Energy and Radiation

GEOG/ENST 2331 – Lecture 3
Ahrens: Chapter 2

Last lecture: the Atmosphere

- Mainly nitrogen (78%) and oxygen (21%)
- T, P and ρ
  - The Ideal Gas Law
- Temperature profiles

Lecture outline

- Energy
- Radiation
- Radiation and the atmosphere

Energy

- What is energy?
  - The ability to do work
- What is work?
  - The transfer of energy from one system to another

Energy

- The ability of one system to change another system
  - Pushing, pulling, lifting, compressing, etc.

- **Work** is the energy transfer required to achieve a change

Some types of energy

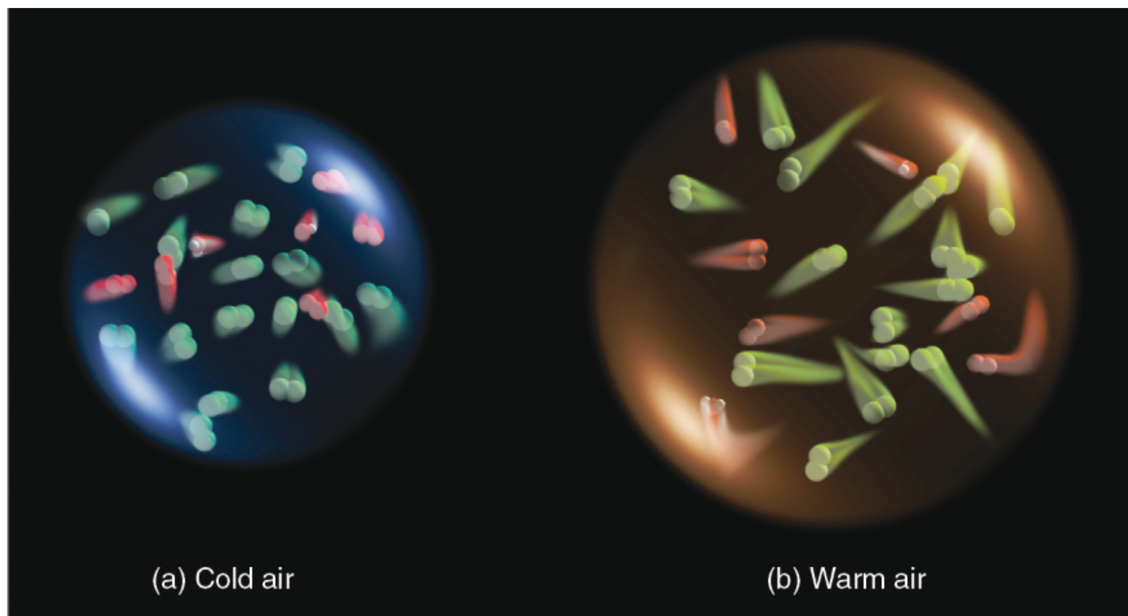
- Potential energy
  - Gravitational
  - Chemical
  - Electrical
- Kinetic energy

Energy, work, and heat

- **Energy** is the ability of one system to change another system
- **Work** is the energy transfer required to achieve a change
- **Heat** is the energy transferred between systems because of the difference in their temperatures

Temperature

- A measure of the average speed of air molecules
- *Average* kinetic energy per molecule



Ahrens: Fig. 2.1

Sensible heat transfer

- Heat exchange that causes a change in temperature
- Can ‘sense’ it

- **Specific heat**
  - A measure of the amount of heat transfer required to raise the temperature of a substance

Specific heat

SUBSTANCE	SPECIFIC HEAT ($J\ kg^{-1}\ K^{-1}$)
Water (pure)	4186
Wet mud	2512
Ice (0°C)	2093
Sandy clay	1381
Dry air (sea level)	1005
Quartz sand	795
Granite	794

