4. SOLAR & TERRESTRIAL RADIATION

PART I: RADIATION

Reading Assignment:
- A&B: Ch. 2 (p. 43-53)
- LM: Lab. 5

1. Introduction

- **Radiation** = Mode of **Energy** transfer
  - by **electromagnetic waves**
  - **only mode** to transfer energy **without the presence of a substance** (fluid or solid)
  - works **best in a vacuum** (empty space)

➔ **Radiation** = the **only way** for Earth to receive **energy from the Sun**

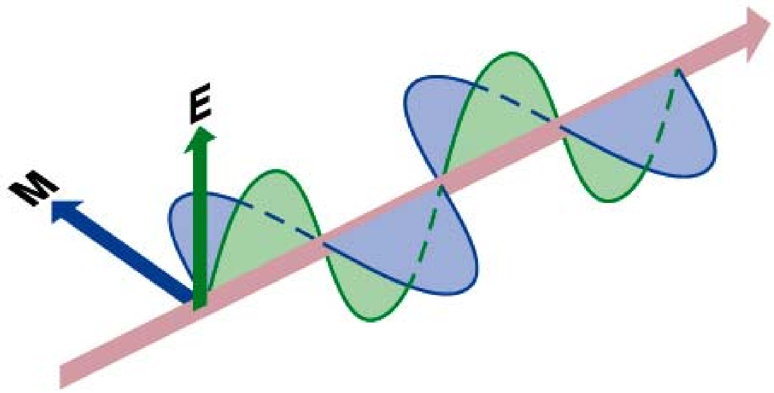
- **Weather** systems are **powered by radiation**

- From **Earth-Sun geometry** we know:
  - spatial and temporal **variations** of receipt of radiation at the top of the atmosphere
- From **Atmospheric Composition**: important for radiation at the surface
  - O_3 → UV radiation, **shortwave**
  - H_2O & CO_2 → IR radiation, greenhouse, **longwave**

➔ need to consider **different types of radiation**

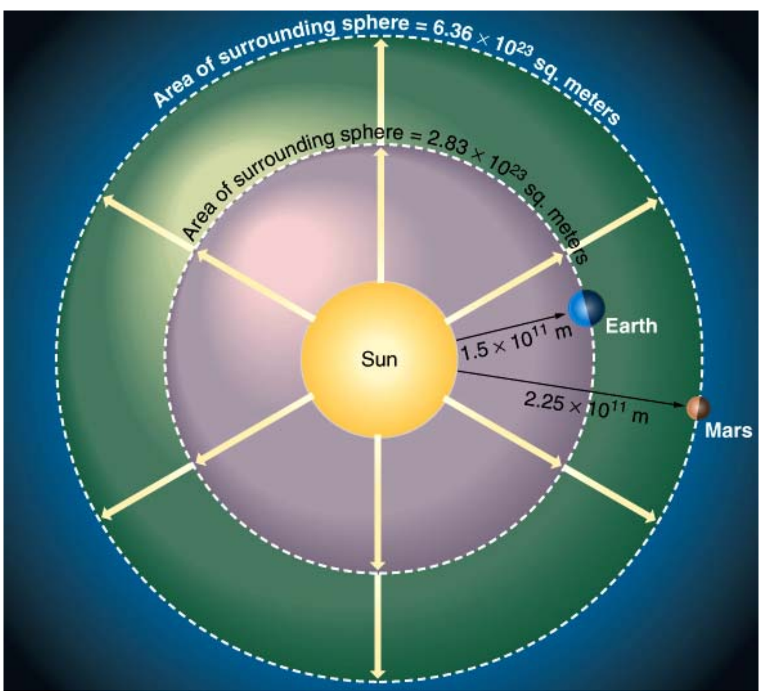
2. Electromagnetic Radiation

- **radiation waves** exhibit characteristics of both **electric fields** and **magnetic fields**



(from A&B, Figure 2-5 a)

- **Electromagnetic** radiation moves at **"speed of light"**
- radiation spreads in **all directions** and moves in straight lines



(from A&B, Figure 2-9)

- Electromagnetic radiation is described by three **interdependent variables**:
  - **wavelength** λ "lambda" [m, μm]
  - **frequency** ν "nu" [s^{-1}, Hz]
  - **velocity** **c** [$m\ s^{-1}$]

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

$$\lambda \cdot \nu = c$$

3. Radiation Spectrum

Definition:

The ***Radiation Spectrum*** is the **distribution** of **radiative energy** over different **wavelengths**, or frequencies.

