Light sources

Major categories: Thermal → broadband
Sun, stars, incandescent light bulb, fire, hot objects
Thermal energy is converted into light

Spectral emission → well-defined spectral lines
Discharge lamps (neon, signs, mercury lamps, etc)
Auroras
Excited atoms/molecule undergo transitions to lower energy states
~~Luminescence~~ →

Luminescence / fluorescence

LEDs, bioluminescence, chemiluminescence
Transitions between energy bands in solids or complex molecules

Stimulated emission - lasers, masers

Thermal / Black body emission

We discussed that any oscillating dipole emits electromagnetic radiation.
Up to now we only considered the case when this oscillation was excited by incoming light (to explain absorption and refraction).
But what if ~~this~~ the oscillation is due to thermal motion?
Temperature = random motion of particles
Higher temperature — faster motion → higher frequency oscillation → higher frequency radiation.

Wien's (displacement) law

$$\lambda_{max} = \frac{2.898 \cdot 10^{3}\ m \cdot K}{T \text{ (in Kelvins)}}$$

Room temperature $T = 300K$ $\lambda_{max} \approx 10\mu m$ (far-IR)

$T = 500K$ (hot oven, stove) $\lambda_{max} \approx 5\text{-}6\mu m$ (mid-IR)

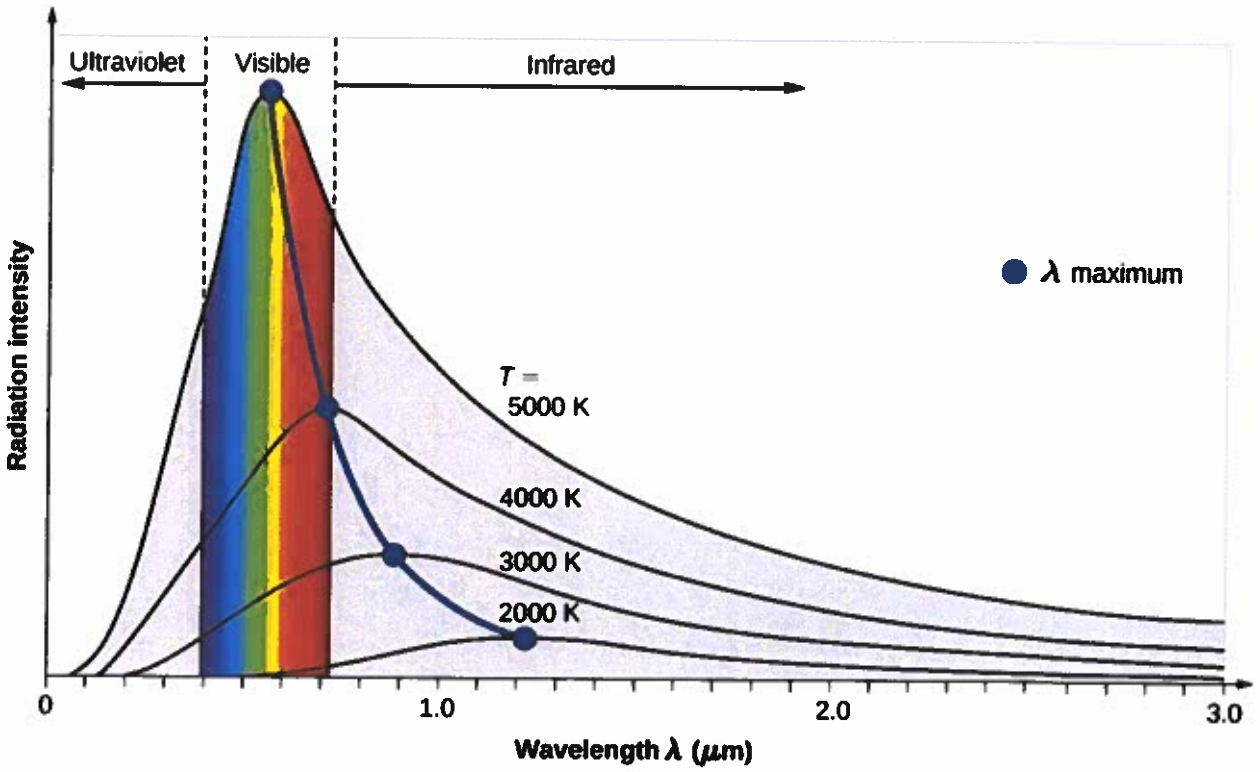
$T = 900K\text{-}1100K$ (blacksmith kiln, furnace, hot metal)
$\lambda = 2\text{-}3\mu m$ (near IR, start glowing red)