Ahrens: Table 2.1

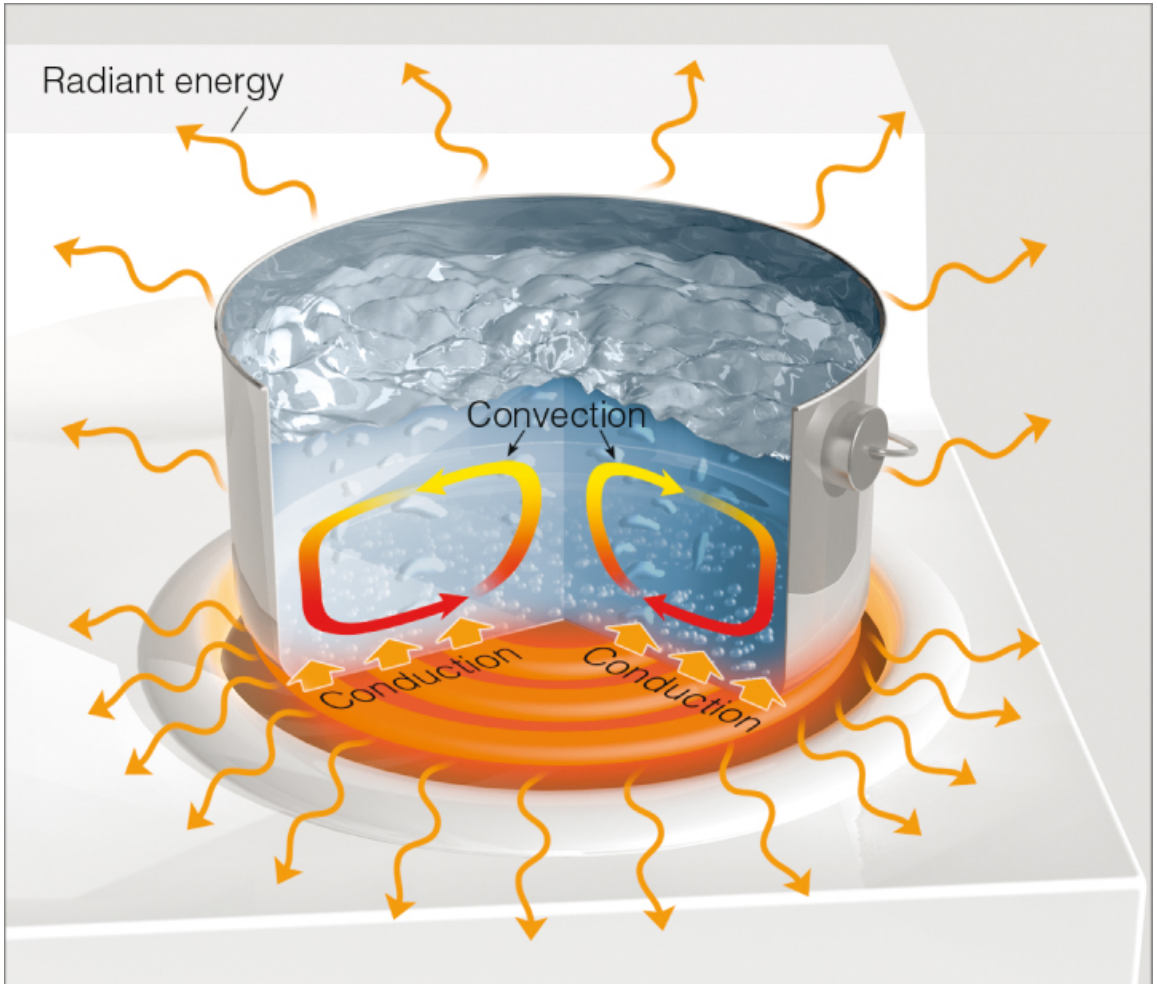
Latent heat transfer – introduced last week

- Energy that is ‘hidden’ by phase changes
  - Gas > Liquid > Solid
- Phase changes absorb or release latent heat without a change in temperature

Heat transfer mechanisms

- Conduction
  - Direct contact between substances
- Convection
  - Heat is transported by a moving fluid
- Radiation
  - Electromagnetic waves

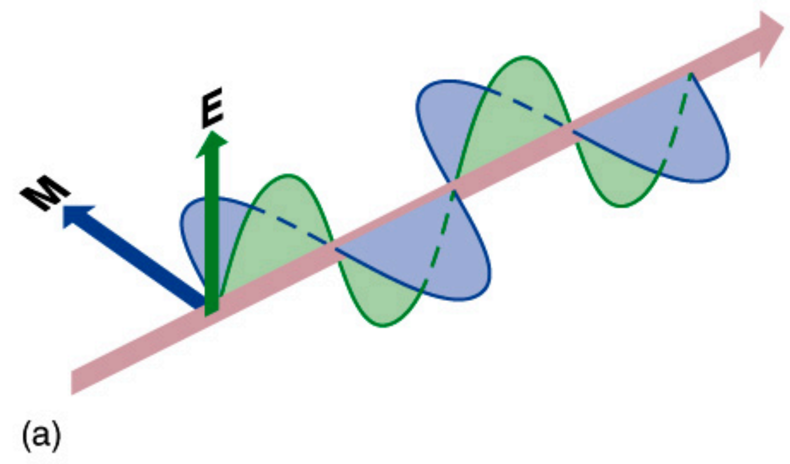
Heat transfer



Ahrens: Fig. 2.8

Radiation

- Electromagnetic waves
- Propagates energy transfer with no physical medium
- Continually emitted by all substances



