Stellar Atmosphere

Reading assignment
TUESDAY 10/20: Chapter 10.1 / 10.2 / 16.3

Homework Assignment #3 due by:
TUESDAY 10/27 before beginning of class
The Pressure Integral:

The microscopic source of pressure in a perfect gas is particle bombardment, resulting in transfer of momentum, hence a force \( F = \frac{dp}{dt} \). The average force per unit of area is the PRESSURE.

In thermal equilibrium in the stellar interior, the angular distribution of particle momenta is isotropic, i.e., particles are moving with equal probability in all directions.
The Pressure Integral:

The microscopic source of pressure in a perfect gas is particle bombardment, resulting in transfer of momentum, hence a force \((F=dp/dt)\). The average force per unit of area is the PRESSURE.

In thermal equilibrium in the stellar interior, the angular distribution of particle momenta is isotropic, i.e., particles are moving with equal probability in all directions.
The Pressure Integral:

The microscopic source of pressure in a perfect gas is particle bombardment, resulting in transfer of momentum, hence a force \( F = dp/dt \). The average force per unit of area is the PRESSURE.

In thermal equilibrium in the stellar interior, the angular distribution of particle momenta is isotropic, i.e., particles are moving with equal probability in all directions.

NOTE: the relation between \( p \) and \( v_p \) depends upon relativistic considerations, whereas \( n(p) \) depends on the type of particles and quantum statistics.
You have seen the Planck's function, or the blackbody radiation from an object at temperature $T$:

$$F_x = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$$\Rightarrow F_x = \frac{2\pi \hbar \lambda^3}{c^2} \frac{1}{e^{\hbar \omega/\lambda kT} - 1}$$

[erg s$^{-1}$ cm$^{-2}$ A$^{-1}$]
You have seen the Planck's function, or the blackbody radiation from an object at temperature $T$:

$$F_\lambda = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$$\Rightarrow F_\nu = \frac{2\pi h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}$$

[erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$]

$$\mu(\nu) d\nu = \frac{4}{c} F_\nu$$

Energy density of photons of frequency in the range $d\nu$ in thermal equilibrium.

$$\mu(\lambda) d\lambda = \frac{4}{c} F_\lambda$$
You have seen the Planck's function, or the blackbody radiation from an object at temperature $T$:

\[
F_\lambda = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}
\]

\[
\Rightarrow F_\nu = \frac{2\pi h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}
\]

\[
\varphi = \frac{c}{\lambda}
\]

\[
d\varphi = \frac{c}{\lambda^2} d\lambda
\]

\[
\mu(\varphi) d\varphi = \frac{4}{c} F_\varphi \int\text{energy density of photons of frequency}
\]

\[
\mu(\lambda) d\lambda = \frac{4}{c} F_\lambda
\]

**Energy Density**

\[
M^\varphi := \int_0^\infty \mu(\varphi) d\varphi = \frac{8\pi^5 K^4}{15 c^3 h^3 T^4} = a T^4
\]

\[
[\mu] = \frac{\text{erg}}{\text{cm}^3}
\]

\[
\sqrt{a} = 7.565 \times 10^{-15} \frac{\text{erg}}{\text{cm}^3 K^4}
\]
You have seen the Planck’s function, or the blackbody radiation from an object at temperature $T$:

$$F_\lambda = \frac{2 \pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$$\int_\nu d\nu = \frac{4}{c} F_\lambda$$

Energy density of photons of frequency $\nu$ in the range $d\nu$ in thermal equilibrium:

$$u(\nu) d\nu = \frac{4}{c} F_\lambda$$

Energy density:

$$u = \int_0^{\nu_0} u(\nu) d\nu$$

$$\int_0^{\nu_0} \frac{4}{c} F_\lambda d\nu$$

$$u = \frac{8 \pi^5 k^4}{15 c^3 h^3 T^4}$$

$$u = \frac{a T^4}{c^3 h^3}$$

Energy density:

$$[u] = \frac{\text{erg}}{\text{cm}^3}$$

$$\sqrt{u} = 7.565 \times 10^{-15} \frac{\text{erg}}{\text{cm}^3 K^4}$$
\[ n_\lambda d\lambda = \frac{\mu(\lambda) d\lambda}{E_\lambda} = \frac{\mu(\lambda) d\lambda}{hc/\lambda} \]