In meteorology: only small part of EM-spectrum of interest.

➔ three important ranges:

- **ultraviolet** radiation (UV)
- **visible** radiation
- **infrared** radiation (IR)

Radiation in the Earth-Atmosphere System

	Ultraviolet Radiation UV	Visible Radiation	Infrared Radiation IR	
Wavelength	10^{-2} – 0.4 μm	0.4 – 0.7 μm	0.7 – 100 μm	
Effect	Sunburn	"sunlight"	heat-radiation	
		0.4 μm violet blue 0.5 μm green yellow 0.6 μm orange 0.7 μm red	**near IR** 0.7-1.5 [μm]	**far IR** 1.5 – 100 [μm]
Class	← Shortwave radiation →			longwave radiation
sun output	7 %	43 %	37 %	11 %
Earth output	0 %	0 %	~0 %	~ 100 %

- **shortwave radiation**: only solar radiation
- **longwave radiation**: IR radiation *emitted* by the E/A-system

4. Radiation Laws

Read: A&B Chapter 2, p 35-39

(i) General Principles

- **all things emit radiation**
  - the amount and wavelengths depend primarily on the emission temperature
  - higher the °T ⇒ faster the electrons vibrate ⇒
    - → shorter wavelength λ
    - → more total radiation emitted

- when any radiation is **absorbed** by an object:
  → increase in molecular motion
  → increase in temperature

(ii) Black Bodies and Gray Bodies

- an object or body that absorbs all radiation incident on it is termed a **black body**
  - → idealization: perfect black bodies do not exist
  - → often a good approximation for absorption in a given range of wavelengths
  - → many natural substances behave nearly like black bodies

- a black body is also an ideal emitter
  - → emission spectrum follows a general law (Planck's curve) describing the maximum possible emission for a given temperature
  - → is often used as comparison standard for emission spectrum
  - → a black body has an **ideal emission efficiency**, termed **emissivity:** $\varepsilon = 1$

- an object or body with a **less than ideal emission** efficiency (same at all wavelengths) is termed a **gray body**:
  - → a **gray body** has a **non-ideal emission efficiency**: **emissivity** $\varepsilon < 1$
  - → is often a good approximation for emission spectra of real objects or bodies

(iii) Reflection – Absorption – Transmission

- only three things can happen, when radiation with a wavelength, λ, hits an object or substance:

1. part or all can be **reflected**:
   - → fraction reflected: **reflectivity,** α_λ
   - → this part does not interact with the object, it is rejected

2. part or all can be **absorbed**:
   - → fraction absorbed: **absorptivity,** $\mathbf{a}_\lambda$
   - → this part raises the temperature of the object

→ **radiative energy** is converted to **heat**

3. part or all can be **transmitted**:
   → fraction transmitted: **transmissivity,** $\mathbf{t_\lambda}$
   → 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:

$$\alpha_\lambda + a_\lambda + t_\lambda = 1$$

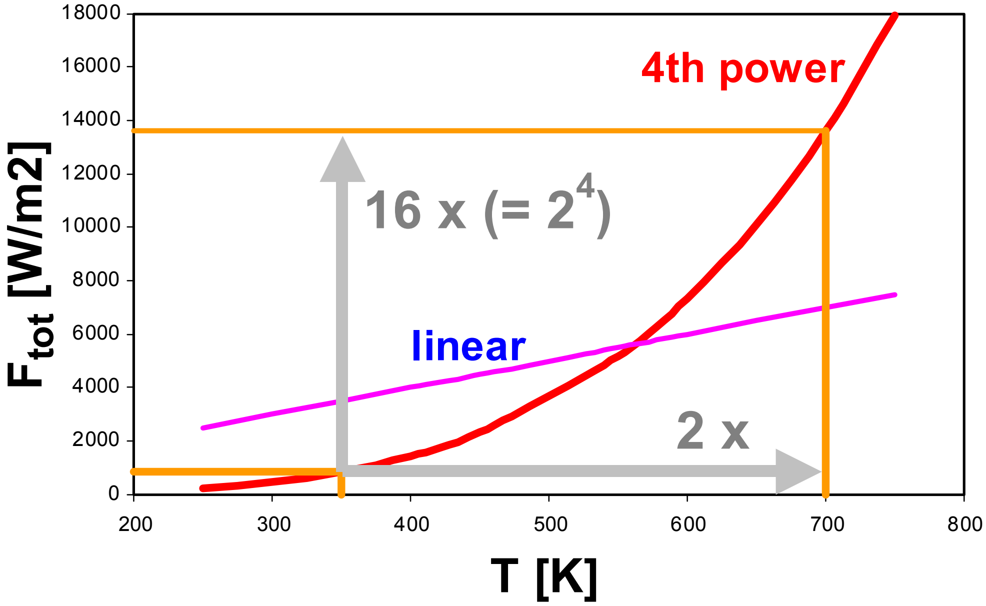
(iv) Stefan-Boltzmann Law:
the total emitted energy flux

All objects or substances emit radiation at a rate proportional to the 4th power of their absolute temperature

Total energy flux emitted: $\mathbf{F_{tot}}$ [W m^{-2}] :

$$F_{tot} = \varepsilon \sigma T^4$$

- ε emissivity (0 ~ 1); depends on quality of material (see Lab Manual #5 for list of values)
- σ Stefan-Boltzmann constant = 5.67×10^{-8} [W m^{-2} K^{-4}]
- **T** *absolute* temperature of emitting object [K]
- $\mathbf{T^4}$ fourth power: faster than linear increase with temperature.



Example Problem

(*see* web *under this topic for more exercise problems*)

If a cloud bottom has a temperature of –10 °C, how much energy would it be emitting if the emmissivity were 1.0?

Solution

- convert temperature to SI-unit: [°C] → [K]

  T = (-10 °C) + 273.15 = **263.15 K**

- use Stefan-Boltzmann law for $\varepsilon = 1$ (black body):

  $$\mathbf{F_{cloud}} = \varepsilon \cdot \sigma \cdot T^4 = 1 \times 5.67 \cdot 10^{-8} \times (263.15)^4$$

  $$= \mathbf{271.9\ W\ m^{-2}}$$

- **Check units**: units okay – physics okay.

  $$[\varepsilon \cdot \sigma \cdot T^4] = [1] \times [W\ m^{-2}\ K^{-4}] \times [K^4] = [W\ m^{-2}]$$ ✓

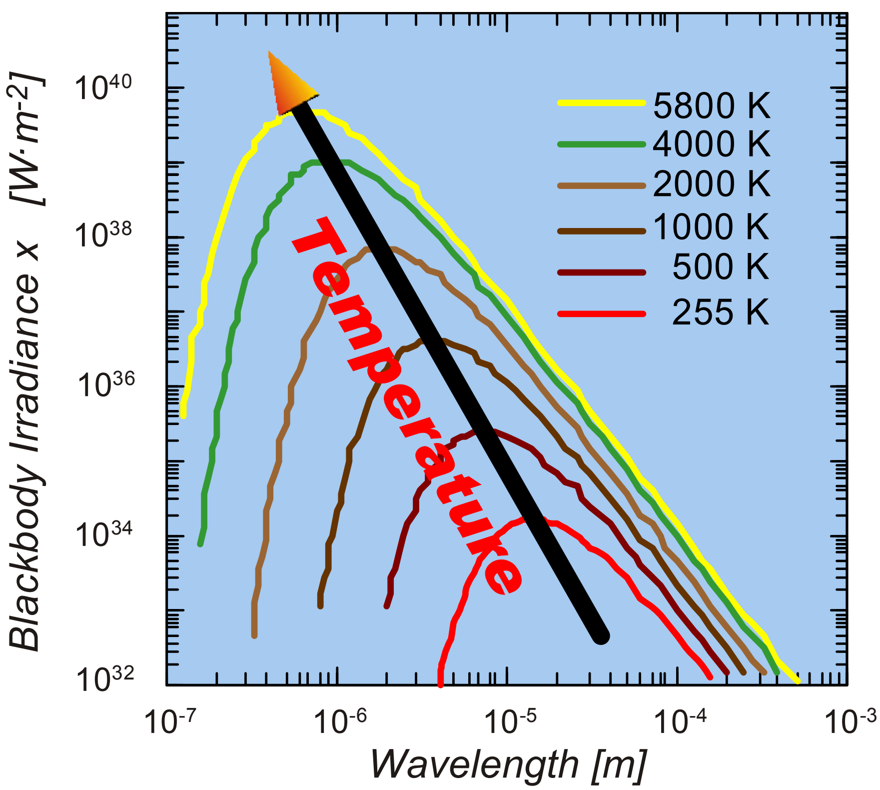
(v) Wien's Displacement Law:
the wavelength of maximum emittance