A&B: Figure 2.5

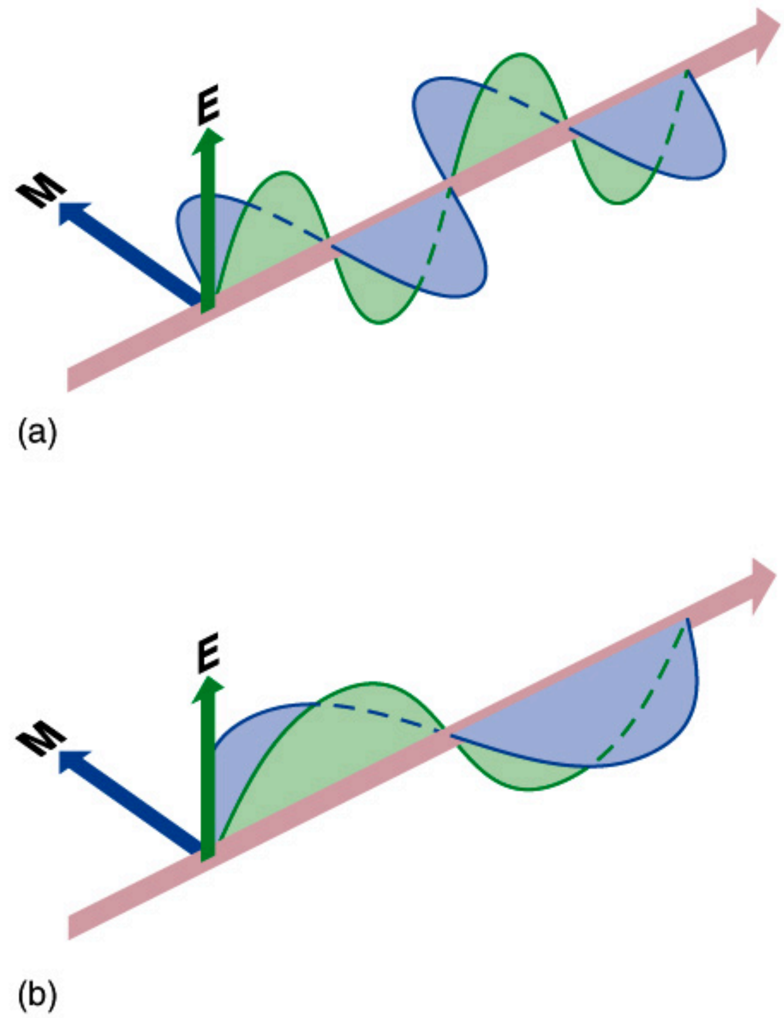
Insolation

Term**: Solar constant**

- Radiant energy from the Sun is transferred to the Earth's surface where it is absorbed, providing energy for:
  - Winds
  - Storms
  - Melting and evaporation
  - Chemical reactions
  - Photosynthesis

Radiation

- Radiation *quantity*:
  - Amount of energy
- Radiation *quality*:
  - Wavelength
- Speed of propagation
  - Constant
  - 300 000 km/s



A&B: Figure 2.5

Stefan-Boltzmann Law (quantity)

- All matter emits radiation
- Intensity of radiation in W/m^2 is proportional to T^4

