ASTR 400/700: Stellar Astrophysics

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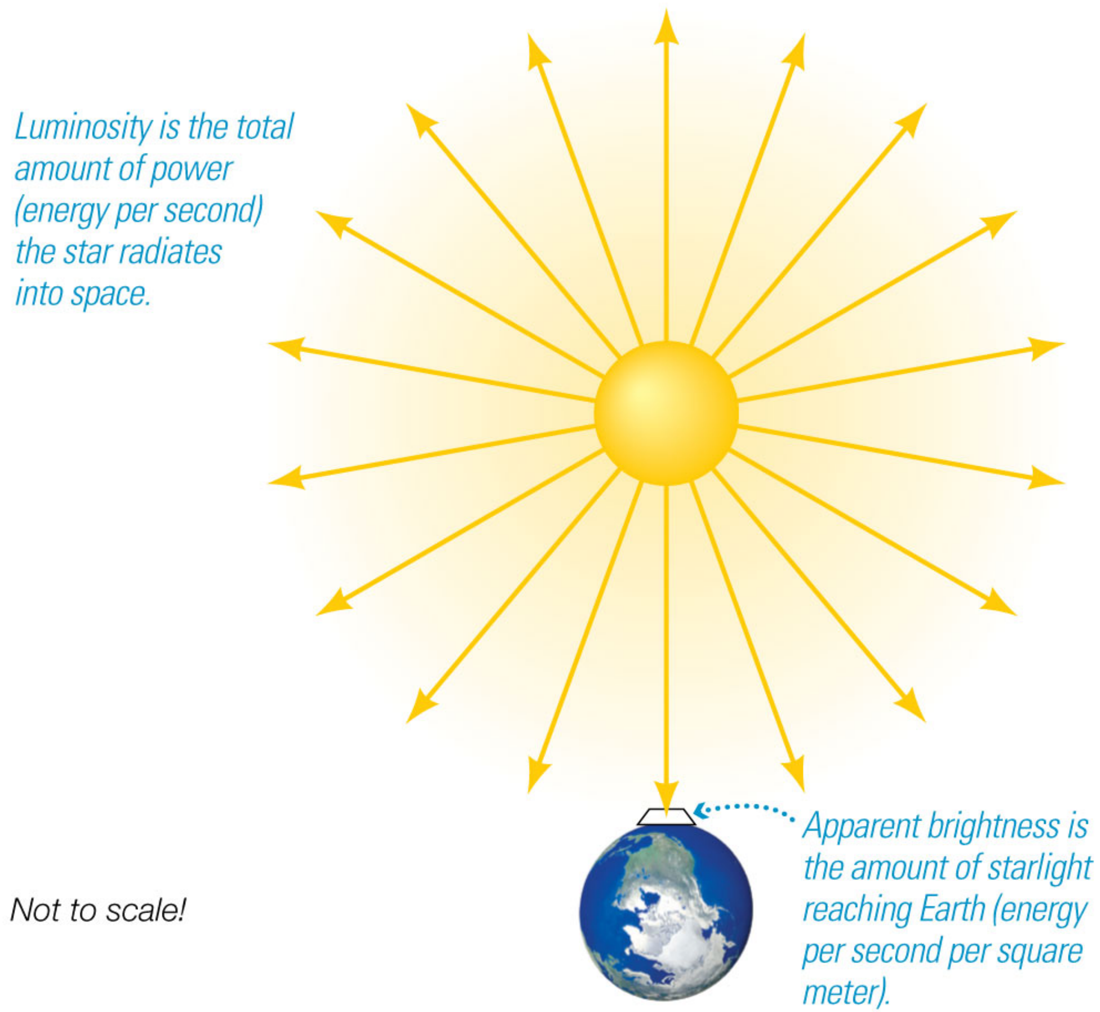
The Magnitude Scale

Chapter 3.2



Luminosity:

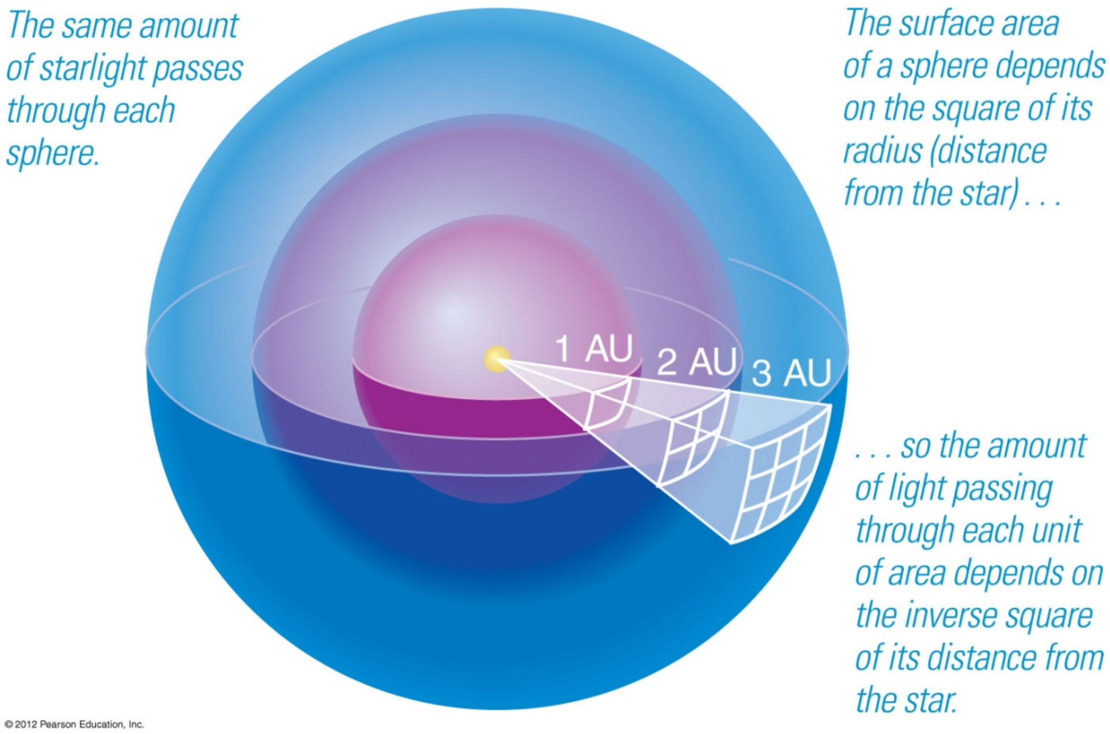
Amount of power a star radiates

(Joules per second = watts)

Apparent brightness:

Amount of starlight that reaches Earth

(energy per second per unit area)



Apparent brightness follows the **inverse square law**.

Luminosity passing through each sphere is the same.

Area of sphere:
$4\pi\,(\text{radius})^2$

Divide luminosity by area to get brightness.

The relationship between apparent brightness and luminosity depends on distance:

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\,(\text{distance})^2}$$

We can determine a star's luminosity if we can measure its distance and apparent brightness:

$$\text{Luminosity} = 4\pi\,(\text{distance})^2 \times (\text{Brightness})$$

Flux and luminosity

- Flux decreases as we get farther from the star – like 1/distance^2

$$F = \frac{L}{4\pi D^2}$$

The Magnitude Scale

- **Apparent magnitude** is a description of how bright stars appear on the sky.
- A difference of 5 magnitudes represents a factor of 100 difference in brightness.
- **Absolute magnitude** is the apparent magnitude of a star at a distance of 10 parsecs.
- The absolute magnitude of the Sun is 4.8.

Object	Apparent Magnitude
Sun	– 26.5
Full moon	– 12.5
Venus (at brightest)	– 4.4
Mars (at brightest)	– 2.7
Jupiter (at brightest)	– 2.6
Sirius (brightest star)	– 1.4
Canopus (second brightest star)	– 0.7
Vega	0.0
Spica	1.0
Naked eye limit in urban areas	3–4
Uranus	5.5
Naked eye limit in rural areas	6–6.5
Bright asteroid	6
Neptune	7.8
Limit for typical binoculars	9–10
Limit for 15-cm (6-in.) telescope	13
Pluto	15
Limit for visual observation with largest telescopes	19.5
Limit for photographs with largest telescopes	23.5
Expected limit for Hubble Space Telescope	28±

Apparent magnitudes of selected objects

Hartmann/The Cosmic Journey, 4th ed., Fig. 16-T1; The Cosmic Voyage, Fig. 16-T1

Compare some stars:

Absolute Apparent

$M_{Sun} = 4.8$ $m_{Sun} = -26$

$M_{Sirius} = 1.4$ $m_{Sirius} = -1.46$

$M_{Betelgeuse} = -5.6$ $m_{Betelgeuse} = 0.50$

Which star looks brightest from Earth?