A **rise 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 emmittance: λ_{max} [m] :

$$\lambda_{max} = \frac{a}{T} = a \cdot T^{-1}$$

- λ_{max} wavelength [µm]
- **a** constant: 2898 [µm K]
- **T** absolute temperature [K]



Example Problem

(*see* web *under this topic for more exercise problems*)

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]

  T = (-10 °C) + 273.15 = **263.15 K**

- use Wien's law:

  $\lambda_{\mathbf{max}} = a \cdot T^{-1} = 2898 \div 263.15 = \mathbf{11.0\ \mu m}$

- **Check units**: units okay – physics okay.

  $[a \cdot T^{-1}] = [\mu m \cdot K] \times [K^{-1}] = [\mu m]$ ✓

Part II: Atmospheric Influences on Radiation

Reading Assignment:
- A&B: Ch. 3 (p. 68-76)
- LM: Lab. 5

1. Introduction

Global Shortwave Radiation Balance (overview)

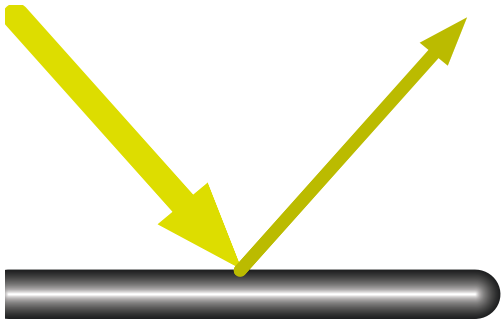
- **~ 30 %** of solar radiation is **reflected** by clouds, atmospheric gases and the surface
- **~ 25 %** of solar radiation is **absorbed by the atmosphere** (clouds, atmospheric gases, aerosol)
- **~ 45 %** of solar radiation is **absorbed by the surface** (oceans, land surface)

Influence of Clouds on Shortwave Radiation Balance

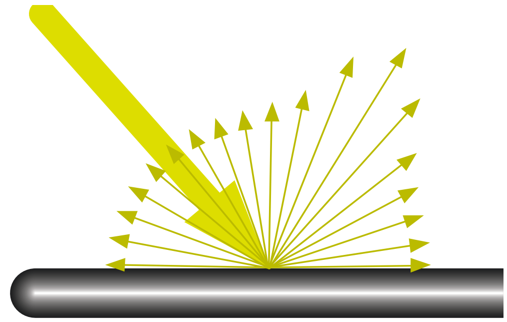
- **Clear conditions** (no clouds):
  - **~ 70 %** of solar radiation is **absorbed by the surface** (**55% direct**, **15% diffuse** sky radiation)
  - **only ~ 13 %** of solar radiation is **reflected**
- **Cloudy conditions** (overcast):
  - **~ 25 %** of solar radiation is **absorbed by the surface** (**4% direct**, **21% diffuse** sky radiation)
  - **51 %** of solar radiation is **reflected**