$T = 1400K$ (candle flame, hot lava) $\lambda_{max} = 1.5\mu m$

$T = 3000K$ (incandescent light) $\lambda_{max} = 950nm$

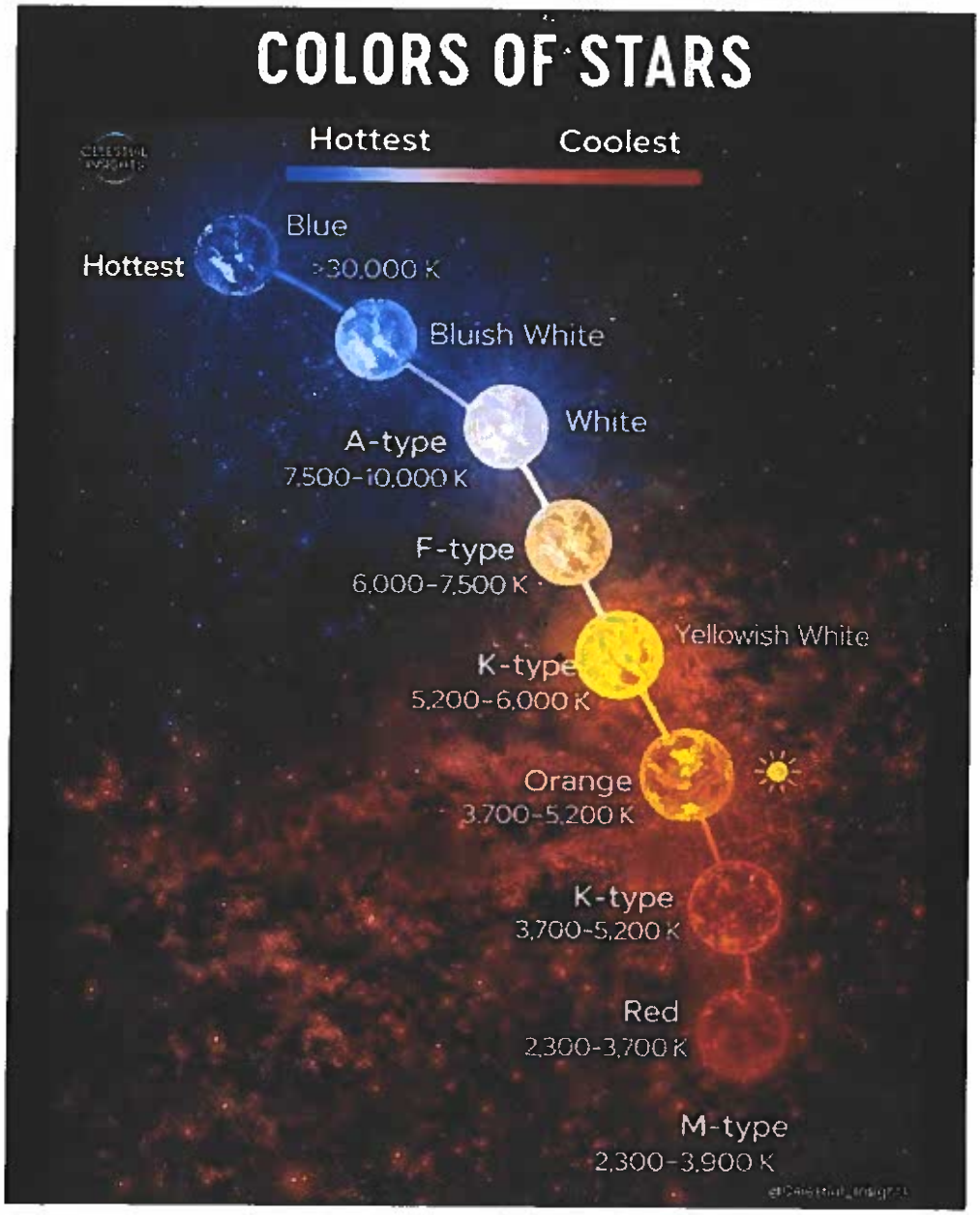
$T = 5000K$ (hot stars, Sun photosphere) $\lambda = 500\text{-}550nm$

