Basic climate science I:

Blackbody radiation, Stefan-Boltzman's law, a simple model of the greenhouse effect…

Martin Persson

Physical Resource Theory
Department of Energy & Environment
Chalmers University of Technology

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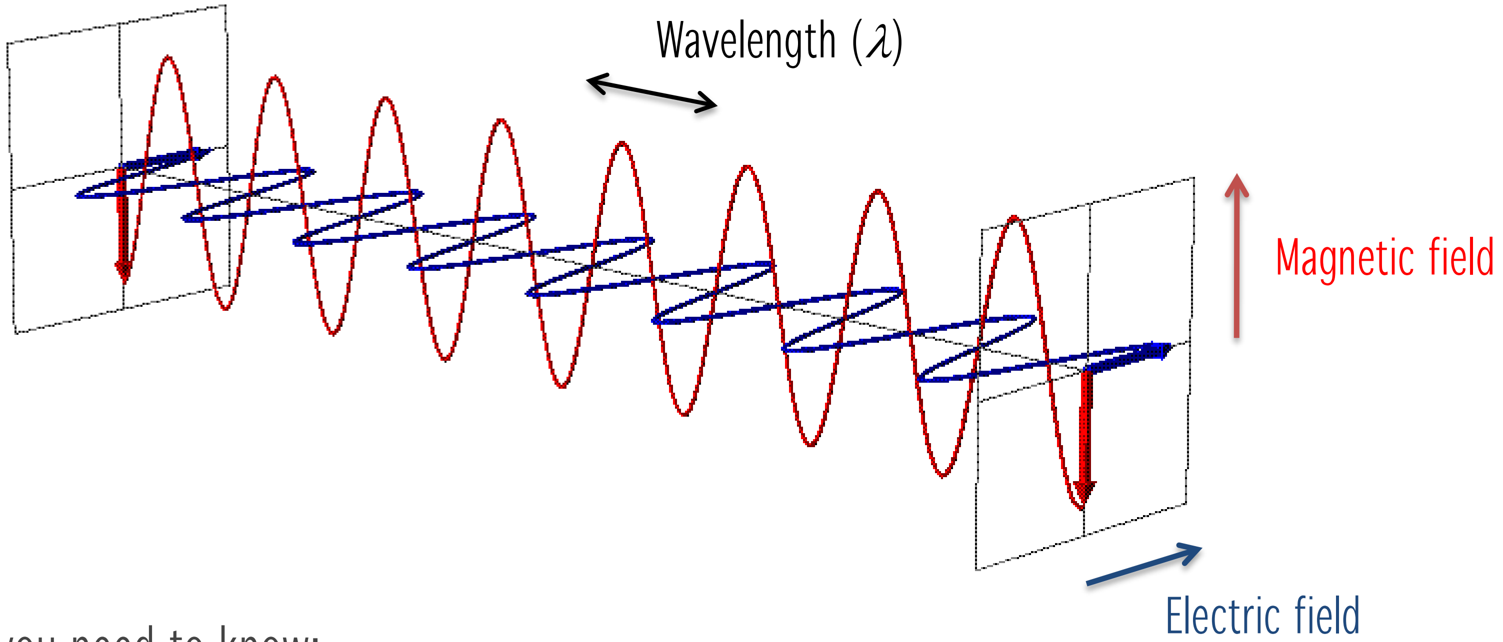
After this lecture you should be able to answer the following questions:

1. What is electromagnetic radiation (light) and how does it interact with matter?
2. What is temperature?
3. What is blackbody radiation?
4. How does the intensity of blackbody radiation depend on the temperature of an object (Stefan-Boltzmann's law)?
5. What is the relation between absorptivity (an objects ability to absorb incoming radiation) and emissivity (it ability to radiate)?

These are the basic concepts you need for understanding the natural greenhouse effect and how humans affect it…

Electromagnetic radiation (light)



What you need to know:

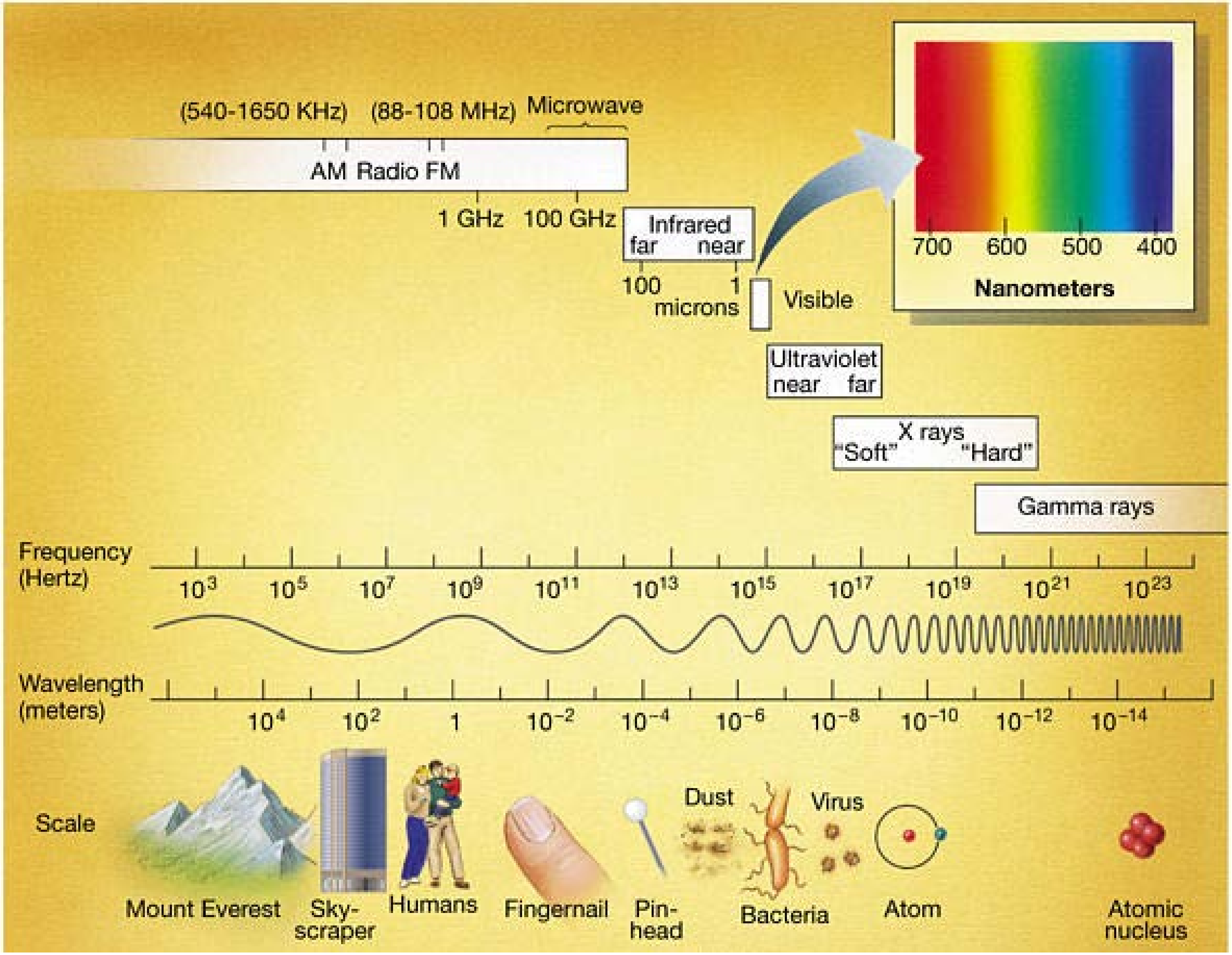
Electromagnetic radiation is characterized by wavelength (λ) / frequency (ν) –

λ [m] = c [m/s] / ν [s^{-1}]

The higher the frequency (shorter wavelength), the more energy the radiation holds –

$E = h\,\nu = h\,c\,/\,\lambda$ [J], where h is Planck's constant (~6.63×10^{-34} [J s])

Can you think of any examples of electromagnetic radiation?
(besides visual light)


(540-1650 KHz)
(88-108 MHz)
Microwave
AM Radio FM
1 GHz
100 GHz
Infrared
far near
100
1
microns
Visible
700 600 500 400
Nanometers
Ultraviolet
near far
X rays
"Soft" "Hard"
Gamma rays
Frequency (Hertz)
10^3 10^5 10^7 10^9 10^{11} 10^{13} 10^{15} 10^{17} 10^{19} 10^{21} 10^{23}
Wavelength (meters)
10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14}
Scale
Mount Everest
Sky-scraper
Humans
Fingernail
Pin-head
Dust
Bacteria
Virus
Atom
Atomic nucleus