$$I = \varepsilon \sigma T^4$$

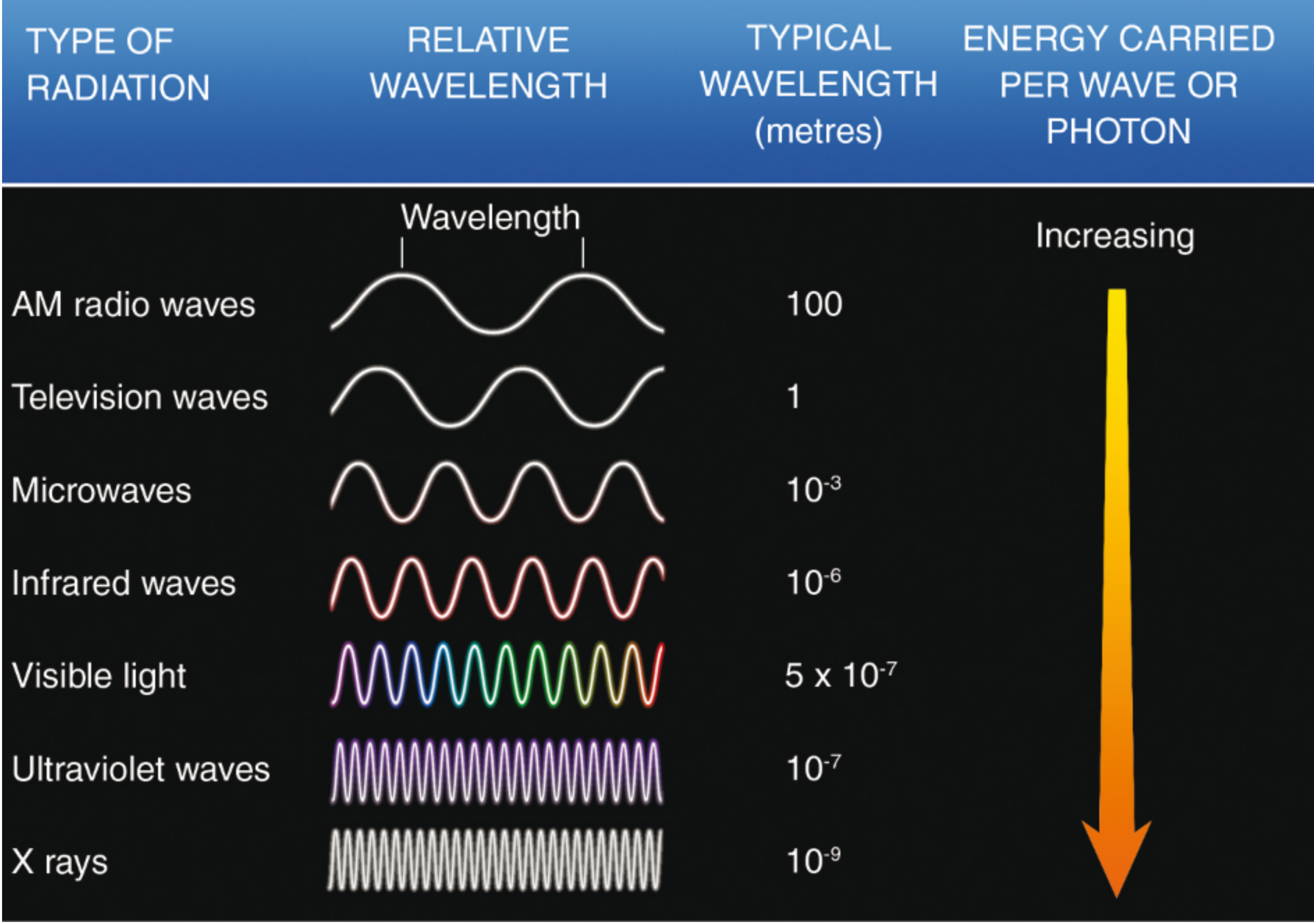
- **σ** = 5.67×10^{-8} W/m^2K^4
- **ε** is the *emissivity* of the object, ranging from 0 to 1

Emissivity and blackbodies

$$I = \varepsilon\sigma T^4$$

- **ε** is the emissivity of the object, ranging from 0 to 1.

- Objects that have an emissivity of 1 (i.e. perfect emitters) are called *blackbodies*.
- A blackbody is a 100% efficient emitter (and absorber) of radiation *at all wavelengths*
- $I = \sigma T^4$
- Most opaque objects can be approximated as black bodies



Ahrens: Fig. 2.7

Wien's Law (quality)

- The wavelength of the peak value of the emission spectra is inversely proportional to temperature

$$\lambda_m = \frac{2897}{T}$$

- Constant of proportionality is 2897 μm K.
  - 1 micrometre (or micron) equals 10^{-6} m.