2. Reflection and Scattering of Radiation

- **Reflection**: redirection of radiation by a surface

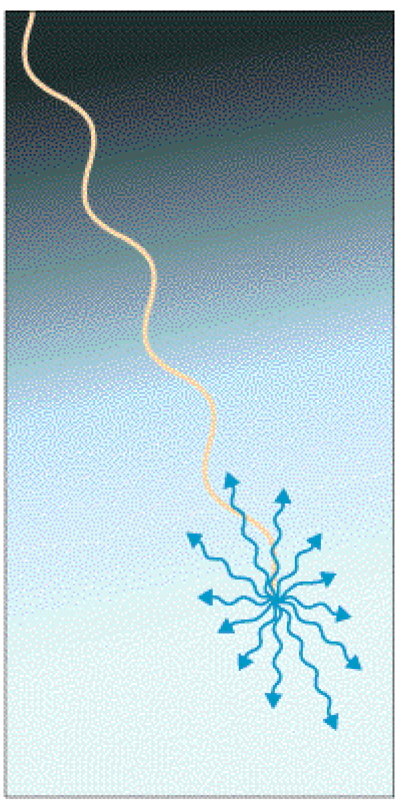


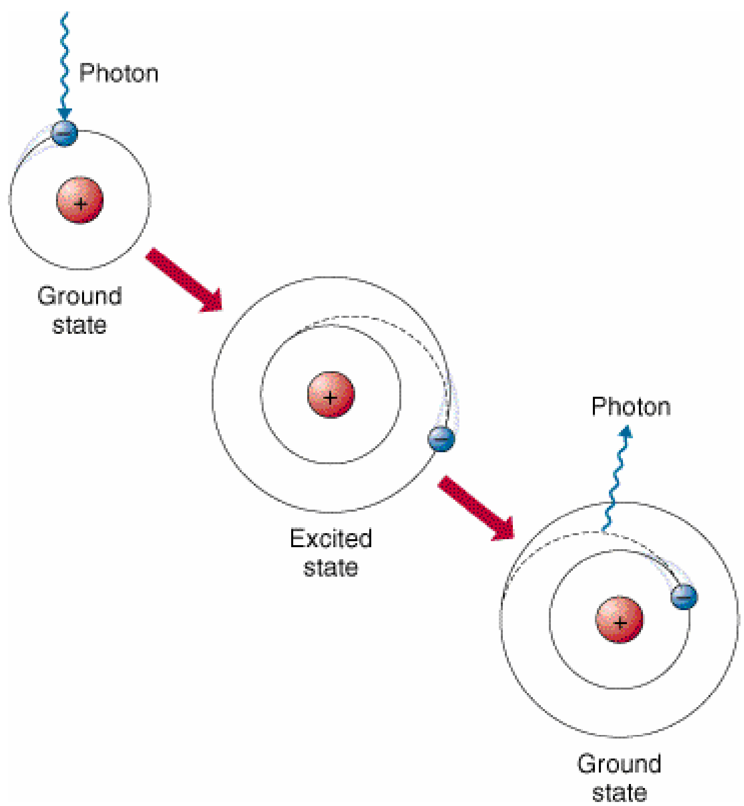
Specular Reflection
(Mirror)