Which star is brightest?

Apparent Magnitude

Consider two stars, 1 and 2, with apparent magnitudes m_1 and m_2 and fluxes F_1 and F_2. The relation between apparent magnitude and flux is:

$$\frac{F_1}{F_2} = 10^{(m_2 - m_1)/2.5}$$

$$m_1 - m_2 = -2.5 \log_{10}\left(\frac{F_1}{F_2}\right)$$

For $m_2 - m_1 = 5$, $F_1/F_2 = 100$.

Absolute Magnitude and Distance Modulus

m – M is a measure of the distance to a star and is called the **distance modulus**.

$$\boxed{m - M = 5\log_{10}(d) - 5 = 5\log_{10}\left(\frac{d}{10\ \text{pc}}\right).}$$

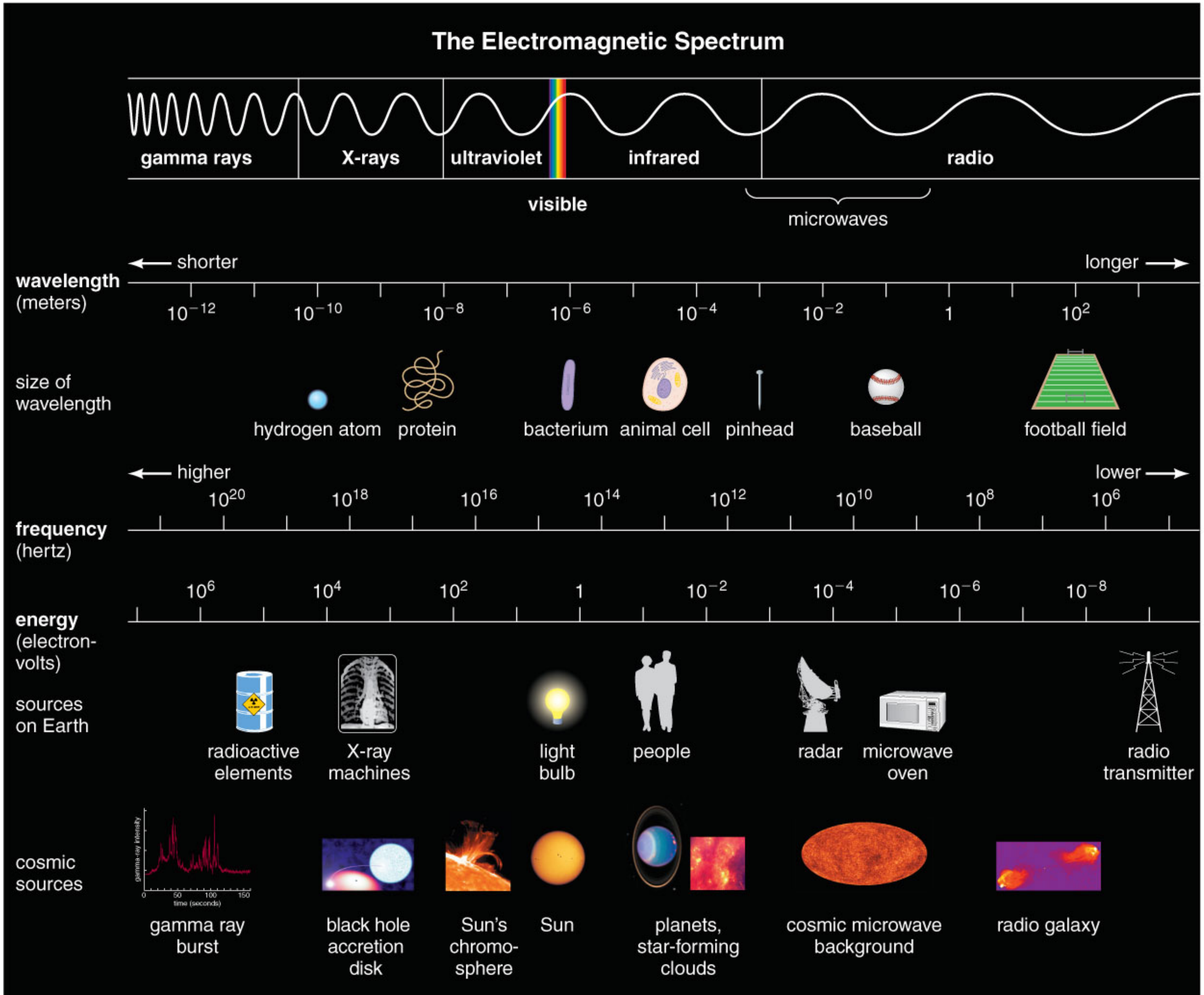
The absolute magnitude of the Sun is *M* = 4.83.
The luminosity of the Sun is L = 3.846×10^{26} W