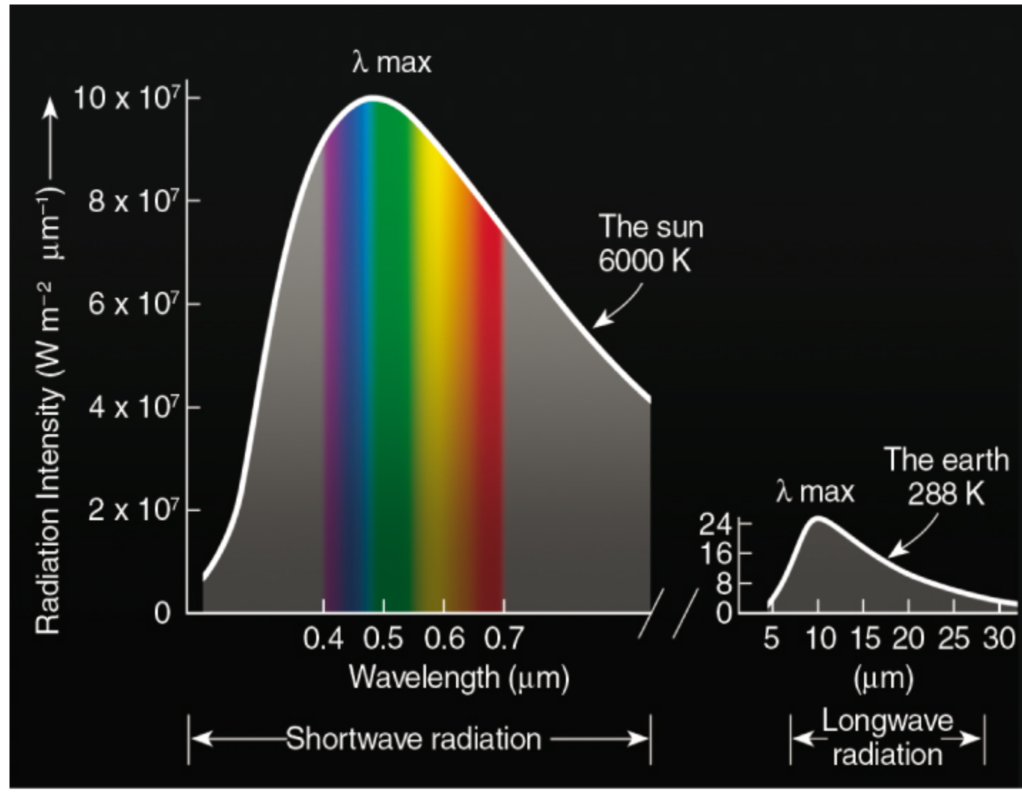
Temperature and Wavelength

Sun

$$\lambda_m = \frac{2897}{6000} \approx 0.48\ \mu m$$

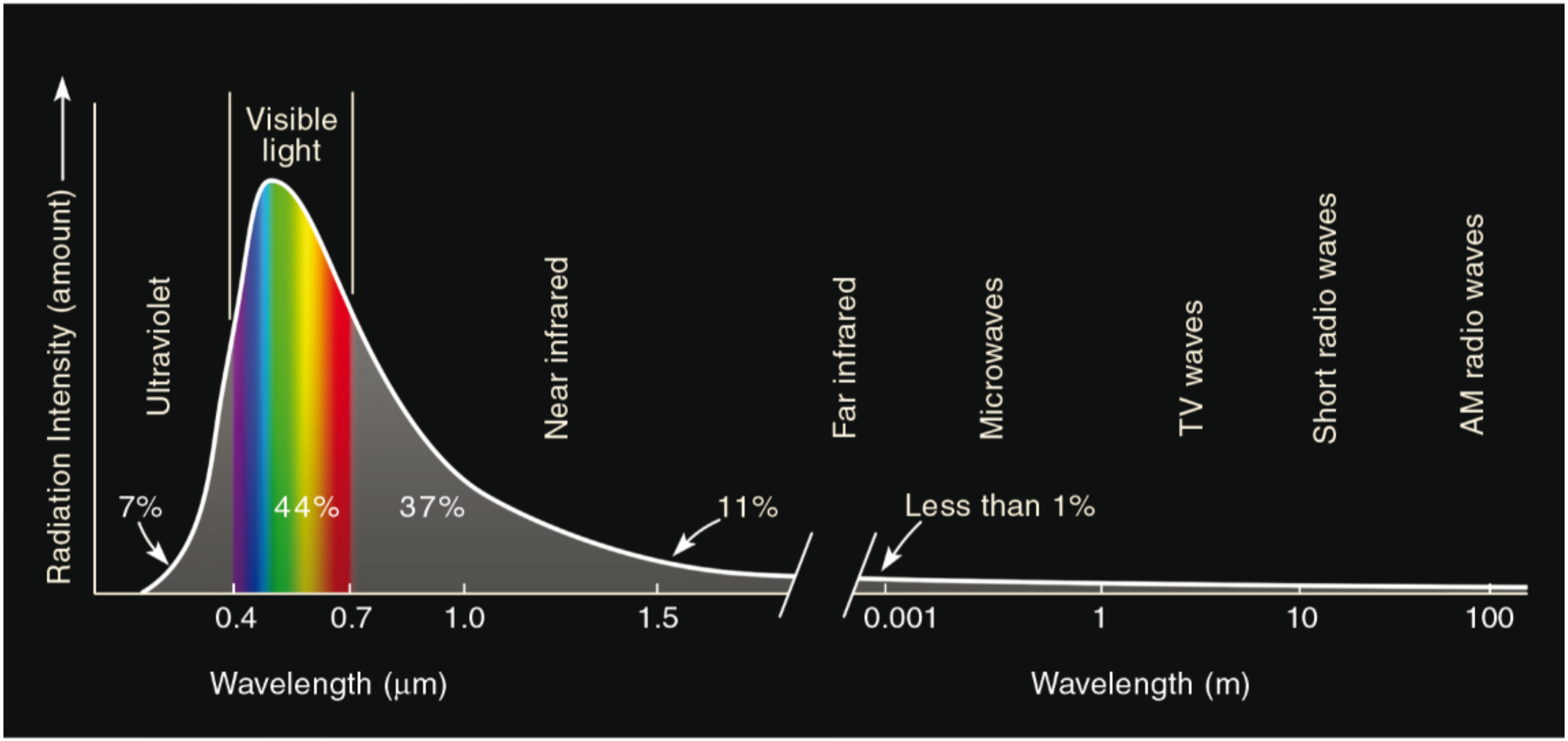
Earth

$$\lambda_m = \frac{2897}{288} \approx 10\ \mu m$$



Ahrens: Fig. 2.9