$T = 30,000K$ (very hot stars, plasma) $\lambda = 100nm$ (UV)

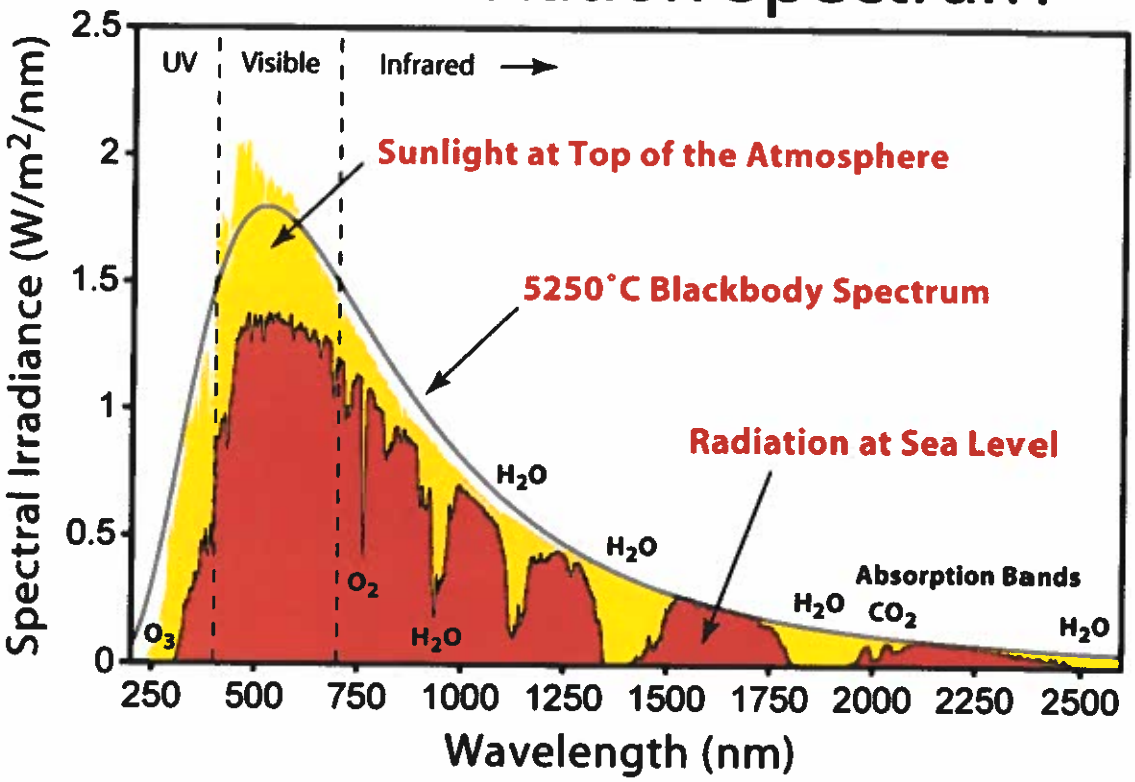

Ultraviolet
Visible
Infrared
Radiation intensity
λ maximum
T =
5000 K
4000 K
3000 K
2000 K
0
1.0
2.0
3.0
Wavelength λ (μm)