$$\boxed{M = M_{\text{Sun}} - 2.5\log_{10}\left(\frac{L}{L_{\odot}}\right),}$$

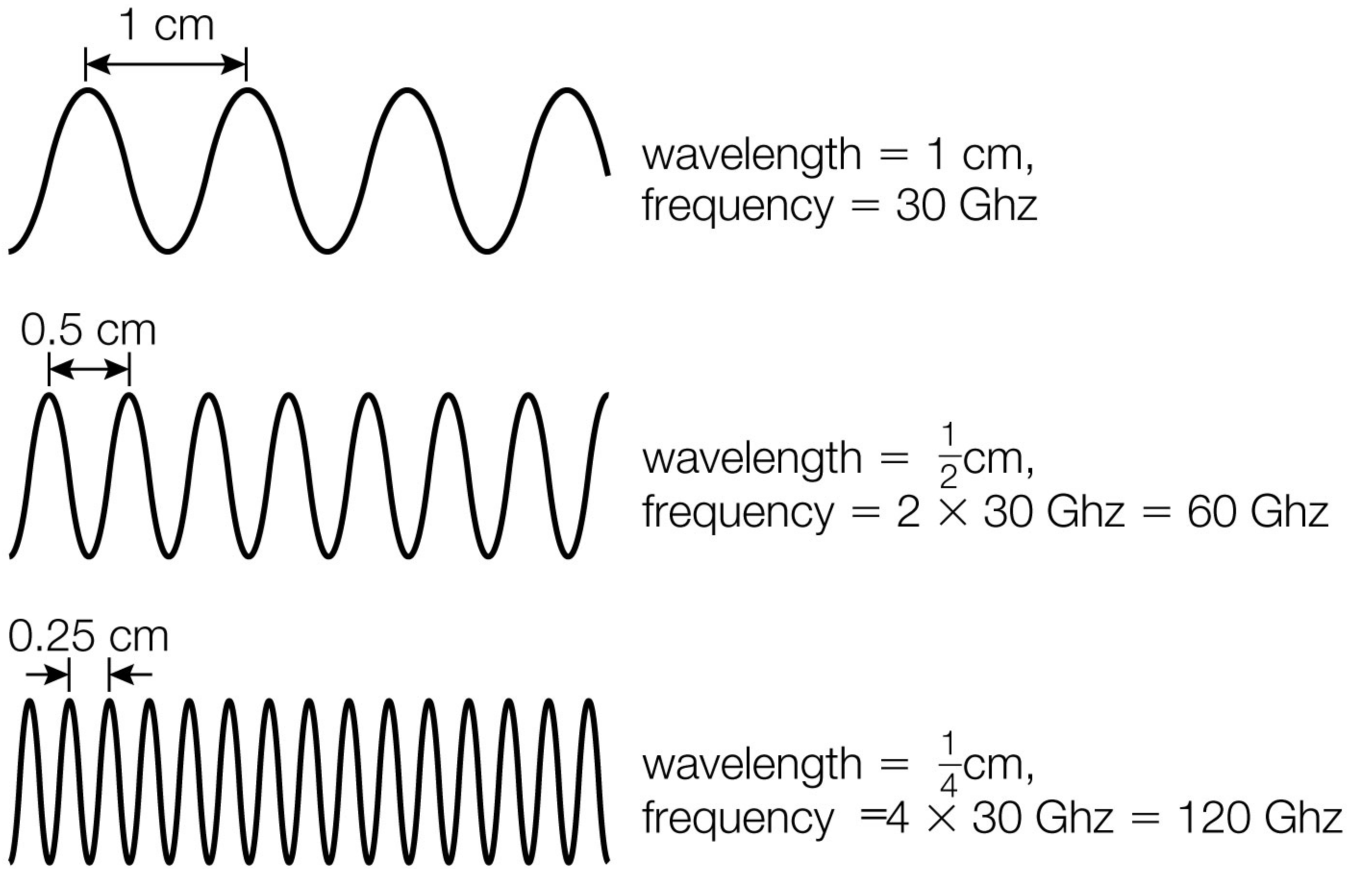
Note the M includes only light in the visible band, so this is accurate only for stars with the same spectrum as the Sun.