Interaction between radiation and matter

-Scattering (reflection) – irrelevant for earth's climate

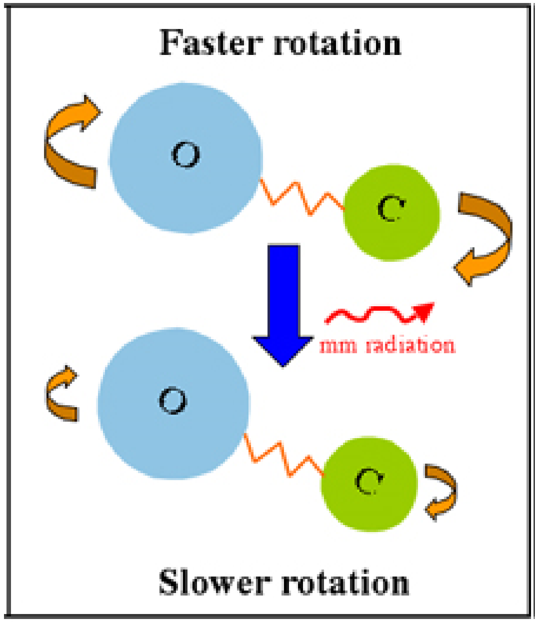
-Absorption

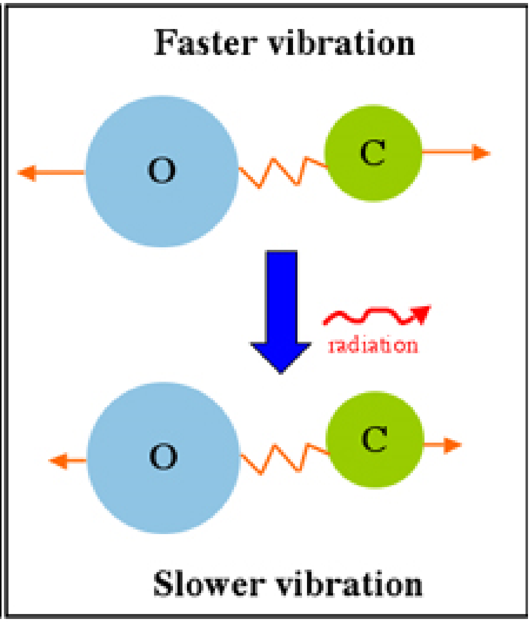
-Emission

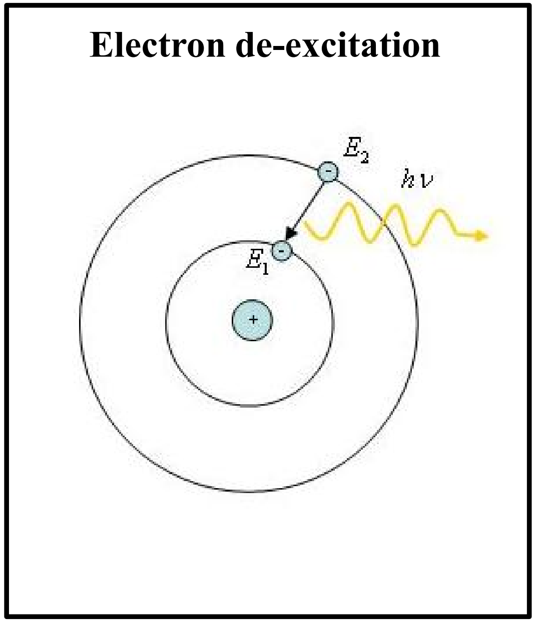
} Same physical processes, essential for the greenhouse effect!