Diffuse Reflection or
Scattering

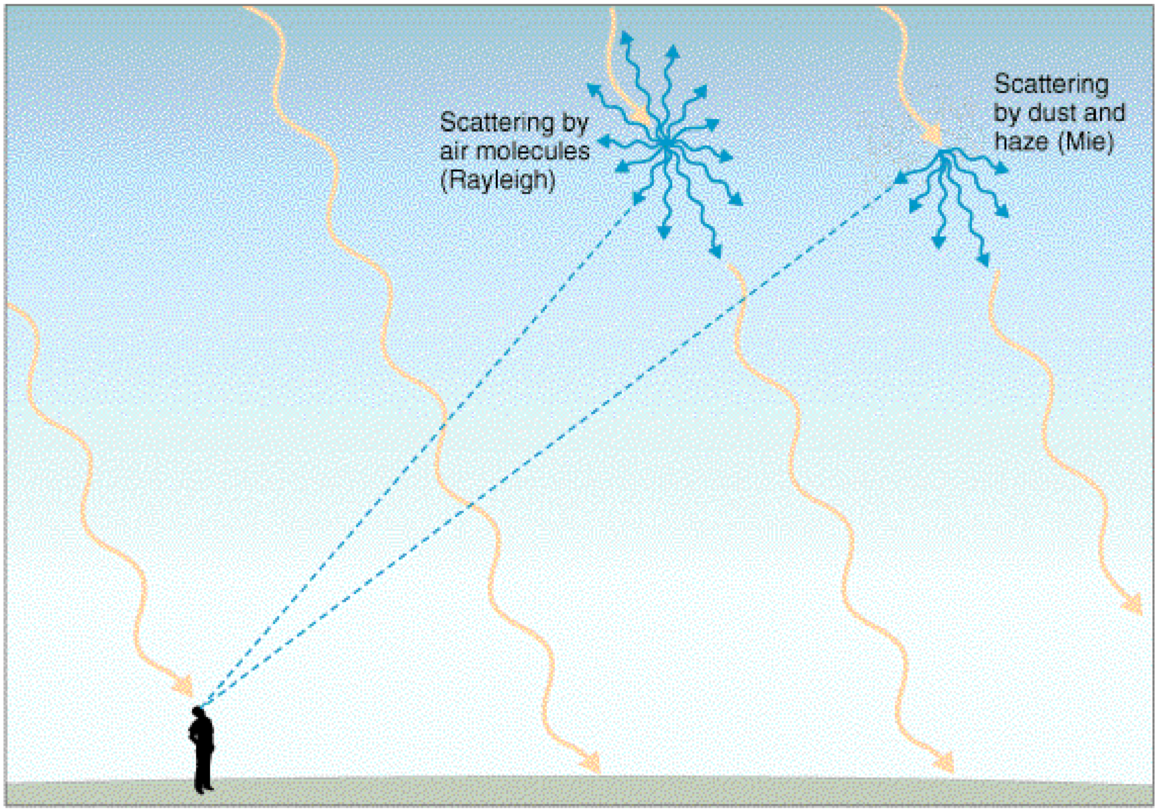
- **Scattering** by gas molecules or small particles/droplets





(from A&B, Figures 3-2, and (Phys.Princ. 2-2) 1)

- **Blue Sky** and **White Clouds**:
  Rayleigh and **Mie** Scattering

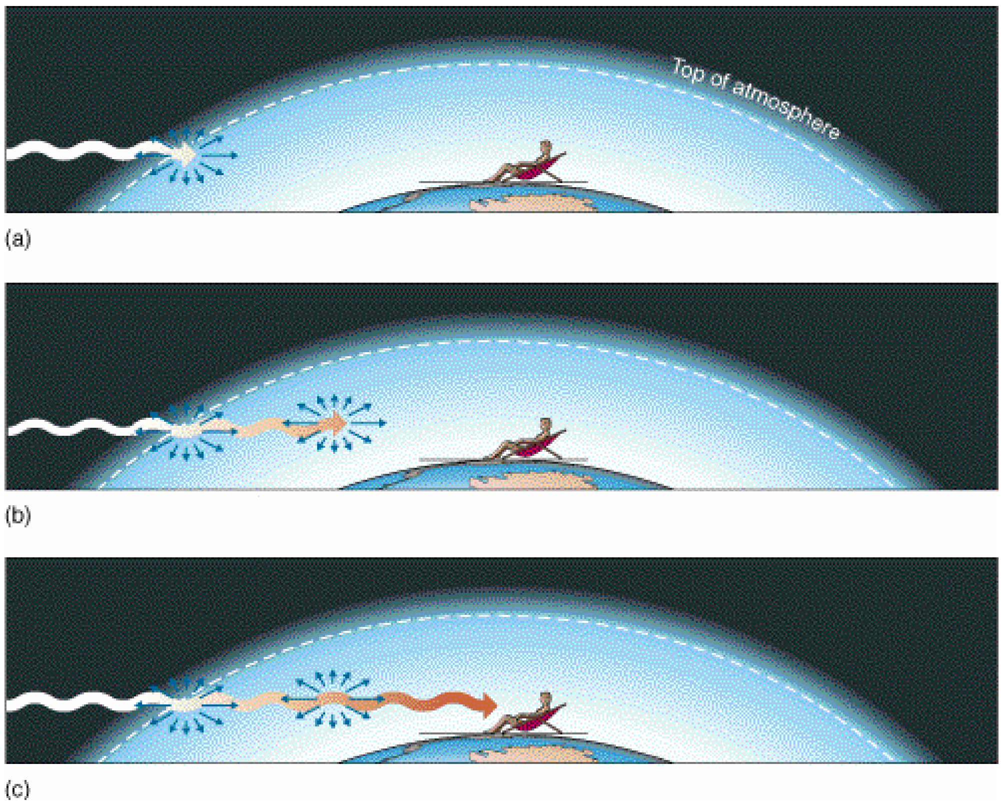


(from A&B, Figure (Spec. Int. 3-1) 1)

