Solar Radiation
Emission and Absorption

Take away concepts
1. Conservation of energy.
2. Black body radiation principle
3. Emission wavelength and temperature (Wien’s Law).
4. Radiation vs. distance relation
5. Black body energy flux (Stefan-Boltzmann Law)
6. Effective temperature calculation, differences from actual temperature.

What is Energy?
Energy: “The ability to do work”

Energy measured in Joules (1 J = 0.24 calories).

Power measured in Watts (1 J/s)

Energy is always conserved (1st law of TD).

Energy can be changed from one form to another, but it cannot be created or destroyed.
Forms of Energy?

Thermal Energy: “The ability to do work through the release of heat (related to the temperature and phase of matter).

Electromagnetic Energy: Energy embedded in electromagnetic waves (such as light, microwaves, x-rays). When this kind of energy impinges on matter, part or all of it is converted to thermal energy.

Kinetic Energy: associated with motion

Gravitational Energy

Solar Energy

Nuclear fusion: H to He
Emits Electromagnetic radiation (radiant E)

EM waves behave like particles and waves

EM travels at c
(3 x 10^8 m/s)
EM Radiation

Electromagnetic radiation is a form of energy transfer that does not require mass exchange or direct contact. The transfer can take place in a vacuum. Electromagnetic waves are a type of energy wave that propagates at the speed of light, $c^* = 3 \times 10^8$ m s$^{-1}$.

The speed of light $c^*$, the frequency of the EM waves $\nu$, and its wavelength $\lambda$ are linked through the following relationship:

$$c^* = \lambda \nu$$

Electromagnetic Energy Transfer

- Radiation involves the propagation of EM waves at the speed of light $c^* = 3 \times 10^8$ m s$^{-1}$.

Properties of waves

- Amplitude (A)
- Wavelength ($\mu$m)
- Period (sec)
- Frequency (1/sec)

$c$ is constant
Heat Energy Radiation

- All bodies in the universe radiate energy at a rate which is proportional to their absolute temperature (°Kelvin), i.e. the internal energy of the body. This is caused by molecular motion that changes based on the energy level of the molecules and atoms that the body contains.

Blackbody Radiation

A “blackbody” absorbs and emits radiation at 100% efficiency (experimentally, they use graphite, or carbon nanotubes)

energy in = energy out

Across all wavelengths
Planck’s Function & Blackbody Radiation

Wien’s Law
emission wavelength and temperature

\[ \lambda_{\text{max}} = \frac{a}{T} \]

Where:
- \( \lambda_{\text{max}} \) is wavelength of emitted radiation (in \( \mu \)m)
- \( a = 2898 \), constant
- \( T \) emitter temperature (in K)

Recall that K = T°C + 273.15

Sun’s temperature is 5800K
What’s its wavelength?

The Sun’s temperature is 5800 K, that is the wavelength of its radiation?

\[ \lambda_{\text{max}} = \frac{a}{T} \]

Where:
- \( \lambda_{\text{max}} \) is wavelength of emitted radiation (in \( \mu \)m)
- \( a = 2898 \), constant
- \( T \) emitter temperature (in K)

Recall that K = T°C + 273.15
What’s your wavelength?

\[ \lambda_{\text{max}} = \frac{a}{T} \]

(a = 2898)

Your body is 37°C or 37 + 273 = 310 K

\[ \lambda_{\text{max}} = ? \]

9.4 µm (far infrared)

Earth as we see it (visible)

Earth’s Infrared “Glow”: 15µm
Electromagnetic spectrum

Visualizing emission temperatures

The Effect of distance on radiation
"The 1/r² rule"

The rate of energy flux decreases with increasing distance from the emitting object, and is directly related to the rate of increase in the surface area of the sphere. Because the surface area of a sphere increases proportional to the square of the radius we have:

\[ S \propto \frac{1}{r^2} \]

where \( S \) is the energy flux and \( r \) is the distance from the source. In the same way:

\[ \frac{S_2}{S_1} = \frac{r_1^2}{r_2^2} \]

Where \( r_1 \) and \( r_2 \) are two distances along the path of the radiation from the source.

The blackbody applet: [http://qsad.bu.edu/applets/blackbody/applet.html](http://qsad.bu.edu/applets/blackbody/applet.html)
Planetary Distances

- Mars (~229 million km)
- Earth (~150 million km)
- Venus (~108 million km)
- Mars is 1.52 AU
  (1 AU = earth-sun distance = 1.5 x 10^{11} m)

Using 1/r^2 rule…

\[ \frac{1}{(1.5\times1.5)} = 0.44 \]

Mars receives ~44% of the Earth’s solar radiation.

