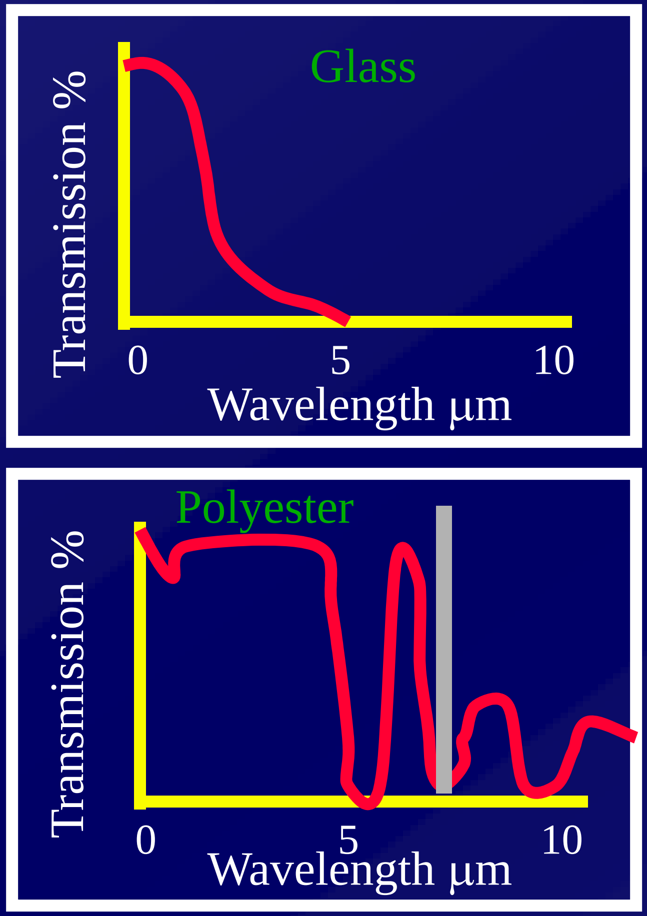
Transmission Characteristics (Selective Emitters)



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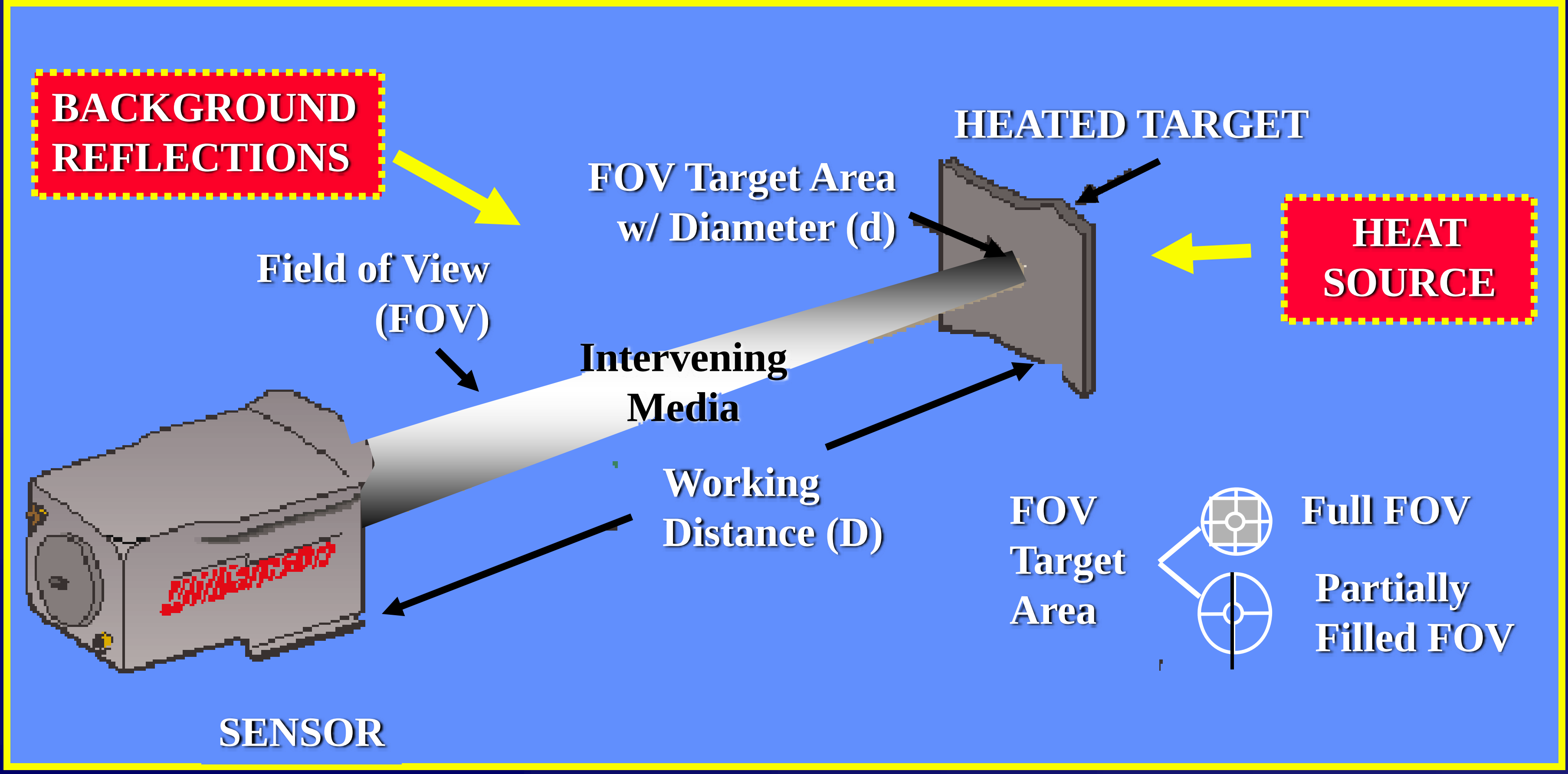
Temperature Application Issues



