

4. SOLAR & TERRESTRIAL RADIATION

PART I: RADIATION

[HTTP://WWW.INTELLICAST.COM/NATIONAL/WIND/JETSTREAM.ASPX](http://www.intellicast.com/national/wind/jetstream.aspx)

Reading Assignment:

- A&B: Ch. 2 (p. 34-42)
- 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**

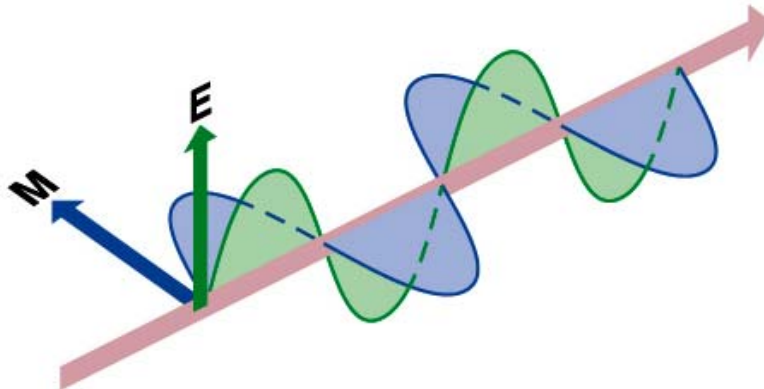
- **Weather** systems are **powered by radiation**
- From **Earth-Sun geometry** we know:
 - spatial and temporal **variations** of receipt of radiation at the top of the atmosphere
- From **Atmospheric Composition**: important for radiation at the surface
 - **O₃** → UV radiation, **shortwave**

- H_2O & CO_2 → IR radiation, greenhouse, **longwave**

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

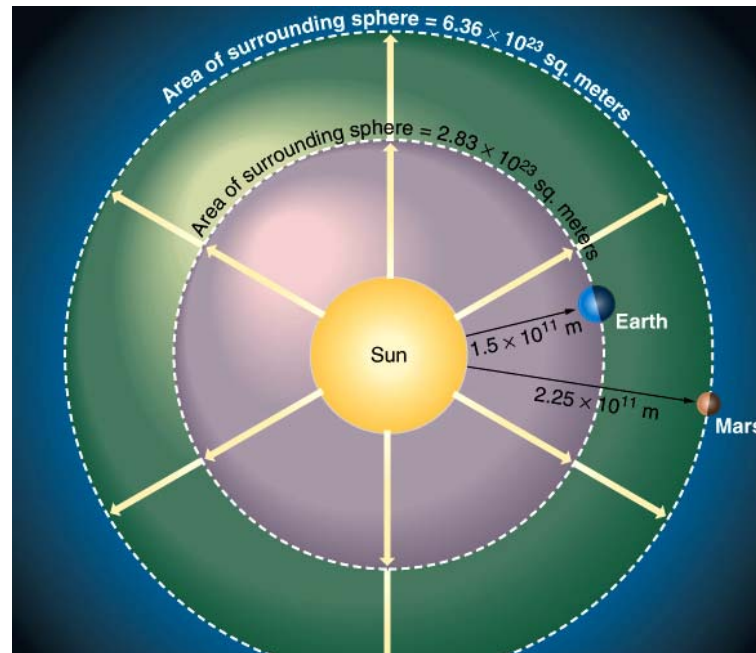
2. Electromagnetic Radiation

- **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" $\sim 3 \times 10^8 \text{ m s}^{-1}$)

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

3. Radiation Spectrum-

Definition:

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

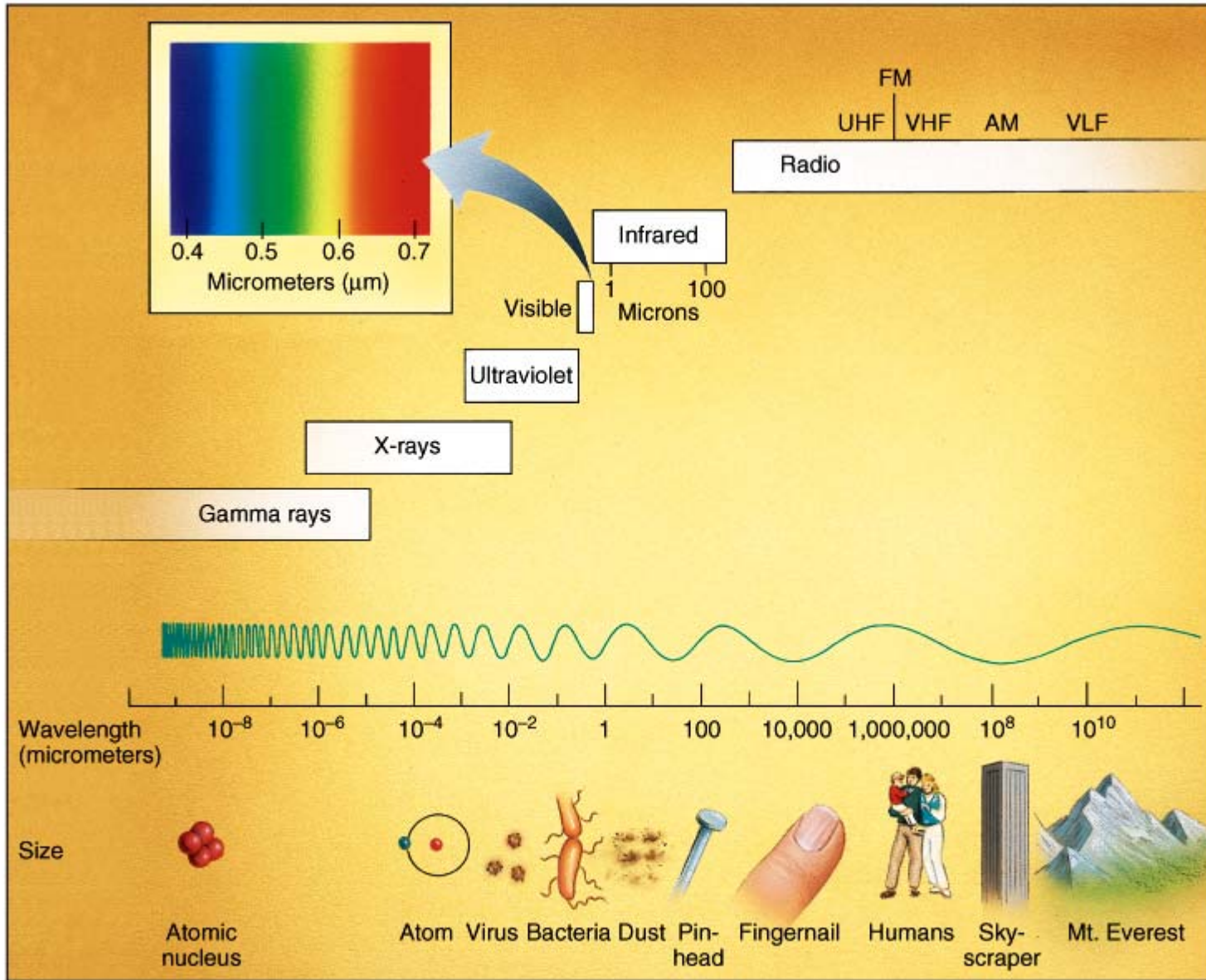
In meteorology: only small part of EM-spectrum of interest.