Jupiter is roughly 5 AU from the Sun, what fraction of Earth’s solar radiation does it get?
Summary so far...

Wien’s Law (emission freq. and temperature)

The “1 / r²” law (radiation amt and distance)

Now let's calculate the total radiative energy flux into or out of a planet using the:

Stefan - Boltzmann Law

Energy emitted by a black body is greatly dependent on its temperature:

\[ I = (1 - \alpha) \sigma T^4 \]

Where:
- \( I \) = Black body energy radiation
- \( \sigma \) = (Constant) \( 5.67 \times 10^{-8} \) Watts/m²/K⁴
- \( T \) = temperature in Kelvin
- \( \alpha \) = albedo ("reflectivity")

Example: Sun surface is 5800K, so \( I = 6.4 \times 10^7 \) W/m²

Stefan - Boltzmann Law

Calculating the Earth’s “Effective Temperature”

Easy as 1-2-3...

1. Calculate solar output.
2. Calculate solar energy reaching the Earth.
3. Calculate the temperature the Earth should be with this energy receipt.
1. Calculate solar output.

Calculate Sun temperature assuming it behaves as a blackbody (knowing that $\lambda_{\text{sun}} = 0.5 \mu m$).

From S-B law: $I_{\text{sun}} = 6.4 \times 10^7 \text{ W/m}^2$

We need surface area of sun:

Area = $4\pi r^2 = 4\pi (6.96 \times 10^8 \text{ m}) = 6.2 \times 10^{18} \text{ m}^2$

Total Sun emission: $3.86 \times 10^{26} \text{ Watts}$

<table>
<thead>
<tr>
<th>Solar</th>
<th>Division</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma T^4$</td>
<td>$4\pi R^2$</td>
</tr>
<tr>
<td></td>
<td>$6.4 \times 10^7$</td>
<td>$6.2 \times 10^{18}$</td>
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2. Calculate solar energy reaching the Earth.

Simple Geometry.
(recall the inverse square law.)

Earth-Sun distance (D): $1.5 \times 10^{11} \text{ m}$

Area of sphere = $4\pi r^2$

So, $3.86 \times 10^{26} \text{ Watts} / (4\pi (1.5 \times 10^{11} \text{ m})^2)$

Earth’s incoming solar radiation: $1365 \text{ W/m}^2$

3. Earth energy in = energy out

You have $I_{\text{earth}}$, solve for $T_{\text{earth}}$

Stefan - Boltzmann law: $I_{\text{earth}} = (1-\alpha) \sigma T_{\text{earth}}^4$

Incoming solar radiation: $1365 \text{ W/m}^2$

About 30% is reflected away by ice, clouds, etc.: reduced to $955 \text{ W/m}^2$

Incoming on dayside only (DISK), but outgoing everywhere (SPHERE), so outgoing is 1/4 of incoming, or $239 \text{ W/m}^2$

that is: $(0.7)^*0.25*1365 = \text{ energy that reaches Earth surface}$

Energy in = $239 \text{ W/m}^2 = \sigma T^4$
Solve for $T_{\text{effective}} = 255K$

Earth Effective temp 255 K, or -18°C
Earth Actual temp 288K, or +15°C

... the difference of +33°C is due to the natural greenhouse effect.

Recall that $K = T°C + 273.1$

So what Earth’s radiation wavelength?

$\lambda_{\text{max}} = \frac{a}{T}$

Where:
- $\lambda_{\text{max}}$ is wavelength of emitted radiation (in µm)
- $a = 2898$, constant
- $T$ emitter temperature (in K)

If Earth effective temperature is 255K
What’s the wavelength?

Emission Spectra: Sun and Earth

Range of wavelengths of solar and Earth spectra.
Radiation and Matter

Also dependent upon the frequency of radiation! (next lecture)

Emission Spectra: Sun and Earth

Blackbody emission curves and absorption bands
Why is the Sky blue?

Rayleigh scattering of incoming, short wavelength radiation (photons with specific energy)
Radiation scattered by O\textsubscript{3}, O\textsubscript{2} in stratosphere (10-50 km)

Why are sunsets red?

Blue wavelengths are scattered/absorbed
Red and orange pass through to surface