\[ \rightarrow n := \int_0^\infty n_\lambda d\lambda = 8\pi \left(\frac{KT}{hc}\right)^3 \int_0^\infty \frac{x^2 dx}{e^x - 1} = 19.2329112\pi \left(\frac{KT}{hc}\right)^3 \approx 2.404114 \]
\[ n \lambda d \lambda = \frac{\mu(\lambda) d \lambda}{E} = \frac{\mu(\lambda) d \lambda}{hc/\lambda} \]

\[ n := \int_0^\infty n_\lambda d \lambda = 8 \pi \left( \frac{KT}{hc} \right)^3 \int_0^\infty \frac{x^2 dx}{e^x - 1} \approx 2.40414 \]

\[ n \approx 19.3329112 \pi \left( \frac{KT}{hc} \right)^3 \]
Radiation Pressure $P_{\text{Rad}}$:

$$n_{\lambda} \, d\lambda = \frac{\mu(\lambda) \, d\lambda}{E_{\lambda}} = \frac{\mu(\lambda) \, d\lambda}{hc/\lambda}$$

$$n := \int_0^\infty n_{\lambda} \, d\lambda = 8\pi \left( \frac{KT}{hc} \right)^3 \int_0^\infty \frac{x^2 \, dx}{e^x - 1} \approx 19.8329112 \pi \left( \frac{KT}{hc} \right)^3$$

$\approx 2.404114$
Radiation Pressure $P_{\text{Rad}}$:

Photon has energy $E = h\nu$ and momentum $p = \frac{E}{c} = \frac{h\nu}{c}$.

$\Rightarrow$ photons can exert a radiation pressure.
Radiation Pressure $P_{\text{Rad}}$:

If in thermodynamic equilibrium, then the radiation flux is isotropic.
Radiation Pressure $P_{\text{Rad}}$:

If in thermodynamic equilibrium, then the radiation flux is isotropic.

$$n_\lambda d\lambda = \frac{\mu(\lambda) d\lambda}{E_\lambda} = \frac{\mu(\lambda) d\lambda}{hc/\lambda}$$

$$n := \int_0^{10} n_\lambda d\lambda = 8\pi \left(\frac{KT}{hc}\right)^3 \int_0^1 \frac{x^2 dx}{e^x - 1} = 19.3329112\pi \left(\frac{KT}{hc}\right)^3$$

$$= 2.404114$$

Photon has energy $E = \hbar \nu$ and momentum $p = \frac{E}{c} = \frac{\hbar \nu}{c}$.

$\rightarrow$ Photons can exert a radiation pressure

$$P = \frac{1}{3} \int_0^{10} p n(p) dp = \frac{1}{3} \int_0^{10} \frac{\hbar^2}{c} n(\nu) d\nu = \frac{1}{3} \int_0^{10} \frac{\hbar^2}{c} n(\nu) d\nu$$

Energy density of photons $n(\nu) d\nu = 2 \pi T^4$

$$\rightarrow P_R = \frac{1}{3} M = \frac{1}{3} a T^4$$

$$a = 7.565 \times 10^{-15} \text{ erg cm}^3 \text{ s}^{-2} \text{ K}^{-4}$$
Radiation Pressure $P_{\text{Rad}}$:

If in thermodynamic equilibrium, then the radiation flux is isotropic:

$$P = \frac{1}{3} \int_0^\infty p n(p) dp = \frac{1}{3} \int_0^\infty \frac{h\nu}{c} c n(\nu) d\nu = \frac{1}{3} \int_0^\infty \frac{h\nu n(\nu)}{c} d\nu$$

Radiation pressure for a blackbody radiation:

$$P_R = \frac{1}{3} \frac{M}{c} = \frac{1}{3} \delta T^4$$

$$\delta = 7.568 \times 10^{-15} \text{ erg/cm}^3 \cdot \text{K}^4$$
The Sun spectrum deviates substantially from the shape of the blackbody Planck function due to solar absorption lines removing light from the Sun’s continuous spectrum (a.k.a., line blanketing)
A star cannot be in THERMODYNAMIC EQUILIBRIUM (no net flow of energy through the box or between matter and radiation; every process occurs at the same rate as its inverse process), as a net flow (outward) of energy occurs through the star, and the temperature varies with location. However, the idealized case of a single temperature can still be employed IF the distance over which the temperature changes significantly is larger compared with the distances traveled by particles and photons between collisions/interactions (mean free paths). In this case, we define LOCAL THERMODYNAMIC EQUILIBRIUM (LTE).
A star cannot be in THERMODYNAMIC EQUILIBRIUM (no net flow of energy through the box or between matter and radiation; every process occurs at the same rate as its inverse process), as a net flow (outward) of energy occurs through the star, and the temperature varies with location. However, the idealized case of a single temperature can still be employed IF the distance over which the temperature changes significantly is larger compared with the distances traveled by particles and photons between collisions/interactions (mean free paths). In this case, we define LOCAL THERMODYNAMIC EQUILIBRIUM (LTE).