Interaction between radiation & matter – absorption and emission

Wavelength of emitted radiation:		
Microwave	Infrared	Visible and shorter

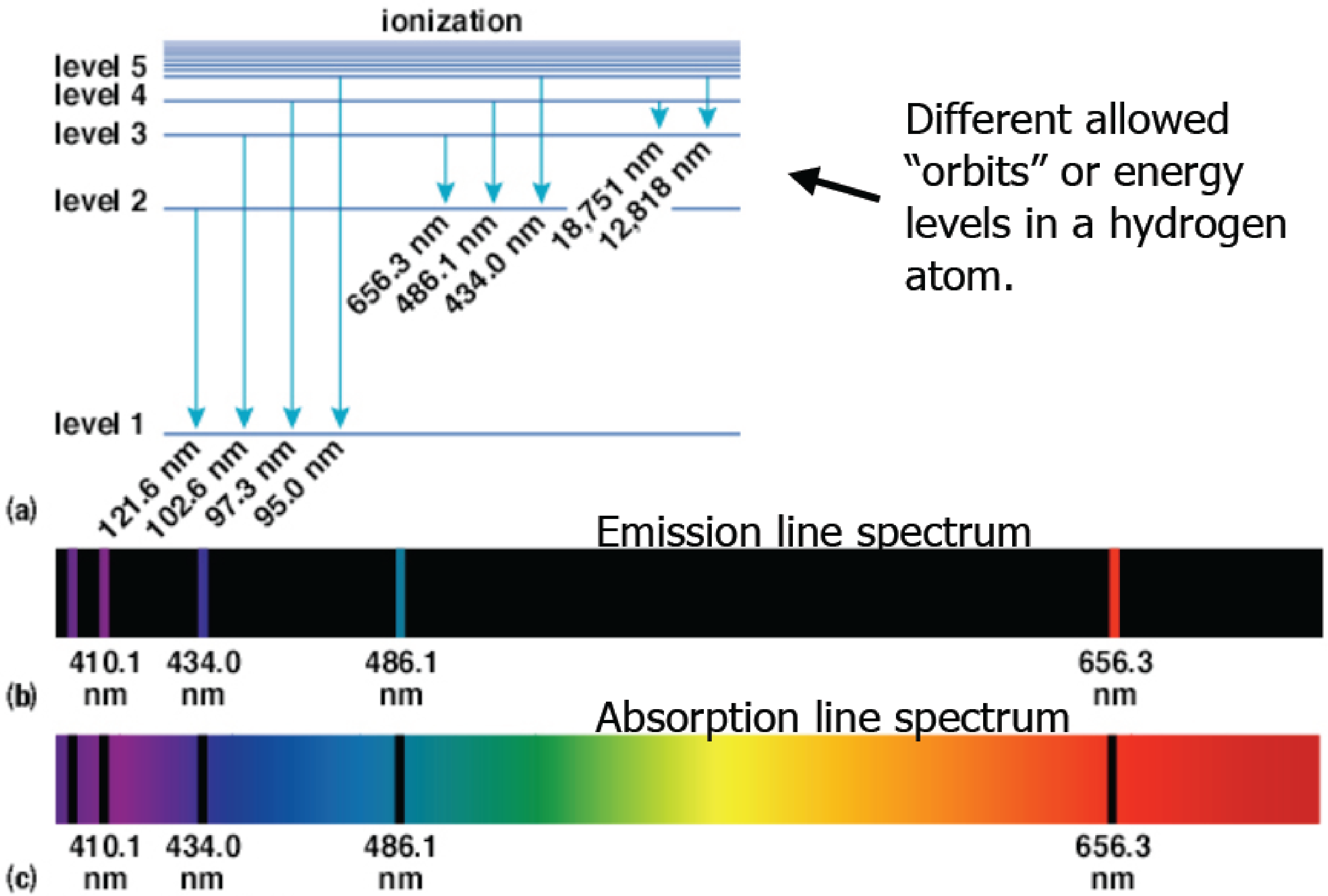






Important to remember – energy is ‘quantitized’, cannot come at any level – implies that most elements will absorb/emit only at given wavelengths!

The radiation 'fingerprint' of hydrogen



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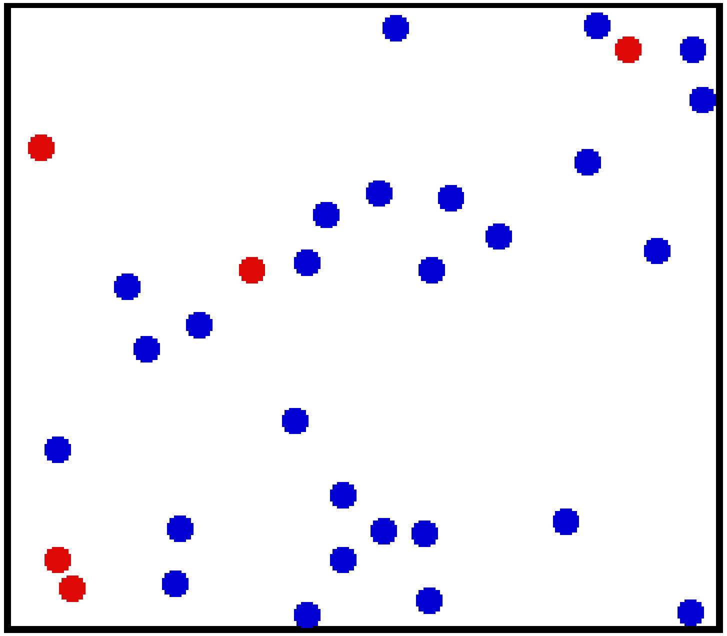
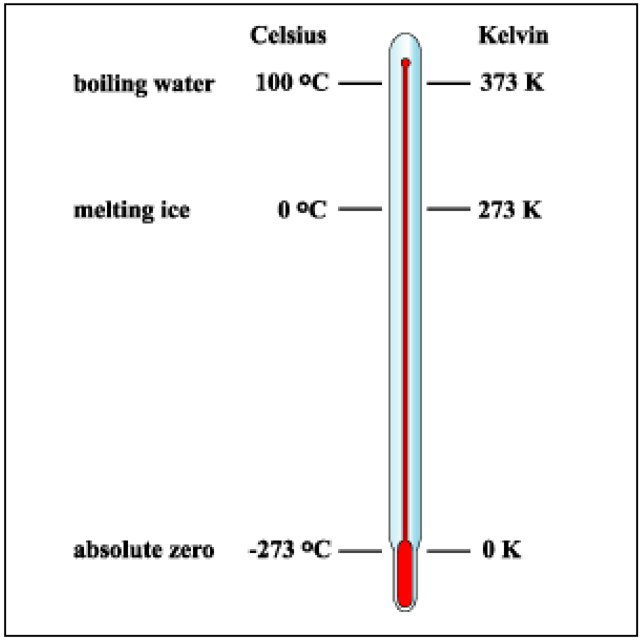
Any more questions on electromagnetic radiation & its interaction with matter before we move on...?