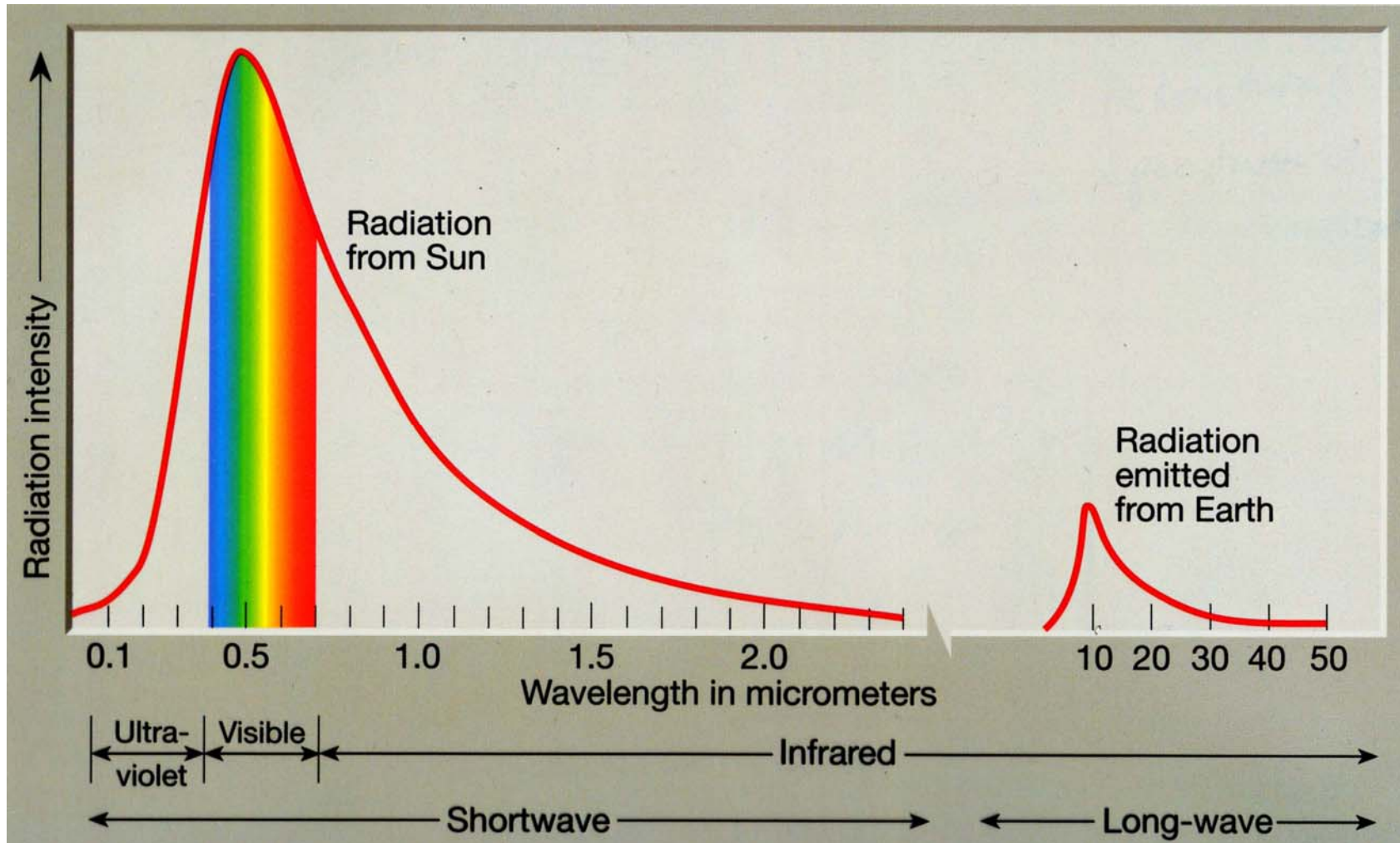
- three important ranges:
- **ultraviolet** radiation (UV)
 - **visible** radiation
 - **infrared** radiation (IR)

Radiation in the Earth-Atmosphere System

	Ultraviolet Radiation UV	Visible Radiation	Infrared Radiation IR	
Wavelength	$10^{-2} - 0.4 \mu\text{m}$	$0.4 - 0.7 \mu\text{m}$	$0.7 - 100 \mu\text{m}$	
Effect	Sunburn	“sunlight”	heat-radiation	
		0.4 μm violet 0.5 μm blue 0.5 μm green 0.6 μm 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 31-42

(i) General Principles

- **all things emit radiation**
 - the amount and wavelengths depend primarily on the **emission temperature**
 - higher the $^{\circ}\text{T}$ \Rightarrow faster the electrons vibrate \Rightarrow
 - \rightarrow **shorter wavelength λ**
 - \rightarrow **more total radiation emitted**
- when any radiation is **absorbed** by an object:
 - \rightarrow increase in molecular motion
 - \rightarrow **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**
 - \rightarrow **idealization**: perfect black bodies do not exist
 - \rightarrow often a **good approximation for absorption** in a given range of wavelengths
 - \rightarrow 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**, a_λ
 - this part **raises the temperature** of the object