Let’s consider the photosphere of the Sun, and the temperature varies from 5580K to 5790K over a distance of 25 km.
A star cannot be in THERMODYNAMIC EQUILIBRIUM (no net flow of energy through the box or between matter and radiation; every process occurs at the same rate as its inverse process), as a net flow (outward) of energy occurs through the star, and the temperature varies with location. However, the idealized case of a single temperature can still be employed IF the distance over which the temperature changes significantly is larger compared with the distances traveled by particles and photons between collisions/interactions (mean free paths). In this case, we define LOCAL THERMODYNAMIC EQUILIBRIUM (LTE).

Let’s consider the photosphere of the Sun, and the temperature varies from 5580K to 5790K over a distance of 25 km.

\[
H_T = \frac{T}{|dT/dr|} = \frac{5685^\circ K}{(5790-5580)/25} = 677 \text{ km}
\]

\[
\frac{dT}{dr} \approx \frac{\Delta T}{\Delta r} = \frac{T_f-T_i}{r_f-r_i}
\]
A star cannot be in THERMODYNAMIC EQUILIBRIUM (no net flow of energy through the box or between matter and radiation; every process occurs at the same rate as its inverse process), as a net flow (outward) of energy occurs through the star, and the temperature varies with location. However, the idealized case of a single temperature can still be employed IF the distance over which the temperature changes significantly is larger compared with the distances traveled by particles and photons between collisions/interactions (mean free paths). In this case, we define LOCAL THERMODYNAMIC EQUILIBRIUM (LTE).

Let’s consider the photosphere of the Sun, and the temperature varies from 5580K to 5790K over a distance of 25 km.

\[ H_T = \frac{T}{|dT/dr|} = \frac{5685 \text{ K}}{(5790 - 5580)/25} = 677 \text{ km} \]

Characteristic distance over which the temperature varies
\[ \rho = 2.1 \times 10^{-4} \frac{\text{kg}}{\text{m}^3} \]

\[ n = \frac{\rho}{m_H} = 1.25 \times 10^{23} \text{ m}^{-3} \]

Mass density of photosphere, primarily made of H in the ground state

Number density of atoms
Mass density of photosphere, primarily made of H in the ground state.

\[ \rho = 2.1 \times 10^{-4} \frac{\text{Kg}}{\text{m}^3} \]

\[ n = \frac{\rho}{m_H} = 1.25 \times 10^{23} \text{ m}^{-3} \]

Number density of atoms

Mean free path between collisions

\[ l = \frac{1}{n \sigma} \]

\[ \sigma = \pi (2a_0)^2 = 3.52 \times 10^{-20} \text{ m}^2 \]

20 radius of Bohr's atom
Mass density of photosphere, primarily made of H in the ground state

\[ \rho = 2.1 \times 10^{-4} \frac{\text{Kg}}{\text{m}^3} \]

Number density of atoms

\[ n = \frac{\rho}{m_\text{H}} = 1.25 \times 10^{-23} \text{ m}^{-3} \]

Mean free path between collisions

\[ l = \frac{1}{n \sigma} \]

\[ \sigma = \pi (2a_0)^2 = 3.52 \times 10^{-20} \text{ m}^2 \]

2\(a_0\) radius of Bohr's atom

\[ l = 2.27 \times 10^{-4} \text{ m} \ll 677 \text{ km} \]
Mass density of photosphere, primarily made of H in the ground state

\[ \rho = 2.1 \times 10^{-4} \frac{\text{kg}}{\text{m}^3} \]

Number density of atoms

\[ n = \frac{\rho}{m_H} = 1.25 \times 10^{23} \text{ m}^{-3} \]

\[ \text{mean free path between collisions} \quad l = \frac{1}{n \sigma} \]

\[ \sigma = \pi (2a_0)^2 = 3.52 \times 10^{-20} \text{ m}^2 \]

\[ 2a_0 \quad \text{radius of Bohr's atom} \]

\[ l = 2.27 \times 10^{-4} \text{ m} \ll 677 \text{ km} \]

i.e., the atoms see a constant kinetic temperature between collisions, hence LTE is valid for H atoms in the photosphere
Consider now a beam of parallel light rays traveling through a gas; absorption is the ensemble of processes of removing photons (including scattering).