Solar radiation as a function of wavelength



Ahrens: Fig. 2.10

Radiation and the atmosphere

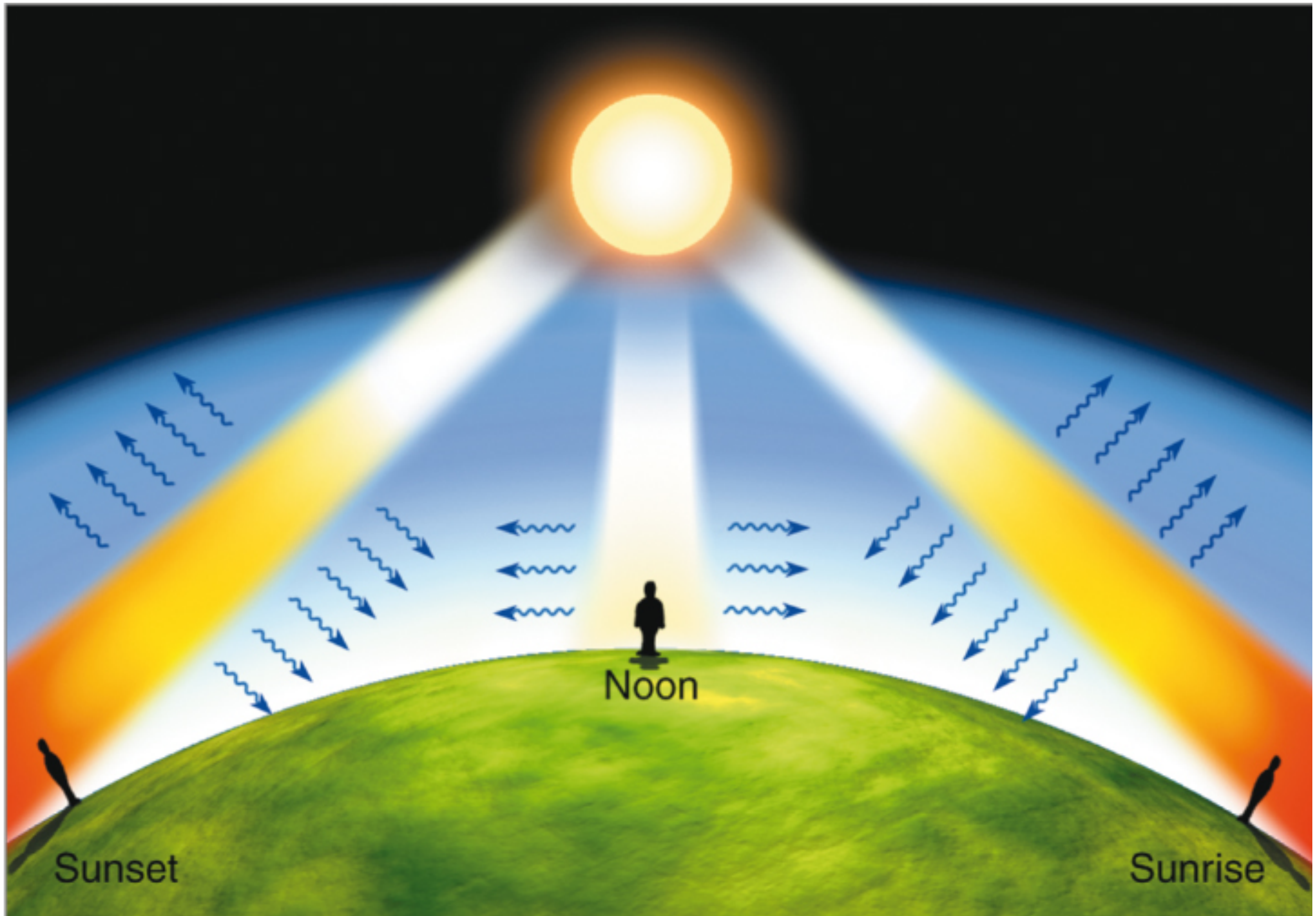
- What can happen to *insolation* that enters the top of the atmosphere?
  - Transmission
  - Scattering
  - Reflection
  - Absorption

