• Temperature on a planet
• Earth’s thermostat

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(Office hours: Mondays 2:30 – 3:30 in X590 and Wednesdays 11-12 in D230 → today only to 11:30)
The hotter, the more it loses

\[ F = \sigma_{SB} T^4 \]

\[ \sigma_{SB} = 5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4} \]

- 100 K \( \rightarrow 5.67 \text{ W m}^{-2} \)
- 1000 K \( \rightarrow 5.67 \times 10^4 \text{ W m}^{-2} \)
- 10,000 K \( \rightarrow 5.67 \times 10^8 \text{ W m}^{-2} \)
Lecture 8: solar energy

Table 1.4 Present-day sources of energy averaged over the Earth.

<table>
<thead>
<tr>
<th>Source</th>
<th>Power/W m(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>total solar radiation</td>
<td>360</td>
</tr>
<tr>
<td>geothermal heat flow</td>
<td>(8.1 \times 10^{-2})</td>
</tr>
<tr>
<td>electrical discharges (lightning)</td>
<td>(5.4 \times 10^{-8})</td>
</tr>
<tr>
<td>cosmic rays</td>
<td>(2 \times 10^{-11})</td>
</tr>
<tr>
<td>shock waves (atmospheric entry)</td>
<td>(1.5 \times 10^{-8})</td>
</tr>
</tbody>
</table>

- We get 360 W/m\(^2\) (daily average)
- What happens with most of it?
What happens with that energy

- We get 360 W/m$^2$
- Supply all our solar panels
- Photosynthesis $\rightarrow$ build trees etc
- Drive hurricanes
- What else?
What else?

- We get 360 W/m²
- Needed to keep Earth warm
- How warm?
Intermediate values

\[ F = \sigma_{SB} T^4 \]

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- 100 K \rightarrow 5.67 \text{ W m}^{-2}
- ?? \rightarrow 5.67 \times 10^1 \text{ W m}^{-2}
- ?? \rightarrow 5.67 \times 10^2 \text{ W m}^{-2}
- ?? \rightarrow 5.67 \times 10^3 \text{ W m}^{-2}
- 1000 K \rightarrow 5.67 \times 10^4 \text{ W m}^{-2}
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Intermediate values

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- 100 K \[ \rightarrow 5.67 \text{ W m}^{-2} \]
- 180 K \[ \rightarrow 5.67 \times 10^1 \text{ W m}^{-2} \]
- 316 K \[ \rightarrow 5.67 \times 10^2 \text{ W m}^{-2} \]
- 560 K \[ \rightarrow 5.67 \times 10^3 \text{ W m}^{-2} \]
- 1000 K \[ \rightarrow 5.67 \times 10^4 \text{ W m}^{-2} \]
Intermediate values

\[ F = \sigma_{SB} T^4 \]

\[ \sigma_{SB} = 5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4} \]

- 100 K \(\Rightarrow\) 5.67 W m\(^{-2}\)
- 180 K \(\Rightarrow\) 56.7 W m\(^{-2}\)
- 316 K \(\Rightarrow\) 567 W m\(^{-2}\)
- 560 K \(\Rightarrow\) 5,670 W m\(^{-2}\)
- 1000 K \(\Rightarrow\) 56,700 W m\(^{-2}\)
Intermediate values

\[ F = \sigma_{SB} T^4 \]

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- 180 K \rightarrow 56.7 \text{ W m}^{-2}
- 273 K \rightarrow 315 \text{ W m}^{-2}
- 293 K \rightarrow 418 \text{ W m}^{-2}
- 316 K \rightarrow 567 \text{ W m}^{-2}
Conclusion

• We get 360 W/m²
• How warm?
  → slightly above freezing
• Forgot about cloud cover
  → 30% reflected
•  → get only 70%
•  → only 255 K (p.49 of RGS)
• Why is it usually much warmer?
Why not 255 K on Earth?

• ...

• .......