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

3. part or all can be **transmitted**:

→ fraction transmitted: **transmissivity**, t_λ

→ 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:

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

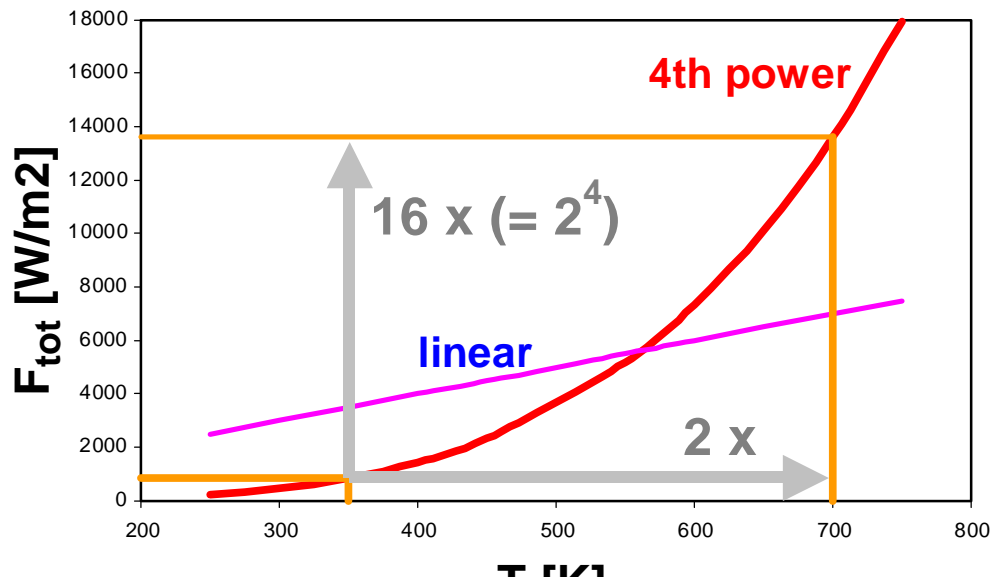
(iv) **Stefan-Boltzmann Law:** the total emitted energy flux

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

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

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

- 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} [$\text{W m}^{-2} \text{K}^{-4}$]
- T *absolute* temperature of emitting object [K]
- 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 $-10\text{ }^{\circ}\text{C}$, how much energy would it be emitting if the emissivity were 1.0?

Solution

- convert temperature to SI-unit: $[^{\circ}\text{C}] \rightarrow [\text{K}]$

$$T = (-10\text{ }^{\circ}\text{C}) + 273.15 = \mathbf{263.15\text{ K}}$$

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

$$\begin{aligned} F_{\text{cloud}} &= \varepsilon \cdot \sigma \cdot T^4 = 1 \times 5.67 \cdot 10^{-8} \times (263.15)^4 \\ &= \mathbf{271.9\text{ W m}^{-2}} \end{aligned}$$

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

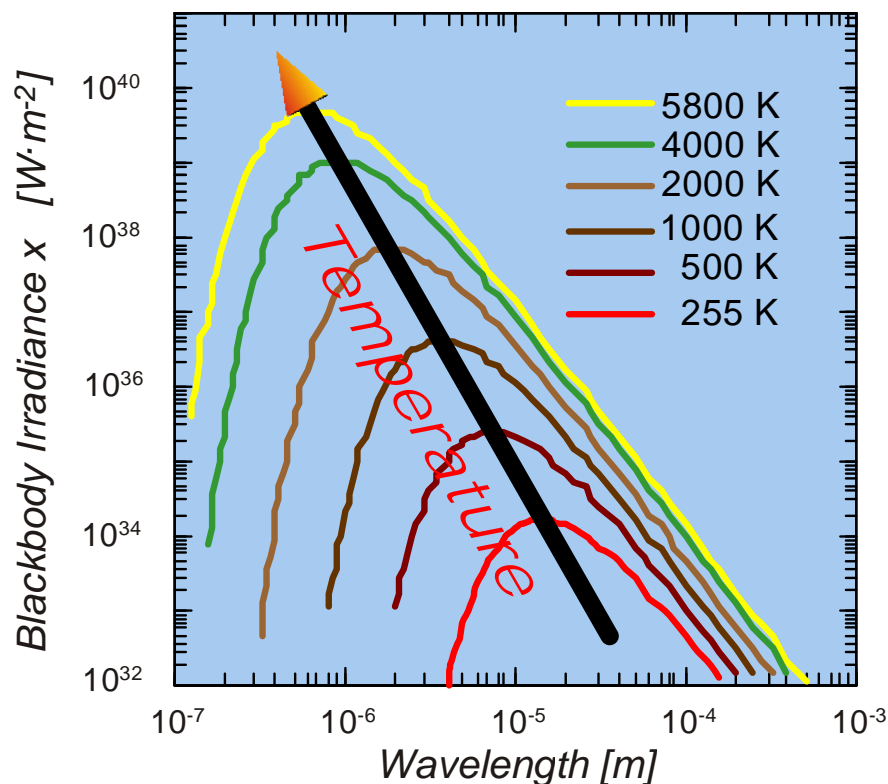
$$[\varepsilon \cdot \sigma \cdot T^4] = [1] \times [\text{W m}^{-2} \text{ K}^{-4}] \times [\text{K}^4] = [\text{W m}^{-2}] \checkmark$$