What is temperature?

Temperature is a measure of the average energy of movement, vibration, and rotation of the atoms/molecules in an object...

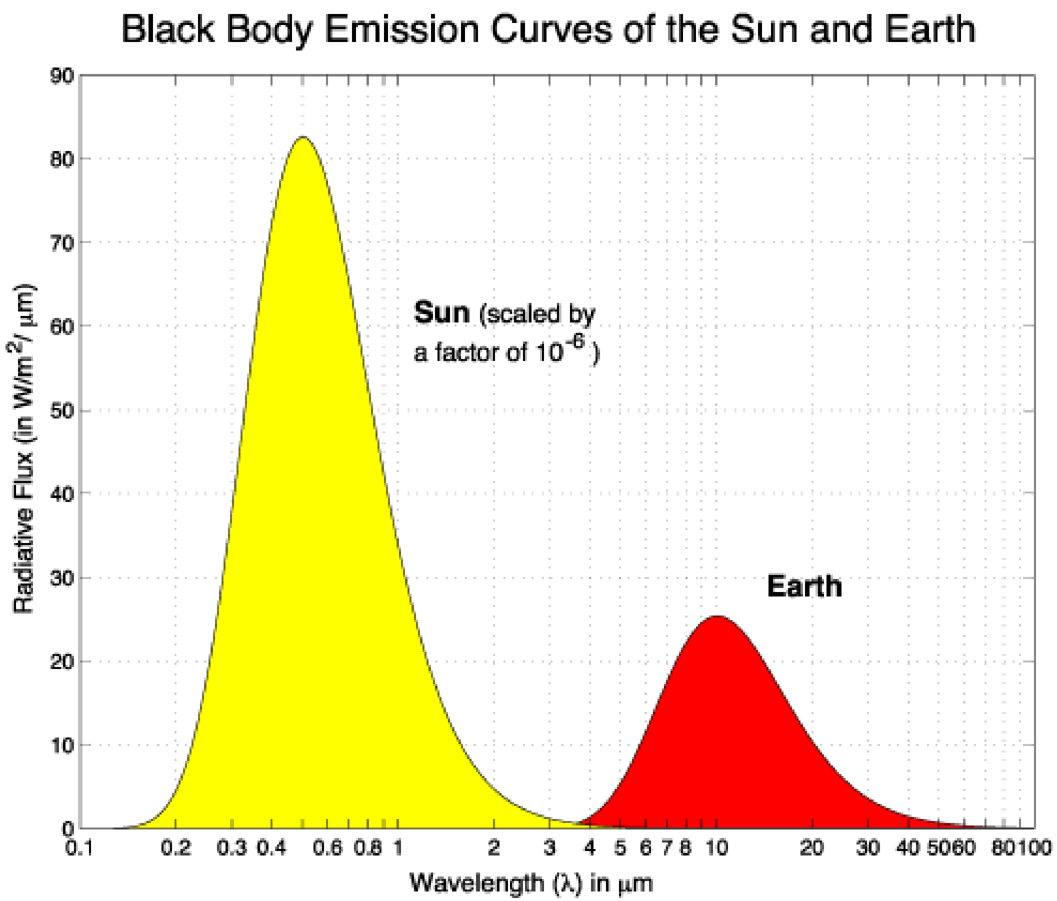
Kelvin-scale – at absolute zero, atoms are (almost) completely still...





Blackbody radiation

- All material above 0 K (absolute zero) will radiate – if it can radiate at all wavelengths we call it a perfect blackbody
- A piece of charcoal, a stove burner, a furnace, planets (solids), and stars (dense gas) are excellent examples of close-to-blackbodies



What happens with blackbody radiation as temperature increases?