• .........
Two “black” bodies

- Hotter $\rightarrow$ brighter
- Hotter $\rightarrow$ color changes
  - Yellow $\rightarrow$ white $\rightarrow$ blue
  - Cooler $\rightarrow$ deeper red

$T=6000K$ $T=300K$
Solar flux at the Earth?

\[ L \times F \times r = \text{const} \]

\[ \frac{L}{4 \pi r^2} = \frac{L}{4 \pi d^2} \]

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Solar flux at the Earth?

$T_{\text{Sun}} = 6000 \text{K}$

$$4\pi r^2 F_r = \text{const} = L$$

$$L = 4\pi R_{\text{Sun}}^2 \sigma_{\text{SB}} T_{\text{Sun}}^4 = 4\pi r^2 F_r$$
Fraction intercepted by the Earth?

\[ T_S = 6000\text{K} \]

\[ \pi r^2 F_r = \text{total energy/sec} \]
In & outgoing energy/sec

Earth must receive more than it loses

Earth must receive as much as it loses

Earth must receive less than it loses
In & outgoing energy/sec

\[ F_{\text{Earth}} = \sigma_{\text{SB}} T_{\text{Earth}}^4 \]

\[ \pi R_{\text{Earth}}^2 F_r \]

gain over exposed surface

Total loss (day&night)

A. Earth must receive more than it loses
B. Earth must receive as much as it loses
C. Earth must receive less than it loses
Eliminate $F$

$T_S = 5778\text{K}$

\[
\pi R_E^2 F_r = 4\pi R_E^2 \sigma_{SB} T_E^4
\]

\[
4\pi R_S^2 \sigma_{SB} T_S^4 = 4\pi r^2 F_r
\]
Google for “Effective Temperature”

\[ T_{\text{Earth}} = T_{\text{Sun}} \left( \frac{R_{\text{Sun}}}{2d} \right)^{1/2} \left( 1 - A \right)^{1/4} \leq 279 \, \text{K} \]

where

- \( T_{\text{Earth}} \rightarrow \text{Earth’s temperature} \)
- \( T_{\text{Sun}} \rightarrow \text{Sun’s surface temperature} \)
- \( R_{\text{Sun}} \rightarrow \text{Radius of the Sun} \)
- \( d \rightarrow \text{distance between Sun and Earth} \)
- \( A \rightarrow \text{Albedo (\text{=how much is reflected})} \)
temperature:

\[ T = \sqrt[4]{\frac{L(1-a)}{16\pi\sigma D^2}} \]

Note that the planet's radius has cancelled out of the final expression.

The effective temperature for Jupiter from this calculation is 112 K and 51 Pegasi b (Bellerophon) is 1,258 K.\(^{\text{[citation needed]}}\) A better estimate of effective temperature for some planets, such as Jupiter, would need to include the internal heating as a power input. The actual temperature depends on albedo and atmosphere effects. The actual temperature from spectroscopic analysis for HD 209458 b (Osiris) is 1,130 K, but the effective temperature is 1,359 K.\(^{\text{[citation needed]}}\) The internal heating within Jupiter raises the effective temperature to about 152 K.\(^{\text{[citation needed]}}\)

**Surface temperature of a planet** \(^{[\text{edit}]}\)

The surface temperature of a planet can be estimated by modifying the effective-temperature calculation to account for emissivity and temperature variation.