ΔT (System) = ΔT (Emissivity) + ΔT (Transmission) + ΔT (Background) + ΔT (Instrument) + ΔT (Alignment)

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Brightness Sensors

- Tend to measure an average temperature value
- Are affected by changes in emissivity, optical obstruction & stray background energy
- **Wavelength Matters!**

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Ratio Sensors

- Compensate for emissivity variation, and tend to measure the hottest temperature viewed.
- Are affected by changes in e-slope, wavelength-selective optical obstruction and excessively hot background reflections.
- Wavelength Matters!

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Multi-Variant Sensors

- Are used whenever traditional sensors are not appropriate.
- Use multiple wavelengths to characterize the emissive nature of the measurement.
- Multi-Variant algorithms are developed for each application type (usually the same from one plant to the next) to address specific emissivity or interference issues.

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Multi-Wavelength Infrared Thermometers

- Designed for difficult materials and challenging applications.
- Used where single- & dual-wavelength sensors can’t meet requirements
- Common measurements include Aluminum, Brass, Copper, Zinc, Galvanneal, Stainless Steel, Electrical Steel, High Strength Steel, Cold Rolled Steel, Magnesium, Chrome, etc… .

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Advanced Infrared Technologies

- Brightness Technology
  - Auto Null Technology for Low-Temperature, Short-Wavelength, Single-Wavelength Measurements.
  - Low or Varying Emissivity at Low Temperatures (below 400-600 F / 200-300 C)
  - Low Temperature Measurement through Windows.
  - Narrow band wavelengths to avoid common interference sources or to measure selective emitters.
- Dual-Wavelength Technology
  - Compensates for varying emissivity, optical obstructions, temperature gradients, and misalignment.
  - Unique wavelength selection to view through water and steam and for low-temperature measurement.
  - Advanced Signal Conditioning with Unique ESP Technology
- Multi-Wavelength Technology
  - Used for Non-Greybody Measurements.
  - Advanced Signal Conditioning with Unique ESP Technology

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Other Infrared Technologies

- Line Scanners
- Thermal Imaging Cameras
- Flame Detectors
- Hot Metal Detectors
- Two-Component Background Compensation System
- Laser Reflection Multi-Variant Type

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