1. The total intensity of the radiation goes up – Stefan-Boltzmann's law:
   $I = \varepsilon\sigma T^4$ [W/m^2];
   ε = emissivity (ε = 1 -> perfect blackbody)
   σ (Stefan-Boltzmann's constant) = $5.67 * 10^{-8}$ [W$m^{-2}K^{-4}$]

2. The wavelength of the peak of the blackbody radiation decreases (frequency increases) – Wien's displacement law:
   $\lambda_{peak} = 2.9 * 10^{-3} / T$ [m]

Blackbody radiation as a function of temperature

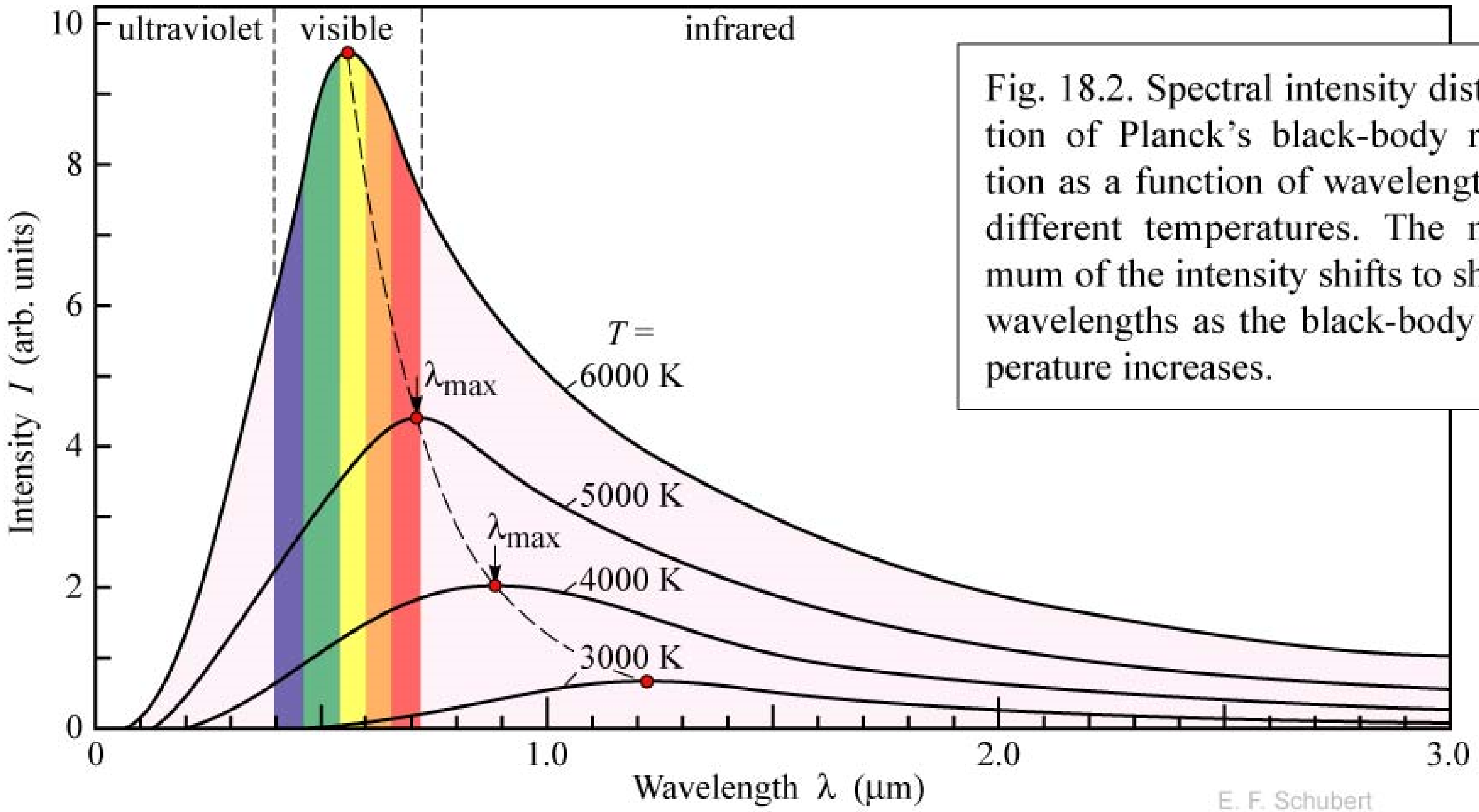
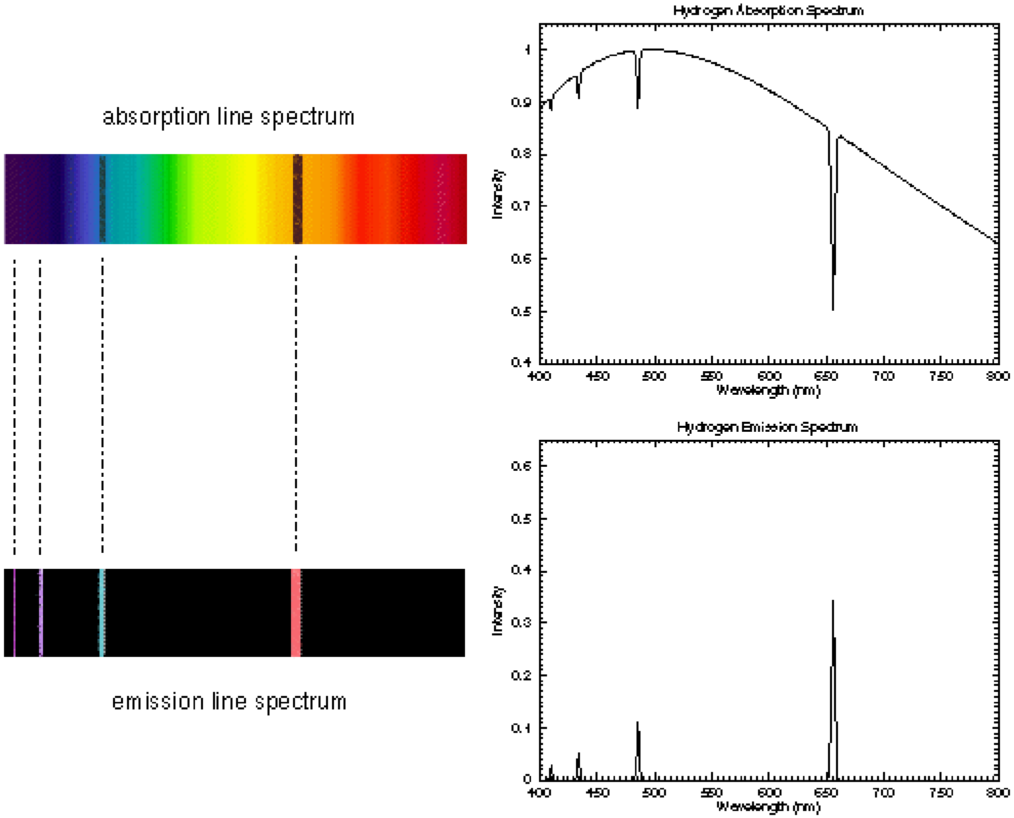