Light

Chapter 3.3


The Electromagnetic Spectrum
gamma rays
X-rays
ultraviolet
infrared
radio
visible
microwaves
shorter
longer
wavelength (meters)
10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^{2}
size of wavelength
hydrogen atom
protein
bacterium
animal cell
pinhead
baseball
football field
higher
lower
10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6}
frequency (hertz)
10^{6} 10^{4} 10^{2} 1 10^{-2} 10^{-4} 10^{-6} 10^{-8}
energy (electron-volts)
sources on Earth
radioactive elements
X-ray machines
light bulb
people
radar
microwave oven
radio transmitter
cosmic sources
gamma ray burst
black hole accretion disk
Sun's chromo-sphere
Sun
planets, star-forming clouds
cosmic microwave background
radio galaxy

Wavelength and Frequency



wavelength × frequency = speed of light = constant

Particles of Light

- Particles of light are called **photons.**
- Each photon has a wavelength and a frequency.
- The energy of a photon depends on its frequency.

Wavelength, Frequency, and Energy

$$\lambda \times f = c$$

$$\lambda = \text{wavelength}, \quad f = \text{frequency}$$

$$c = 3.00 \times 10^{8} \text{ m/s} = \text{speed of light}$$

$$E = h \times f = \text{photon energy}$$

$$h = 6.626 \times 10^{-34} \text{ joule} \times \text{s} = \text{photon energy}$$

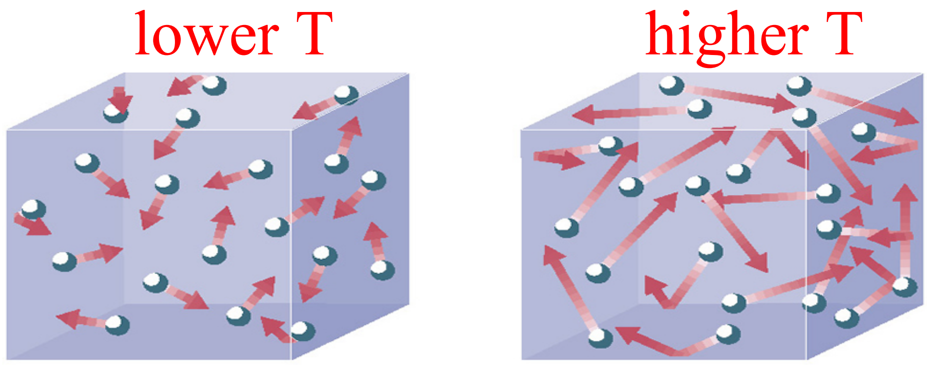
Blackbody Radiation

Chapter 3.4

Thermal (Blackbody) Radiation

- Nearly all large or dense objects emit thermal radiation, including stars, planets, and you.
- An object's thermal radiation spectrum depends on only one property: its **temperature.**
- A **blackbody** is an ideal emitter that absorbs all incident energy and reradiates the energy.
- We can use this to determine the temperatures of stars and planets.