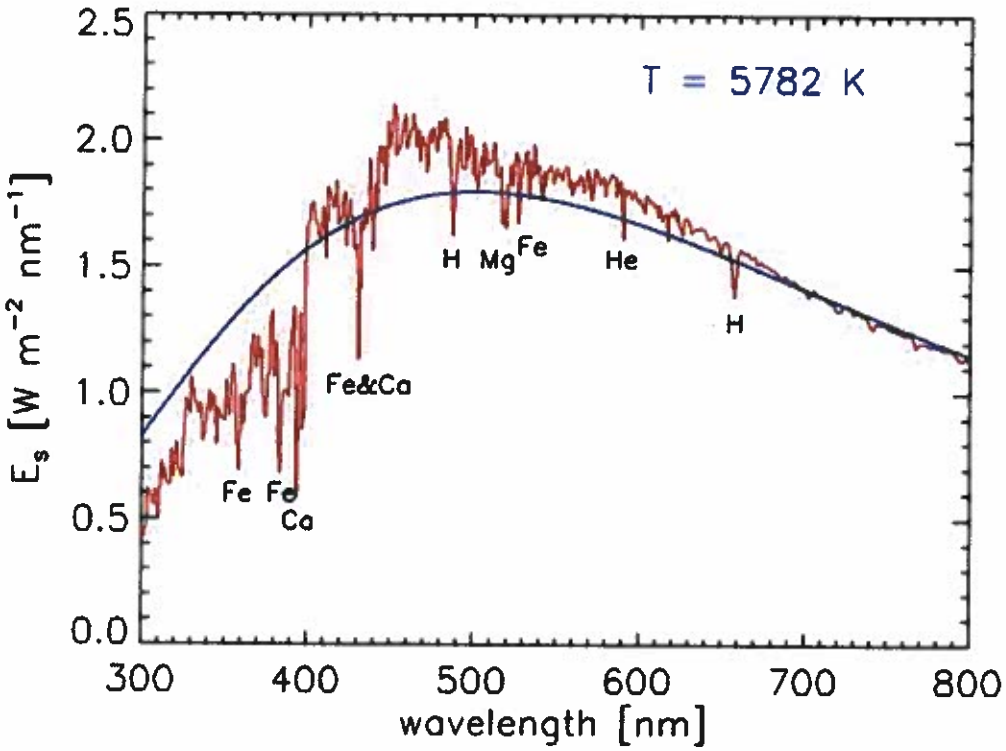
Black body is a model of an ideal thermal emitter

Black ≡ absorbs energy at any wavelength and redistributes it equally among all possible oscillations (degrees of freedom)
That is why the "color" distribution of a black body depends only on its temperature.
Many thermal sources can be approximated by the black body spectrum
Another characteristic – broadband, emits at wide range of frequencies


COLORS OF STARS
Hottest
Coolest
Hottest
Blue
>30,000 K
Bluish White
White
A-type
7,500-10,000 K
F-type
6,000-7,500 K
Yellowish White
K-type
5,200-6,000 K
Orange
3,700-5,200 K
K-type
3,700-5,200 K
Red
2,300-3,700 K
M-type
2,300-3,900 K

Solar Radiation Spectrum



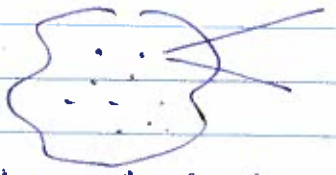


Spectral lines – very specific frequencies

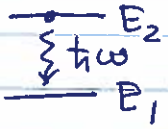
Atoms / molecules have very specific energy levels that electrons can occupy. If some process excites electrons in ~~that~~ an excited state, it can move to a lower energy state by emitting light. ~~Heat~~ In this case the frequency of light will be such that

$$\hbar\omega = \frac{2\pi\hbar c}{\lambda} = E_{excited} - E_{ground}$$

$\hbar\omega$: energy of a single photon
minimal amount of energy light can carry – energy quantum