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Why is it called ‘blackbody’ if it emits at all wavelenghts – ‘whitebody’ seems more fitting, or?

Kirchhoff's law – absorptivity equals emissivity



Two ways of showing the same spectra: on the **left** are pictures of the dispersed light and on the **right** are plots of the intensity vs. wavelength. Notice that the pattern of spectral lines in the absorption and emission line spectra are the **same** since the gas is the same.

I.e., a perfect blacbody both absorbs and emits in all wavelengths.

What would happen if this was not the case – e.g., if the emissivity of an object was smaller than its absorptivity?

Any more questions on temperature and blackbody radiation before we have a quiz...?

Summary quiz

Question 1:

Which is more energetic (holds the most energy): yellow light (λ~580 nm) or blue light (λ~470 nm)?

1. Yellow X. Equally energetic 2. Blue

Summary quiz

Question 2:

Through which physical process does infrared radiation interact (emission/absorption) with matter?

1. Through increases / decreases in rotational energy

X. Through increases / decreases in vibrational energy

2. Through electron excitation / de-excitation

Summary quiz

Question 3:

Consider two perfect blackbodies, one heated to a temperature of 300 K, the other to 600 K. How much more energy does the warmer blackbody radiate?

1. Twice as much X. Eight times as much 2. Sixteen times as much

Summary quiz

Question 4:

Consider two planets that are identical—i.e., they have the same size, the same distance from the sun, receiving the same amount of sunlight, etc—apart from the fact that the planet A has an emissivity (for all wavelenghts) of 0.9 and planet B an emissivity of 0.3. Which one will be hotter?

1. Planet A   X. They will be equally hot   2. Planet B

Summary quiz

Question 1:

Which is more energetic (holds the most energy): yellow light (λ~580 nm) or blue light (λ~470 nm)?

1. Yellow — X. Equally energetic — **2. Blue**

The higher the frequency (shorter wavelength), the more energy the radiation holds – $E = h\nu = hc/\lambda$ [J], where h is Planck's constant (~$6.63 \cdot 10^{-34}$ [J s])

Summary quiz

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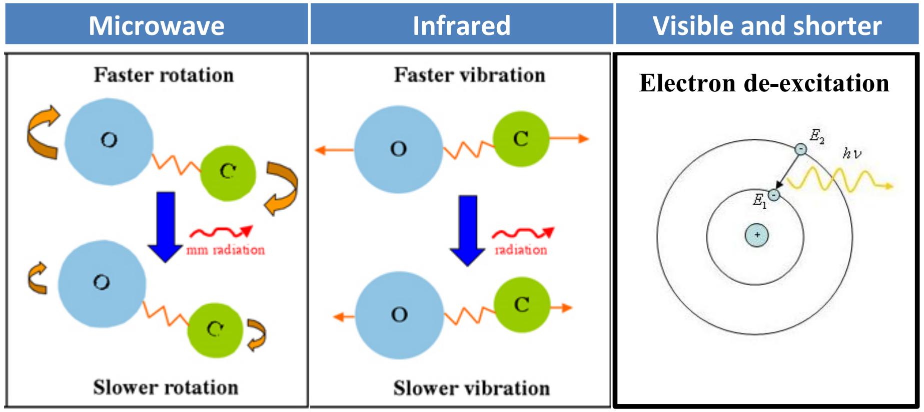