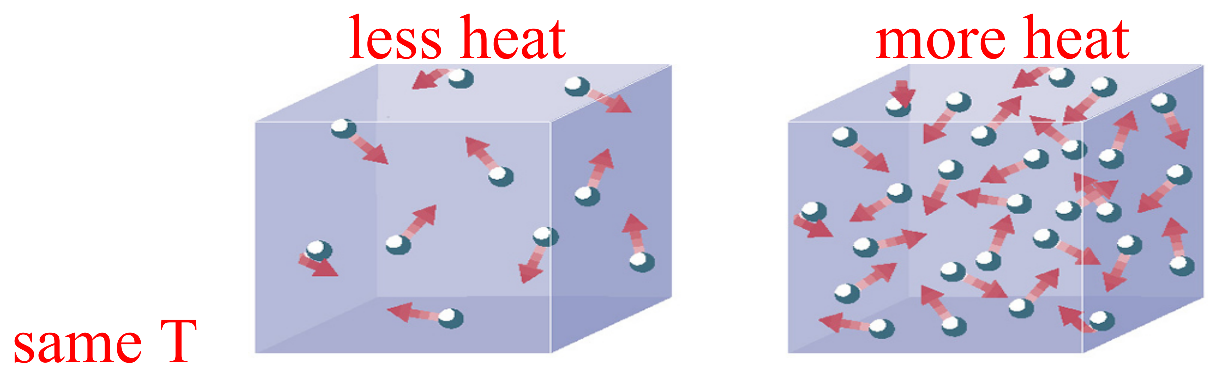
Temperature vs. Heat



Longer arrows mean higher average speed.

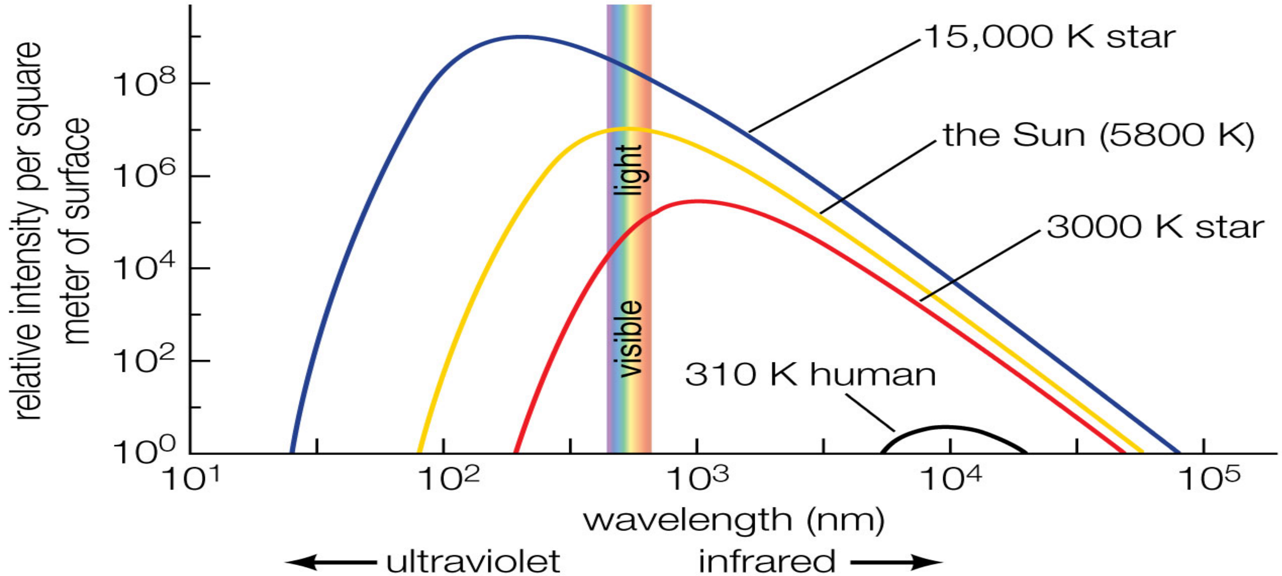
- Temperature is proportional to the <u>average</u> kinetic energy per molecule