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

A rise of temperature increases the total radiation, and shifts this energy output to shorter wavelengths, in inversely proportional to the absolute temperature. **Hotter Body – Shorter Wavelength of maximum emittance:** λ_{\max} [m] :

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

- λ_{\max} wavelength [μm]
- a constant: 2898 [$\mu\text{m K}$]
- 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: $[^{\circ}\text{C}] \rightarrow [\text{K}]$

$$T = (-10^{\circ}\text{C}) + 273.15 = \mathbf{263.15\text{ K}}$$

- use Wien's law:

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

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

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

PART II: ATMOSPHERIC INFLUENCES ON RADIATION

Reading Assignment:

- A&B: Ch. 3 (p. 56-68)
- LM: Lab. 5

1. Introduction

Global Shortwave Radiation Balance (overview)

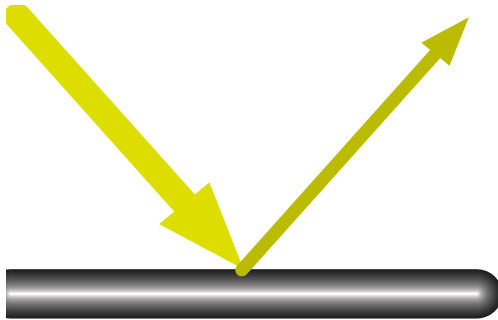
- ~ **30 %** of solar radiation is **reflected** by clouds, atmospheric gases and the surface
- ~ **25 %** of solar radiation is **absorbed by the atmosphere** (clouds, atmospheric gases, aerosol)
- ~ **45 %** of solar radiation is **absorbed by the surface** (oceans, land surface) (transmission)

Influence of Clouds on Shortwave Radiation Balance

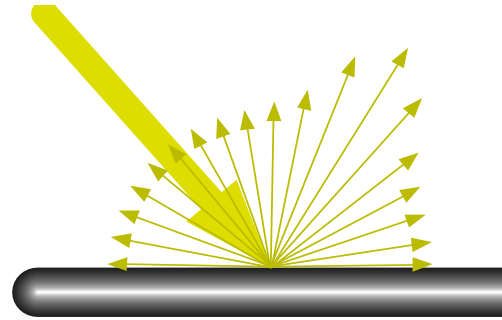
- **Clear conditions** (no clouds):
 - ~ **70 %** of solar radiation is **absorbed by the surface** (**55% direct**, **15% diffuse** sky radiation)
 - **only ~ 13 %** of solar radiation is **reflected**
- **Cloudy conditions** (overcast):
 - ~ **25 %** of solar radiation is **absorbed by the surface**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

