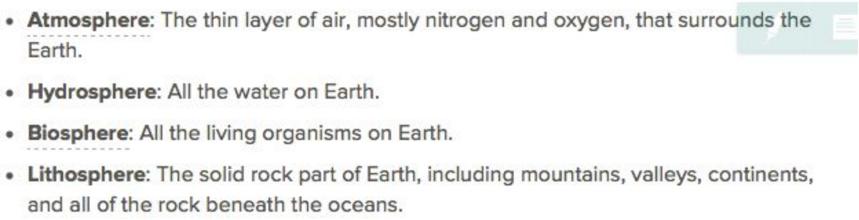
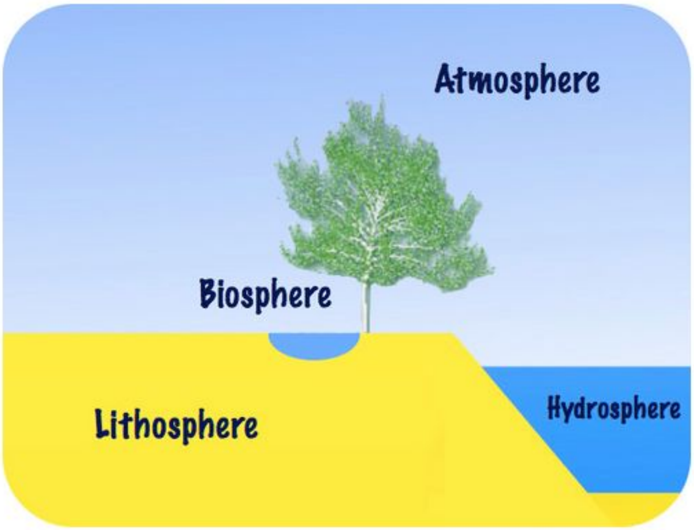
Chapter 1 Energy



- **Atmosphere**: The thin layer of air, mostly nitrogen and oxygen, that surrounds the Earth.
- **Hydrosphere**: All the water on Earth.
- **Biosphere**: All the living organisms on Earth.
- **Lithosphere**: The solid rock part of Earth, including mountains, valleys, continents, and all of the rock beneath the oceans.



Earth has four layers: atmosphere, hydrosphere, biosphere, and lithosphere.

- Role of atmosphere - move energy from areas of surplus to areas of deficit.

- All weather phenomena exist to balance the energy deficit.

- Heat on the ground drives processes in the lithosphere (surface weathering and erosion) => landscapes and create soil => interaction with **biosphere**

- Energy on the surface melts **cryosphere's** snow and ice into water, which changes how Earth reflects sunlight and determine how the ground absorbs heat

- Heating the cryosphere supplies water for the lithosphere and hydrosphere by delivering fresh water runoff to land and surface water

- Heating Earth's surface heats the lower atmosphere and evaporates water; water vapour => cloud, precipitation

- Sunshine => photosynthesis => CO2 and water for all the food webs in **biosphere**, including **anthrosphere**

Energy and Heat

Heat flux: rate of heat flow (Js^-1 or Watt)

Heat flux density: rate of energy flow over one square metre (Wm^-2 or J s^-1 m^-2)

Radiant Energy or Radiation

Radiation moves as photons and electromagnetic waves

$$RE = h * \frac{c}{\lambda}$$

Shorter the wavelength, greater the photon's energy

H: Planck constant

Sensible Heat

Latent Heat

Heat capacity: ratio of the amount of sensible heat absorbed by the substance to its corresponding increase in temperature

Cp of water = 4186 J kg^-1 K^-1

A large loss or gain of energy - a small temperature change in water => strong modifying effect on weather and climate

Heat transfer in Atmosphere

Conduction
Air - poor conductor => good insulator
Convection
- Thermals: hot air bubbles
- Convection circulation or thermal cells
- Types of convection:
- **Free convection**
- **Turbulence**
- Can occur on a small scale when wind blows over a rough surface, twisting and swirling the air currents
- When turbulent air flows over a hot surface, the swirling eddies transport warm air upward and cold downward
- **Advection**: horizontal transport of heat and other properties
- -water vapour from the evaporating surface and advect it elsewhere in the atmosphere