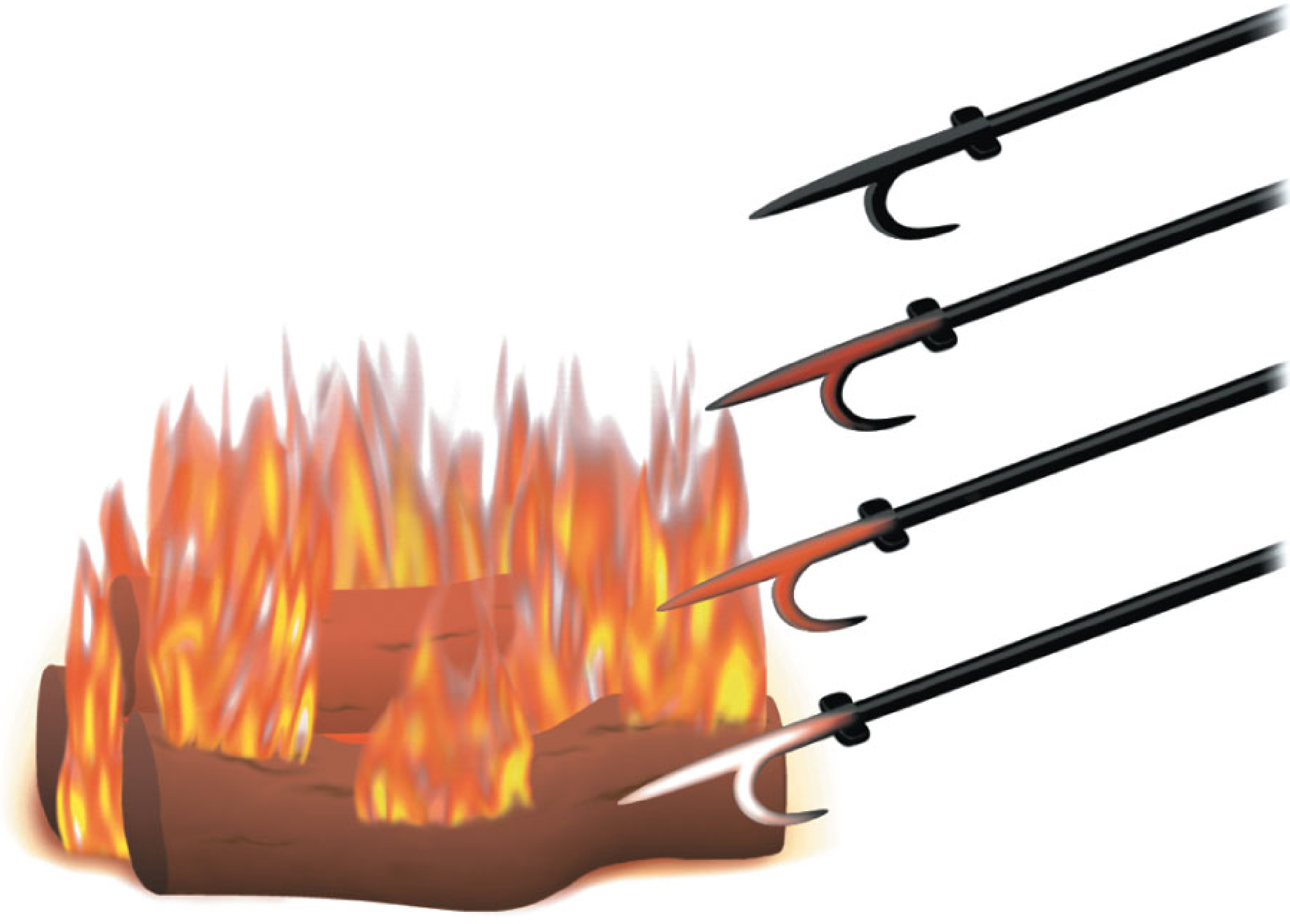
- Heat (thermal energy) is proportional to the <u>total</u> kinetic energy in box



Properties of Thermal Radiation

1. Hotter objects emit more light at all frequencies per unit area (Stefan-Boltzmann law).
2. Hotter objects emit photons with a higher average energy (Wien's law).





Stefan-Boltzmann law

- Stefan-Bolzmann constant:

$$\sigma = 5.670400 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}.$$

- For a spherical star of radius R:

$$\boxed{L = 4\pi R^2 \sigma T_e^4.}$$

- The **Stefan-Boltzmann equation**.

Wien’s law

- Cooler objects produce radiation which peaks at lower energies = longer wavelengths = redder colors.
- Hotter objects produce radiation which peaks at higher energies = shorter wavelengths = bluer colors.
- Wavelength of peak radiation: Wien's Displacement Law

$$\boxed{\lambda_{max} T = 0.002897755 \text{ m K}.}$$