- **Air Molecules** tend to scatter **Short Wavelengths** more, and in **all directions**
  → the blue end of the visible range
  → **diffuse (sky) radiation** appears as **blue**
- **Particles** (**droplets**, **aerosol**) tend to scatter **All Wavelengths** equally, and more **forwards** than backwards (backscatter ~ reflection)
  → mixture of all wavelengths: white light
  → **clouds, fog, haze** appear as **white**, gray or milky
- **short-wave reflectance**: the **albedo** (~ whiteness)

3. Transmission of Radiation through the Atmosphere

- **Transmission**: the **amount** of radiation **that is left**, after going through the atmosphere



(from A&B, Figure (Spec. Int. 3-1) 3)

a) At the top of the atmosphere white (sun-) light is started to be scattered: mostly the blue portion

b) As radiation proceeds through the atmosphere, more of the blue portion is scattered away from the direct beam (further transmitted as diffuse radiation)
$\rightarrow$ **multiple scattering**

c) At the surface mostly the **red light is left** in the **direct beam $\rightarrow$ sun appears red at sunset/sunrise**

4. Absorption of Radiation in the Atmosphere

- **Absorption**: conversion of radiation to heat
  → raises the temperature of the absorbing substance

- **Kirchoff's law**: if a substance is an efficient emitter in a given wavelength range, it is also an efficient absorber at the same wavelength range:

$$\varepsilon_\lambda = \alpha_\lambda$$

- **Selective absorption**: the absorptivities of atmospheric gases are highly specific to certain spectral bands or wavelength ranges
  - **solar radiation** (shortwave) absorbers:
    - UV-absorbers: ozone (O_3), oxygen (O_2)
    - visible range (0.4 - 0.7 μm): almost none (→**window**)
  - **terrestrial radiation** (longwave) absorbers:
    - IR absorbers: H_2O, CO_2, N_2O, O_3, O_2
    - peak terrestrial radiation (8 - 12 μm):almost none (→**window**)

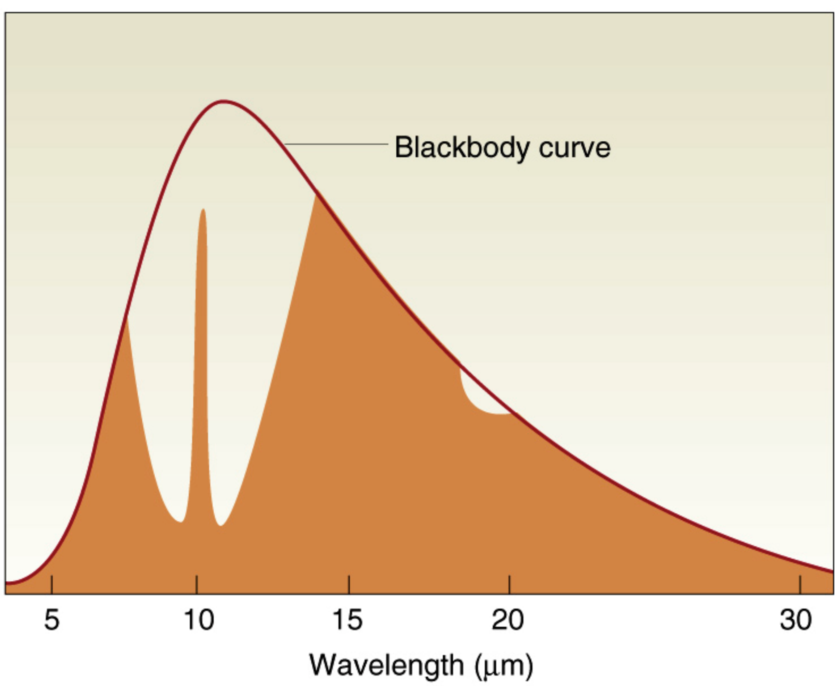
The atmosphere is **transparent for solar radiation**, but **nearly opaque for terrestrial radiation**: **greenhouse radiation trap**