The area of the planet that absorbs the power from the star is \(A_{\text{abs}}\) which is some fraction of the total surface area \(A_{\text{total}} = 4\pi r^2\), where \(r\) is the radius of the planet. This area intercepts
Google for “Effective Temperature”

\[ T_E = T_S \left( \frac{R_{\text{Sun}}}{2d} \right)^{1/2} (1 - A)^{1/4} \leq 279 \text{ K} \]

What would happen if the Earth were bigger

A. The Earth gains more heat
B. The Earth gains less heat
C. The Earth temp remains unchanged
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\[ T_{\text{Earth}} = T_{\text{Sun}} \left( \frac{R_{\text{Sun}}}{2d} \right)^{1/2} (1 - A)^{1/4} \leq 280 \text{ K} \]

What would happen if the Earth were bigger

A. The Earth gains more heat
B. The Earth gains less heat
C. The Earth temp remains unchanged
What does it mean?

\[ T_{\text{Earth}} = T_{\text{Sun}} \left( \frac{R_{\text{Sun}}}{2d} \right)^{1/2} \]

\[ F \propto \frac{1}{d^2} \]

\[ F = \sigma_{\text{SB}} T^4 \]

What if distance \( d \) were 4 times larger

- \( 1/d^2 \) becomes 16 times smaller
- \( F \) decreases by 1/16
- \( T_{\text{Earth}} \) decreases by 1/2
The $\text{CO}_2$ thermostat

$\text{CO}_2$ low, cool, less rain

$\text{CO}_2$ high, warm, more rain

atmospheric $\text{CO}_2$ builds up

atmospheric $\text{CO}_2$ reduced
On Earth, CO$_2$ is recycled

- Sources of CO$_2$
  - ....
  - ....

- Sinks of CO$_2$
  - ...
  - ...
On Earth, CO$_2$ is recycled

- Sources of CO$_2$
  - Animal life on Earth
  - Oxidation of exhumed CH$_2$O
  - Other C oxidation (e.g. fire)
  - Outgassing (volcanoes)
  - CaCO$_3$ $\rightarrow$ CaO+CO$_2$ or rather
    - Silicate minerals + CaCO$_3$ $\rightarrow$
      new silicate minerals+CO$_2$
Sources of CO₂

On Earth, CO₂ is recycled...
On Earth, CO$_2$ is recycled through various processes including:

- Terrestrial photosynthesis
- Respiration
- Human emissions
- Weathering of terrestrial rocks
- Leaching/Runoff
- Ocean sediments
- Fossil carbon
- Microbial respiration and decomposition

These processes help in the carbon cycle, maintaining the balance of carbon in the environment.
**Sinks of CO$_2$**

- Photosynthetic life (of course)
- Acid rain: $\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3$
  - Contact with rock: weathering
- $\text{CaSiO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2$
  - Calcium carbonate
  - solid deposit (sea bed)
  - carbonate rock (limestone)
  - Details in RGS p.51
**Sinks of CO$_2$**

- Acid rain: $\text{H}_2\text{O}+\text{CO}_2 \rightarrow \text{H}_2\text{CO}_3$
  - Contact with rock: weathering

- $\text{CaSiO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2$
  - Calcium carbonate (solid deposit)
  - Details in RGS p.51

- On Earth: 170,000 times more CO$_2$ in carbonate rocks than in atmosphere

See BS p.139 for details!
The CO$_2$ thermostat

• Recycling rate sensitive to temperature
• CO$_2$ $\rightarrow$ warmer (greenhouse)
  – More evaporation, more rainfall
• Pulling more CO$_2$ out of atmosphere
  – Weaker greenhouse effect
• Negative feedback
Feedbacks

• Negative feedback
  – Stable

• Positive feedback
  – Unstable, runaway

• Examples?
  – loudspeaker


CO₂ thermostat: other way around

• Less CO₂ → cooler
  – less evaporation, less rainfall

• Less removal of CO₂ out of atmosphere
  – greenhouse effect becomes stronger
  – and it gets warmer again

• Again: negative feedback
The CO\(_2\) thermostat

CO\(_2\) high, warm, more rain

atmospheric CO\(_2\) reduced
The CO$_2$ thermostat

CO$_2$ low, cool, less rain

CO$_2$ high, warm, more rain

atmospheric CO$_2$ builds up

atmospheric CO$_2$ reduced
Next time

• Carbon cycle
• Plate tectonics
• Great Oxidation Event (GOE)
• pp. 50 - 53