- If the air cools, condenses into cloud droplets and release latent heat, converting it into sensible heat
- Both water and energy are advected, carried by the water vapour as it is swept along with the wind

Radiation and Temperature

Stefan Boltzmann law

$$E = \sigma T^4$$

E: rate of energy in the form of radiation that is emitted by each square metre (W m^-2)
T: object's surface temperature in K

The wavelengths that each object emits depend on its temperature. The higher the temperature, the faster its electrons vibrate and the shorter the wavelengths of radiation it emits

As temperature increases, more energy in the form of radiation is emitted each season. This relationship can be expressed as the Stefan Boltzmann Law.

Radiation of the Sun and Earth

Wien's Law (to calculate the wavelength of greatest emission of the object)

$$\lambda max = \frac{WDC}{T}$$

λmax: in μm
T: in K
WDC: Wien's displacement constant

Two ways to find the wavelength at which maximum radiation occurs:

Find the peak of graphs for sun and earth and read off the wavelength
Use Wien's law to calculate it

λmax of sun= 0.5 μm => Sun emits the majority of its radiation at wavelength less than 2 => sun's energy (solar radiation) is called **shortwave radiation**.

λmax of earth= 10 μm => Earth emits most of its radiation at longer wavelength between about 5 and 25 μm, which is in the infrared band => Earth's radiation (terrestrial radiation) is called **longwave radiation**.

Eyes are sensitive to radiation between 0.4 - 0.7 μm, these waves reach the eye and stimulate the sensation of the colour. This portion of the spectrum is refereed to as **visible band.** The radiant energy that reaches our eye is called visible light.

Incoming Solar Energy

Solar constant: (1361 Wm^-2) the solar radiation received by a surface perpendicular to the sun's rays remains fairly constant. This value is known as solar constant.

Average **total solar irradiance** (TSI): used in recognition of the small but observable variability in this value over various sunspot and solar cycles

When solar radiation enters the atmosphere, it can be
Absored
Reflected
Absorbed

Scattering: Solar rays can be deflected in all in directions in a process called scattering by striking air molecules, dust molecules and clouds.

Scattering and reflection

Air molecules are much smaller than the wavelength of visible light => they more effectively scatter shorter (blue) wavelengths than longer (red) wavelength.

This phenomenon makes the daytime sky blue. The preferential scattering of the shortest wavelengths by air molecules creating a blue sky is called **Rayleigh scattering.**

Sunlight can be reflected from objects.
Difference between scattering and reflection: in reflection, more light is sent backward.
Albedo: percentage of shortwave radiation returning from a given surface compared with the amount of radiation initially striking that surface
Reflectivity of the surface to shortwave radiation

Albedo - very important climatic characteristic of a surface since the solar radiation that is not reflected back to a space is absorbed by the surface. The absorbed sunlight is usually the main energy source at a location: it drives all the weather processes and determine the climate a a site.

Radiation Absorption, Emission and Equilibrium

Rate at which something radiates and absorbs energy depends on its surface characteristics such as colour, texture, and moisture as well as temperature.

Perfect absorber: an object that absorbs all the radiation that strikes it

Perfect emitter: one that emits the maximum radiation possible at its given temperature]

Blackbody: one that is both a perfect absorber and perfect emitter

Earth’s surface and the sun - blackbodies (this is the reason why we can use Wien’s law and Stefan Boltzmann law)

The term blackbody applies only to particular wavelengths of radiation

Earth’s surface behaves as a blackbody for emissions of longwave => does not say anything about how well it absorbs shortwave radiation

Greybodies: objects that do not emit and absorb the maximum possible radiation for their temperature

Emissivity (ξ): the fraction of radiation that a greybody emits or absorbs compared with the blackbody

Stefan Boltzmann law for a greybody

$$E = \xi\sigma T^4$$

Radiative equilibrium

The Earth’s average temperature is not changing much - the short wave radiation absorbed by Earth and its atmosphere = long wave radiation leaving Earth and its atmosphere

Long wave radiation leaving Earth and its atmosphere required to balance the shortwave radiation received by Earth can be estimated by Stefan - Boltzmann Law

