Radiation

Topics: Part I: Radiation
1. Introduction
2. Electromagnetic Radiation
3. Radiation Spectrum
4. Radiation Laws
   a. General Principles
   b. Reflection, Absorption & Transmission
   c. Black Bodies & Gray Bodies
   d. Planck’s Law
   e. Stefan-Boltzmann Law
   f. Wien’s Law

Introduction: Radiation is…

• A Mode of Energy transfer
  ▪ by electromagnetic waves
  ▪ only mode to transfer energy in a vacuum, i.e. without the presence of a substance (fluid or solid)

• The only way for Earth to receive energy from the Sun

• What powers Weather systems

• Spatially & temporally variable; influenced by
  ▪ Earth-Sun geometry
  ▪ Atmospheric Composition
    • O₃ absorbs (shortwave) UV radiation
    • H₂O, CO₂, greenhouse gases trap Infrared (longwave) radiation
Electromagnetic Radiation

- Radiation waves exhibit characteristics of both

- Electromagnetic radiation moves at the speed of light
- Radiation spreads

Electromagnetic Radiation

- Electromagnetic radiation is described by three interdependent variables:
  - $\lambda$ “lambda” [m, µm]
  - $\nu$ “nu” [s⁻¹, Hz]
  - $c$ [m s⁻¹]

- $(c = \text{speed of light} \sim 3 \times 10^8 \text{ m s}^{-1})$

  $$\lambda \cdot \nu = c$$
Radiation Spectrum

- The *Radiation Spectrum*: the distribution of radiative energy over different wavelengths or frequencies.

- In meteorology
  - Three important ranges:
    - Shortwave radiation: only solar radiation
    - Longwave radiation: IR radiation emitted by E/A system
Radiation Laws: General Principles

• All things emit radiation
  ▪ The amount and wavelengths depend primarily on the emission temperature
  ▪ The higher the temperature
    →
    →
    →

• When any radiation is absorbed by an object:
  →
  →

Conservation of Radiant Energy: Reflection, Absorption & Transmission

• Three things can happen when radiation with a given wavelength, \( \lambda \), hits an object or substance:
  1. Part or all can be reflected:
     • fraction reflected: ____________________________
     • This part does not interact with the object, it is reflected
  2. Part or all can be absorbed:
     • fraction absorbed: ____________________________
     • This part is converted to another form of energy – usually heat energy, which raises the temperature of the object
  3. Part or all can be transmitted:
     • fraction transmitted: ____________________________
     • This part does not interact with the object, it just goes through it.

• Since these are the only possibilities, it follows from the principle of conservation:
  \[ \alpha_\lambda + a_\lambda + t_\lambda = 1 \]
Black Bodies and Gray Bodies

• **Black body:**
  - Absorbs all radiation incident on it
    - Absorptivity: ____________
  - Emits maximum possible radiation for a given temperature
    - Emission spectrum follows a general law (Planck’s curve)
    - Emission efficiency or emissivity: ____________
  - An idealization: perfect black bodies do not exist
    - Often a good approximation for absorption in a given range of wavelengths
    - Often used as comparison standard for emission spectrum
  - Many natural substances behave nearly like black bodies

• **Gray body:**
  - Non-ideal emissivity: \( \varepsilon < 1 \)
  - Non-ideal absorptivity \( a < 1 \) \( \varepsilon = a \)
  - A good approximation for emission spectra of real objects or bodies

• **Kirchoff’s law:**
  \[ \varepsilon_\lambda = a_\lambda \]
Planck’s Law

- Radiant energy emitted by a black body at a given wavelength depends only

- The emission spectrum follows a characteristic shape: Planck’s curve
- As temperature of the blackbody increases
  - The amount of radiation
  - The wavelength of

Stefan-Boltzmann Law

- Describes
- All objects emit radiation at a rate proportional to the ______ of their absolute temperature

- Total energy flux emitted: \( F_{\text{tot}} \) [W m\(^{-2}\)]
  \[
  F_{\text{tot}} = \varepsilon \sigma T^4
  \]
  - \( \varepsilon \):
    - depends on material*
  - \( \sigma \):
    - \( = 5.67 \times 10^{-8} \) [W m\(^{-2}\) K\(^{-4}\)]
  - \( T \):

* See Lab 5 for list of values of emissivity
Stefan-Boltzmann Law

Sample Problem

• If a cloud bottom has a temperature of –10°C, how much energy would it be emitting if the emissivity were 1.0?
• Solution
  • Convert temperature to SI-unit: [°C] → [K]
  • Use Stefan-Boltzmann law for ε=1 (black body approx.):
  • Check units: if units are okay, physics is okay.
  • (see geog109 webpage for more exercise problems)

Wien’s Displacement Law

• Describes

• An increase of temperature in an object not only increases the total radiant output, but also shifts this energy output to shorter wavelengths, in inverse proportion to the absolute temperature
• Wavelength of maximum emittance: $\lambda_{\text{max}} [\text{m}]$
  \[ \lambda_{\text{max}} = \frac{a}{T} \]
  • $\lambda_{\text{max}} : [\mu\text{m}]$
  • $a : = 2898 [\mu\text{m K}]$
  • $T : [\text{K}]$
Wien’s Displacement Law

Sample Problem
• If a cloud bottom has a temperature of -10°C what is the wavelength of the peak energy emission? What part of the electromagnetic spectrum is this in?
• Solution
• Convert temperature to SI-unit: [°C] → [K]
• Use Wien’s law:
• Check units: if units are okay, physics is okay.

• (see geog109 webpage for more exercise problems)

Solar and Terrestrial Radiation

We distinguish between solar and terrestrial radiation, using Planck’s Law and Wien’s Law

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Peak Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>6000 K</td>
</tr>
<tr>
<td>Earth</td>
<td>288 K</td>
</tr>
</tbody>
</table>

Shortwave radiation
Longwave radiation