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If temperature increases total intensity of the radiation goes up – Stefan-Boltzmann's law: $I = \varepsilon\sigma T^4$ [W/m^2];

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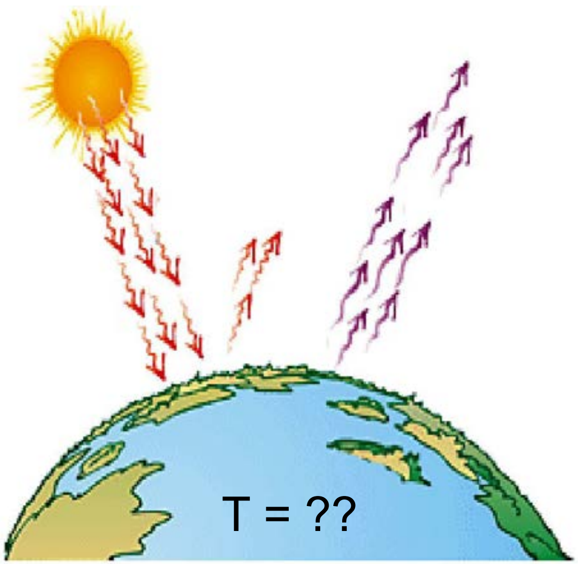
1. Planet A

X. They will be equally hot

2. Planet B

Kirchoffs law: emissivity equal absorptivity -> although planet A will absorb a larger share of the incoming solar radiation, it will also emit more radiation and hence they will have the same temperature

A simple model of the natural greenhouse effect



Earth without atmosphere
– energy balance

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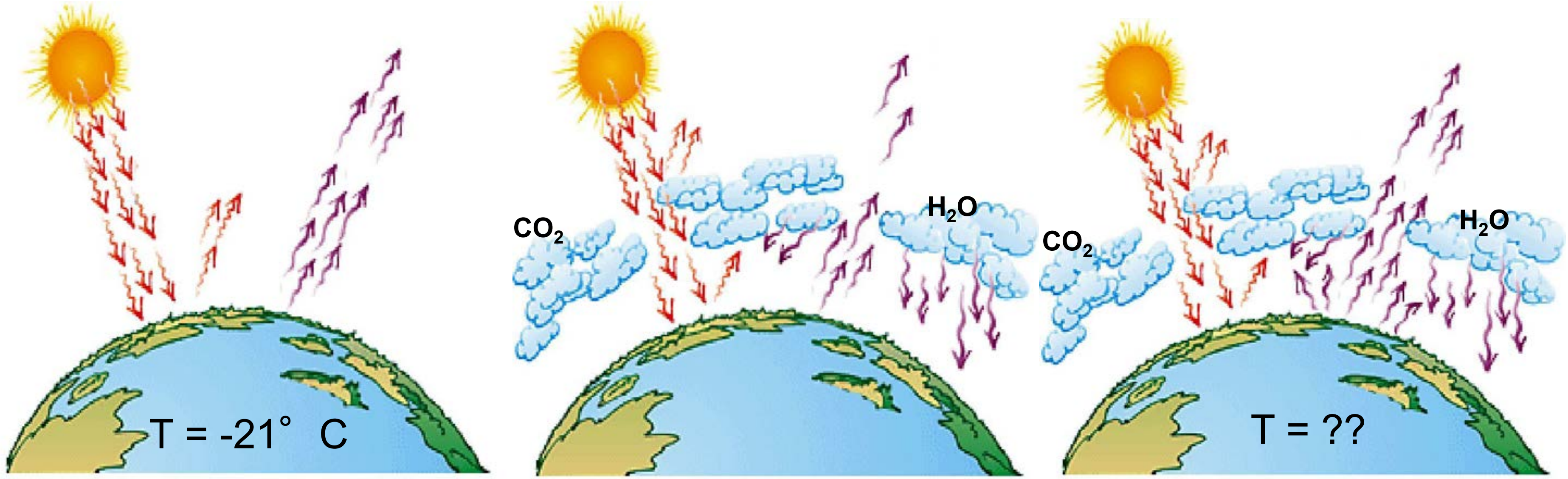
A simple model of the natural greenhouse effect



Earth without atmosphere – energy balance

Earth with atmosphere – energy imbalance

Earth with atmosphere – energy balance

Home assignment

Do calculation exercises 1.1 and 1.2…