Scattering

Term: **Rayleigh scattering**

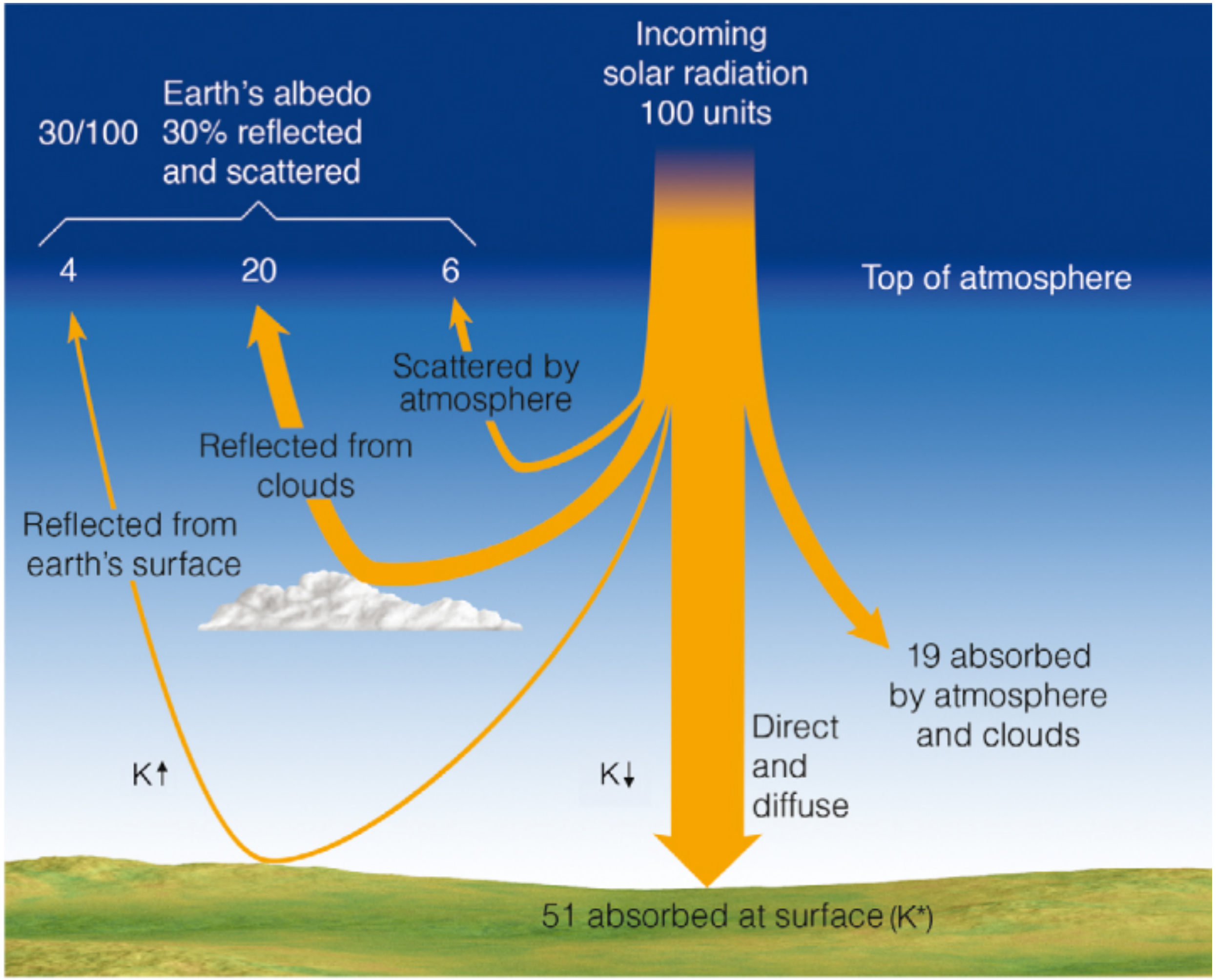
- When incoming radiation encounters small particles the radiation is deflected in all directions.
- The amount of scattering from air molecules is much higher for short wavelengths (blue and violet) than for longer waves (yellow and red).
- The colour of the sky is determined by the scattering of visible light in the atmosphere.