Atmospheric Windows for Radiation

- **Window**: something that lets light (radiation) through
- **Atmospheric Window**: a spectral range where the atmosphere is nearly transparent

There are **two atmospheric windows**:

- **visible range window** (0.4 - 0.7 μm):
  - lets most solar radiation through to the surface
  - enables solar radiation to "deliver" the bulk of its energy to the surface (for use in climate processes)
- **longwave window** (8 - 12 μm):
  - lets some terrestrial radiation through to space
  - enables Earth to "vent off" some of its energy back to space



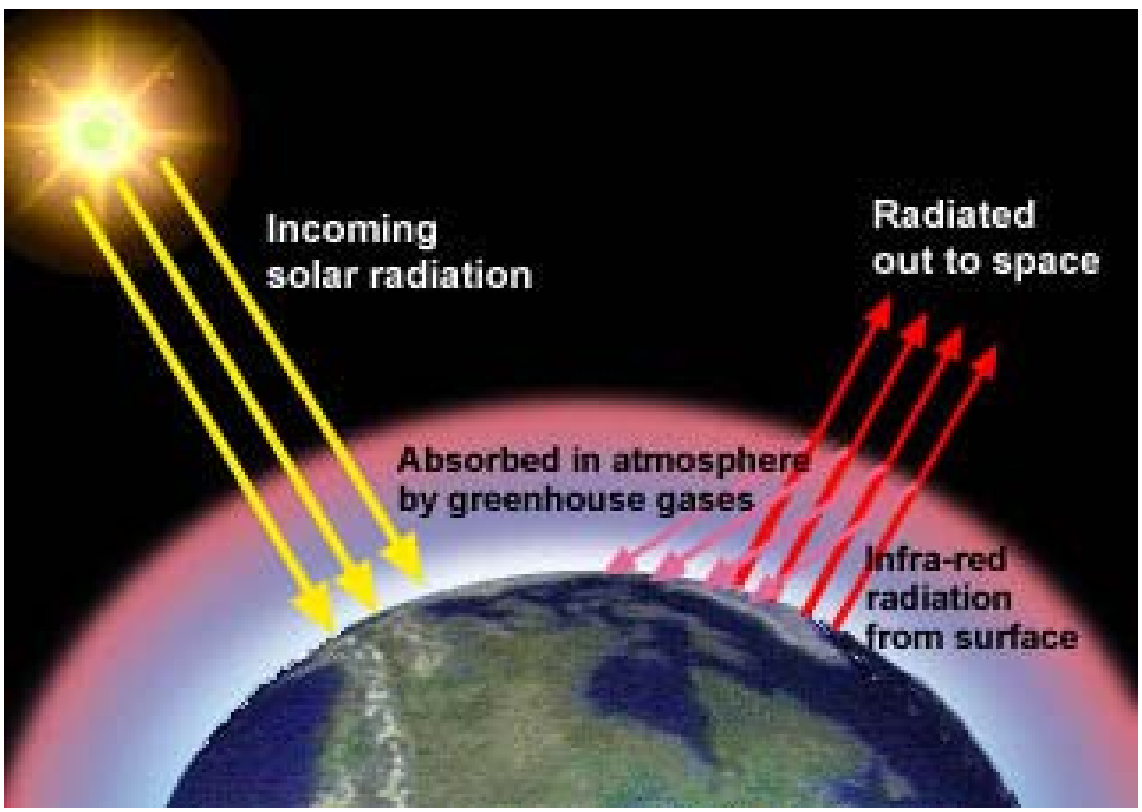
(from A&B, Figure 3-6a)

What happens if the windows are closed?

- **visible range window** (0.4 - 0.7 μm):
  - increased cloud cover, and/or reflective aerosol
  - **increase in global albedo**
  - reduction of energy input into E/A system
  - **cooling effect**

- **longwave window** (8 - 12 μm):
  - increased H_2O, CO_2 or other **greenhouse gases**
  - increased IR-absorption in atmosphere
  - **warming effect** → **The Greenhouse Effect**

(more accurately: the ***enhanced*** Greenhouse Effect)



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