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

<table>
<thead>
<tr>
<th>Star</th>
<th>Absolute</th>
<th>Apparent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>$M_{\text{Sun}} = 4.8$</td>
<td>$m_{\text{Sun}} = -26$</td>
</tr>
<tr>
<td>Sirius</td>
<td>$M_{\text{Sirius}} = 1.4$</td>
<td>$m_{\text{Sirius}} = -1.46$</td>
</tr>
<tr>
<td>Betelgeuse</td>
<td>$M_{\text{Betelgeuse}} = -5.6$</td>
<td>$m_{\text{Betelgeuse}} = 0.50$</td>
</tr>
</tbody>
</table>

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**.

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

The absolute magnitude of the Sun is $M = 4.83$. The luminosity of the Sun is $L = 3.846 \times 10^{26} \text{ W}$

\[ M = M_{\odot} - 2.5 \log_{10} \left( \frac{L}{L_{\odot}} \right), \]

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
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

\[ \lambda \times f = c \]
\[ \lambda = \text{wavelength}, \quad f = \text{frequency} \]
\[ c = 3.00 \times 10^8 \text{ m/s} = \text{speed of light} \]

\[ E = h \times f = \text{photon energy} \]
\[ h = 6.626 \times 10^{-34} \text{ joule } \times \text{s} = \text{photon energy} \]
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**

- **Temperature** is proportional to the **average** kinetic energy per molecule.

- **Heat** (thermal energy) is proportional to the **total** kinetic energy in the box.

Lower arrows mean higher average speed.

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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:

\[ \sigma = 5.670400 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}. \]

• For a spherical star of radius R:

\[ L = 4\pi R^2 \sigma T_e^4. \]

• 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

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