The sky is blue



Ahrens: Fig. 5, p. 48

Reflection



Ahrens: Fig. 2.17

Absorption

- Blackbodies absorb all non-reflected radiation
  - E.g. the planet surface
- *Selective absorbers* absorb some wavelengths, but allow other wavelengths to pass through (transmission)
- The atmosphere is generally transparent to visible wavelengths, but not to others

Kirchhoff's Law (absorption)

- All substances do not absorb all wavelengths equally
- Kirchhoff's Law states that strong absorbers are also strong emitters at the same wavelength

$$\varepsilon_\lambda = a_\lambda$$

ε is the emissivity

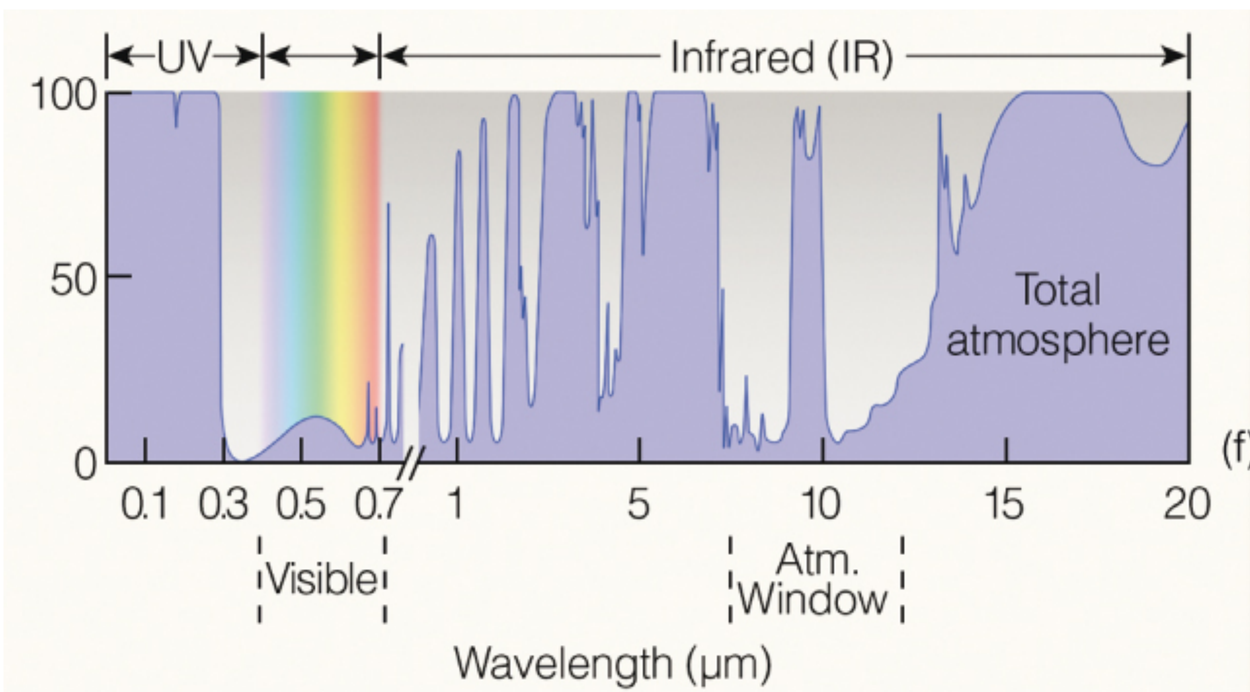
a is the absorptivity

λ is a wavelength of radiation.

Absorption in the atmosphere

Ultraviolet radiation is absorbed by oxygen (thermosphere) and ozone (stratosphere).

Infrared radiation is absorbed by *greenhouse gases*



Ahrens: Fig. 2.14

Greenhouse gas

- An atmospheric constituent that traps outgoing terrestrial radiation.
  - Water vapour (H_2O)
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous oxide (N_2O)
  - Ozone (O_3)
  - and another group including CFCs, HFCs

Next lecture

- Earth's radiation budget
- Ahrens: Chapter 2