2. Reflection and Scattering of Radiation

▪ Reflection

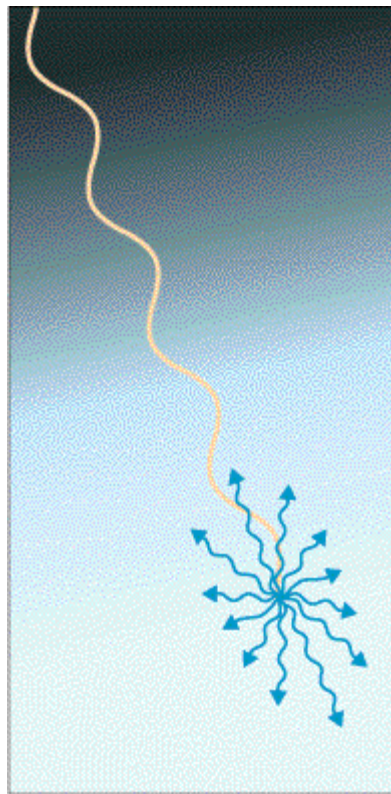


Specular Reflection
(Mirror)



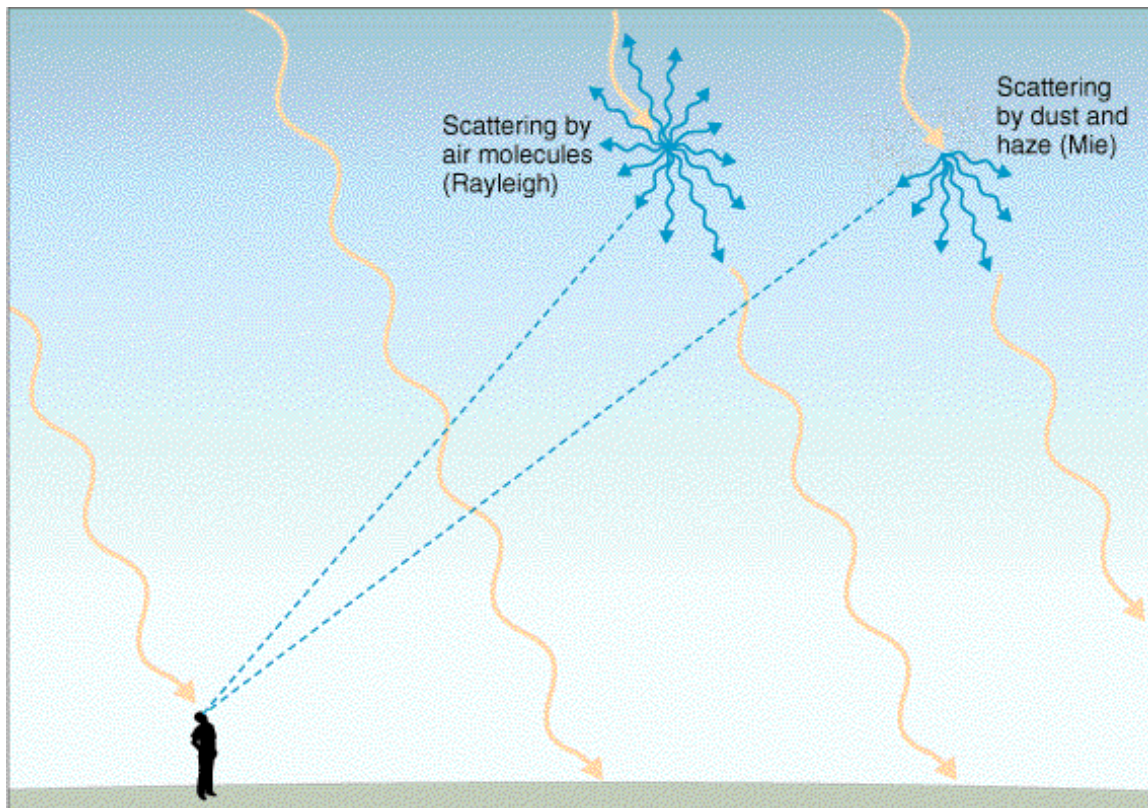
Diffuse Reflection or
Scattering

▪ Scattering



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

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

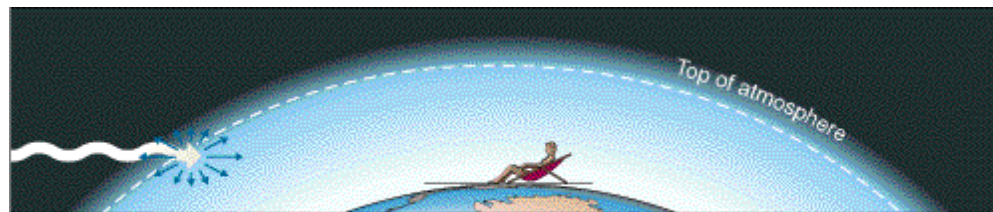


(from A&B, Figure (Spec. Int. 3-1) 1)