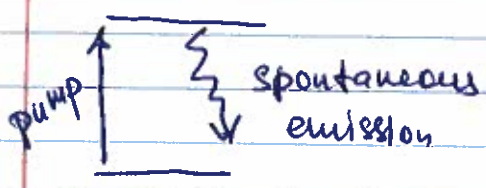
total # of atoms

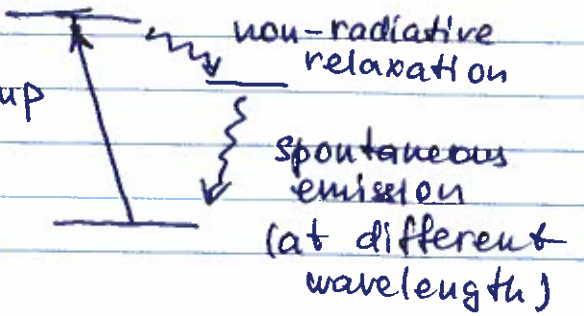


Total emitted energy
$N_2 \cdot \hbar\omega$
N_2 – # of atoms in the excited state

The light is emitted in all directions at random moment (within excited state life time) – spontaneous emission

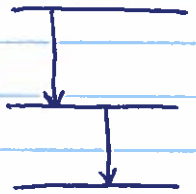
How to excite atoms / molecules
– using another light source





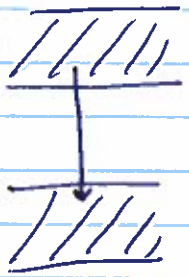
Many complex molecules and solid state systems have some energy level / band structure

Simple atom



well-defined energy levels

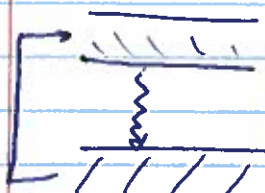
Complex materials



energy bands ~~cross~~

emitted radiation is more broad band (emitted in a range of wavelength, but still much more defined than black body)

Light-emitted diodes
Semiconductor material



conduction band (empty)

band gap

valence band (filled)

One can use electric current to "promote" some electrons from valence to conduction band. To "jump" back electrons must release the energy given by the energy band gap
→ emitted light color is determined by the band gap value

LED Colors and Specifications



WHITE
Wavelength
Full spectrum
Forward voltage
3.5–4.0 V
Forward current
Approx 20 mA
Material
InGaN (with phosphor)



GREEN
Wavelength
550–570 nm
Forward voltage
3.5 V
Forward current
Approx 20 mA
Material
GaP (Gallium Phosphide)



BLUE
Wavelength
430–505 nm
Forward voltage
3.6 V
Forward current
Approx 20 mA
Material
InGaN (Indium Gallium Nitride)



YELLOW
Wavelength
585–595 nm
Forward voltage
2.2 V
Forward current
Approx 20 mA
Material
GaAsP (Gallium Arsenide Phosphide)



ULTRAVIOLET
Wavelength
850–940 nm
Forward voltage
1.2 V
Forward current
Approx 20 mA
Material
InGaN (Indium Gallium Nitride)



RED
Wavelength
630–660 nm
Forward voltage
1.8 V
Forward current
Approx 20 mA
Material
AlGaAs (Aluminum Gallium Arsenide)