Radiative equilibrium temperature (T_re) - the average temperature at which this balance occurs

$$E = \sigma T_{re}^4$$

Earth’s observed temperature < T_re

Earth’s atmosphere absorbs and emits infrared radiation

Earth's surface. the atmosphere does not behave like a blackbody: absorbs some wavelengths of radiation and is transparent so others

Portion of the infrared radiation leaving Earth's surface reaches space —much of it is absorbed by the atmosphere

Selective absorbers: objects that selectively absorb and emit radiation. such as gases in our atmosphere

SELECTIVE ABSORBERS — THE GREENHOUSE EFFECT

absorb only certain wavelengths of radiation
Glass is a good example of a selective absorber - absorbs some of the infrared and ultraviolet radiation it receives but not the visible radiation that is transmitted through the glass

Objects that selectively absorb radiation also selectively emit radiation at the same wavelength => Kirchhoff's law

Kirchhoff's law: a particular wavelength good absorbers are good emitter, and poor absorbers are poor emitters..

Water vapour (H_2O) and carbon dioxide (CO_2):strong absorbers of infrared radiation and poor absorbers of visible solar radiation

Other important selective absorbers: nitrous oxide (N_2O), methane (CH_4), and Ozone (O_3) - most abundant in the stratosphere

As these gases absorb Infrared radiation emitted from Earth's surface, they gain sensible heat as the kinetic energy of gas molecules increases.

The gas molecules share this energy by colliding with neighbouring air molecule, such as oxygen and nitrogen (both poor absorbers of infrared energy)

These collisions increase the average kinetic energy of the air => increase in air temperature.

most of the infrared energy emitted from Earth's surface =>lower atmosphere warm, increasing its sensible heat.

Besides being selective absorbers, water vapour and CO: also selectively emit radiation at infrared wavelengths => travels away from these gases in all directions.
A portion of this energy is radiated toward Earth's surface and absorbed => heating the ground.
Earth's surface constantly radiates infrared energy upward, where it is absorbed and warms the lower atmosphere.

water vapour and CO2 absorb and radiate infrared energy => an insulating layer around Earth, keeping part of Earth's infrared radiation from escaping rapidly into space

Earth's surface and the lower atmosphere more warmer than they would be if these selectively absorbing and emitting gases were not present

Absorption characteristics of water vapour, CO2, and other gases, such as methane and nitrous oxide => similar to the glass of a greenhouse.

In a greenhouse, the glass allows visible radiation to come in but inhibits to some degree the passage of outgoing infrared radiation

the absorption of infrared radiation from Earth by water vapour and CO. => the greenhouse effect

The warm air inside a greenhouse <= the alr's inability to circulate and mix with the cooler outside air rather than by the entrapment of infrared energy

greenhouse effect = the atmosphere effect = atmospheric greenhouse effect

Between about 8 and 11 µm where neither water vapour nor CO2, readily absorbs infrared radiation => these wavelengths of emitted energy pass upward through the atmosphere and out into space => the atmospheric window (wavelength range)

Clouds can enhance the atmospheric greenhouse effect
Tiny liquid cloud droplets - selective absorbers that effectively absorb infrared radiation but do not absorb all visible solar radiation

absorb the wavelengths between 8 and 11 m => enhance the atmospheric greenhouse effect by closing the atmospheric window
Clouds—especially low, thick one- excellent emitters of infrared radiation

Their tops => infrared energy upward
Their bases => energy back to Earth's surface, where it is absorbed

calm, cloudy nights warmer than calm, clear ones

prevent much of the sunlight from reaching the ground by reflecting it back to space

Since the ground does not heat up as much as it would in full sunshine - cloudy, calm days are cooler than clear, calm days

clouds => nighttime temperatures higher and daytime temperatures lower the atmospheric greenhouse effect <= water vapour, COs, and other greenhouse gases(all selective absorbers)

They allow most of Meson's visible rad, don to reach Earth's surface, but they absorb a good portion of Earth's outgoing infrared radiation, preventing it from escaping into space (see • Figure 2.I3). It is the atmospheric greenhouse effect, then, that keens the temoemture of our