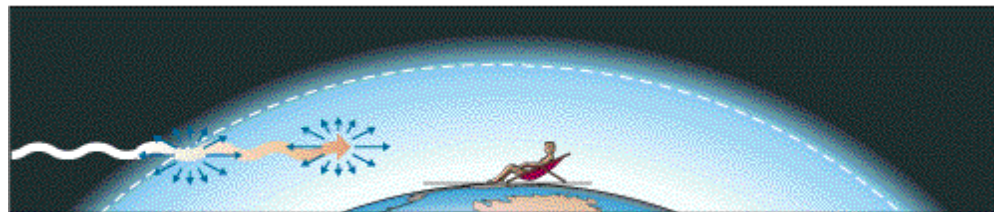
- **Air Molecules** tend to scatter **Short Wavelengths** more, and in **all directions**
- **Particles (droplets, aerosol)** tend to scatter **All Wavelengths** equally, and more **forwards** than backwards
- **short-wave reflectance**: the **albedo** (~ whiteness)

3. **Transmission** of Radiation through the Atmosphere

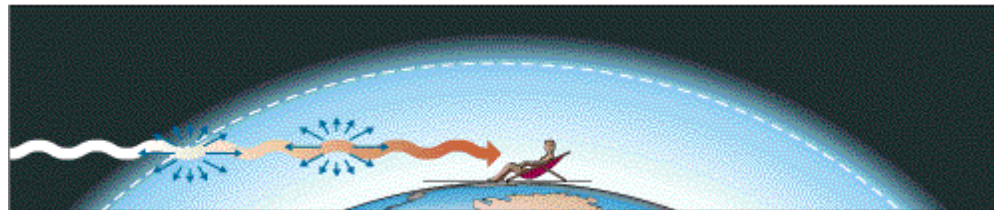
- **Transmission:**



(a)



(b)



(c)

(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)
- c) At the surface mostly the **red light is left** in the **direct beam** →

4. Absorption of Radiation in the Atmosphere

- **Absorption:**

- **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:

$$\varepsilon_{\lambda} = a_{\lambda}$$

- **Selective absorption:** the absorptivities of atmospheric gases are highly specific to certain **spectral bands** or **wavelength ranges**
 - **solar radiation** (shortwave) absorbers:
 - UV-absorbers: ozone (O₃), oxygen (O₂)
 - visible range (0.4 - 0.7 μm): almost none (→**window**)
 - **terrestrial radiation** (longwave) absorbers:
 - IR absorbers: H₂O, CO₂, N₂O, O₃, O₂
 - peak terrestrial radiation (8 - 12 μm): almost none (→**window**)