LED Chromaticity Diagram Locations

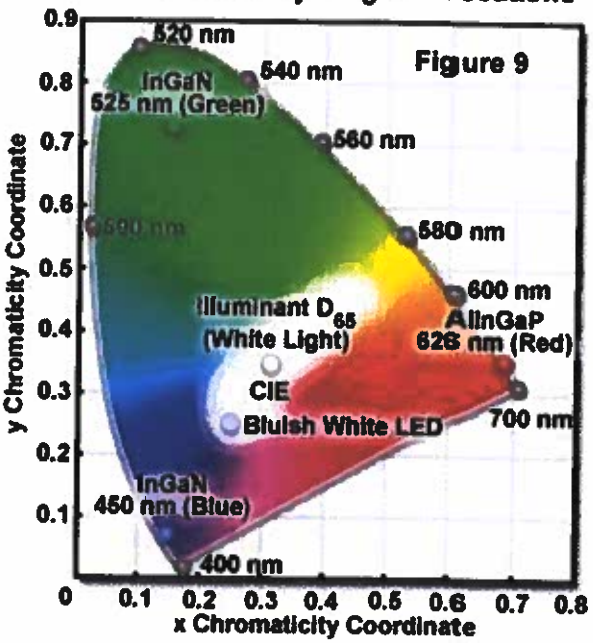
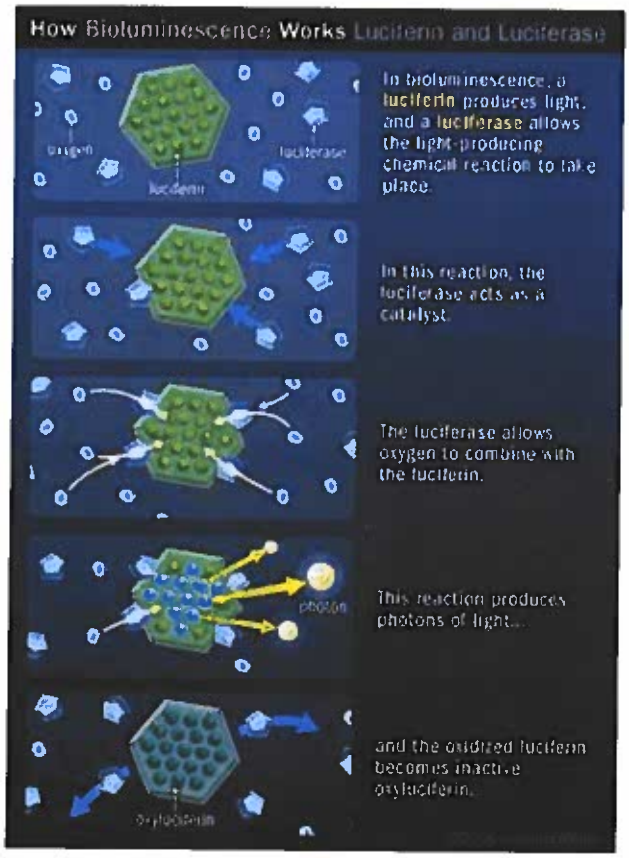


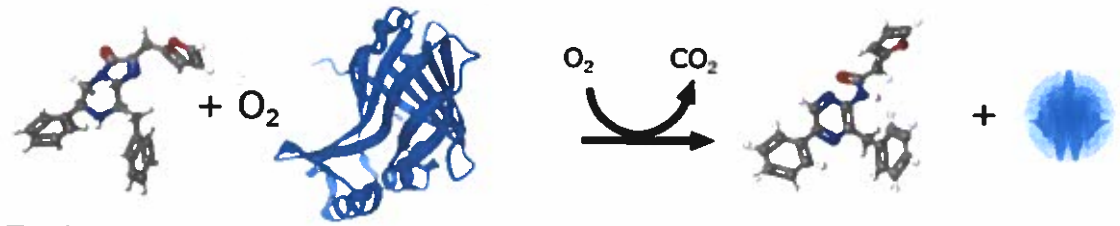
Figure 9

Bioluminescence / Chemiluminescence

Molecules are formed in the excited state during some chemical reaction, return to the ground state by releasing energy in a form of a photon



Bioluminescence mechanisms



Furimazine Nanoluc Furimamide hv