greenhouse radiation trap

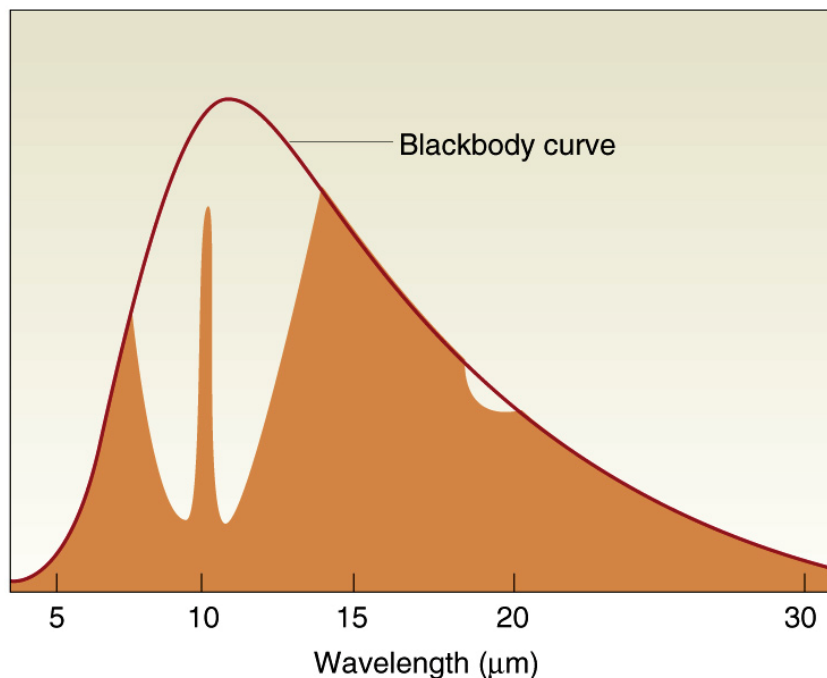
Atmospheric Windows for Radiation

- **Window:** something that lets light (radiation) through

Atmospheric Window:

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



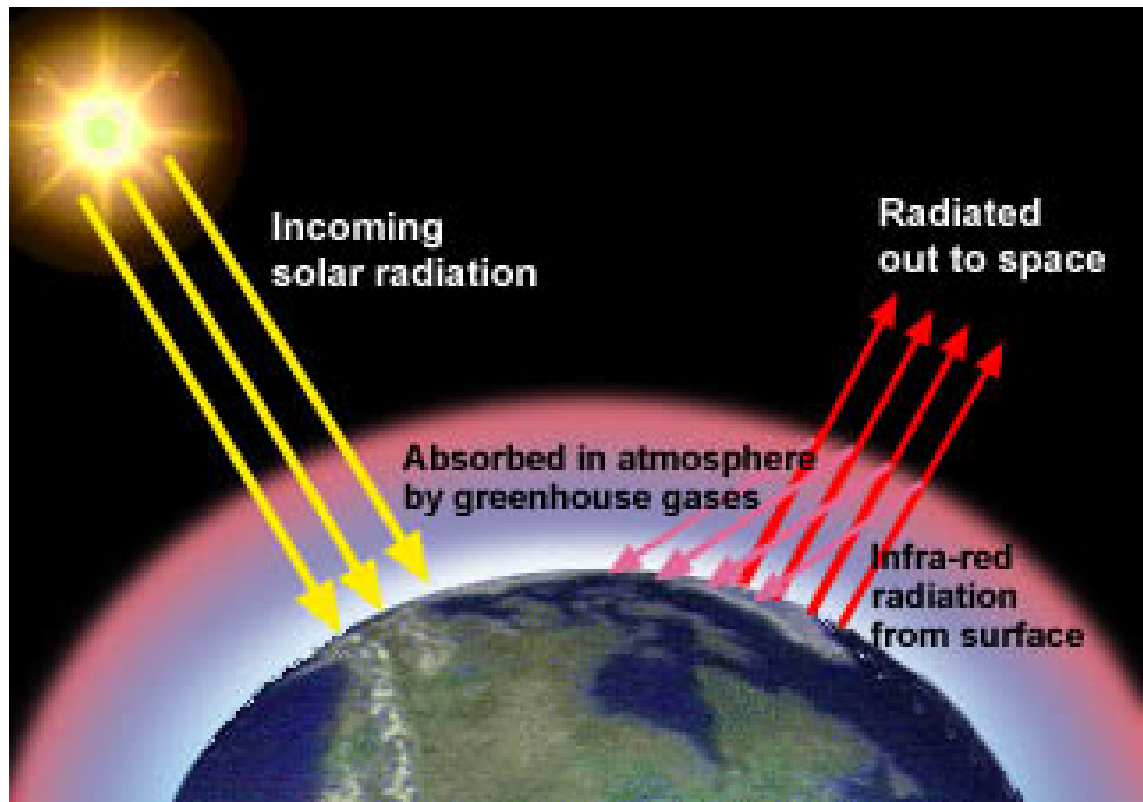
(from A&B, Figure 3-6a)

What happens if the windows are closed?

- **visible range window** (0.4 - 0.7 μm)
-

- **longwave window** (8 - 12 μm):

(more accurately: the *enhanced* Greenhouse Effect)



source:

http://www.fe.doe.gov/issues/climatechange/globalclimate_what.html
(Jan. 22, 2001)