For pure absorption, the intensity declines exponentially falling by a factor of $e^{-1}$ over a characteristic distance:

$$e = \frac{1}{k_\lambda}$$

With $k_\lambda$, opacity (or absorption coefficient)

$$[k_\lambda] = \text{m}^2/\text{kg}$$

cross section for absorbing photons of wavelength $\lambda$ per unit of mass of stellar material.

In the photosphere:

$$k_{500\text{nm}} = 0.03 \text{ m}^2/\text{kg} \quad \rightarrow \quad e = 160 \text{ km}$$

Not too impressive from $H_T = 677 \text{ km}$
Consider now a beam of parallel light rays traveling through a gas; absorption is the ensemble of processes of removing photons (including scattering).

For pure absorption, the intensity declines exponentially falling by a factor of $e^{-1}$ over a characteristic distance:

$$e = \frac{1}{k \sigma}$$

with $k\sigma$ opacity (or absorption coefficient)

$$[k\sigma] = m^2/kg$$

cross section for absorbing photons of wavelength $\lambda$ per unit of mass of stellar material.

In the photosphere:

$$k_{500\text{nm}} = 0.03 \frac{m^2}{kg} \rightarrow e = 160 \text{ km}$$

i.e., the photospheric photons do not see a constant temperature, and so LTE is not strictly valid in the photosphere. LTE must be used with caution in stellar atmosphere.
Equivalent width (EW, or W) of spectral line

\[ W = \int \frac{1 - F_\lambda}{F_c} d\lambda \]

The EW represents the width of a hypothetical line which drops to an intensity of zero and has the same integrated flux deficit from the continuum as the true one.
Let $N$ be the column density (i.e., $m^{-2}$), i.e., the number of atoms of a certain element lying above a unit area of the photosphere.
Let $N$ be the column density (i.e., m$^{-2}$), i.e., the number of atoms of a certain element lying above a unit area of the photosphere.

$N_a$ = number of absorbing atoms per unit of area (this is obtained from the Boltzmann and the Saha equations once the temperature and the density are known).
Let $N$ be the column density (i.e., m$^{-2}$), i.e., the number of atoms of a certain element lying above a unit area of the photosphere.

$N_a =$ number of absorbing atoms per unit of area (this is obtained from the Boltzmann and the Saha equations once the temperature and the density are known).

But not all transitions have the same likelihood to happen, hence we use “$f$” representing the relative probabilities to make transitions. For example, $f($Halpha$)=0.637$ and $f($Hbeta$)=0.119.$
Let $N$ be the column density (i.e., m$^{-2}$), i.e., the number of atoms of a certain element lying above a unit area of the photosphere.

$N_a =$ number of absorbing atoms per unit of area (this is obtained from the Boltzmann and the Saha equations once the temperature and the density are known).

But not all transitions have the same likelihood to happen, hence we use “$f$” representing the relative probabilities to make transitions. For example, $f(\text{Halpha})=0.637$ and $f(\text{Hbeta})=0.119$.

$fN_a =$ effective number of atoms lying above each square meter of photosphere actively involved in producing a given spectral line
Growth curve method

This is used to determine the value of \( N_a \), hence the abundances of elements in the stellar atmosphere.

Increasing abundance (10x more for each curve)
Variation of the EW of an absorption line with increasing $N_a$ (a.k.a., curve of growth)

For small abundances, when the absorption line is has not saturated, EW is proportional to $N_a$. In the central region is when the line saturates and the EW changes little because only the wings becoming deeper and so little change in the EW. Increasing Na even further increases the importance of pressure broadening, and the wings are significantly affected, with the EW growing as $N_a^{1/2}$. 
For a given element, the EW is measured from the spectrum (e.g., of the Sun). Using the appropriate curve of growth, I can obtain $fN_a$. Known $fN_a$ and $f$, I can derive the total number of atoms of a specific element using the Boltzmann and Saha equations.

Repeating this for many elements, transitions, I can derive the chemical composition of the photosphere of stars.
### Table 9.2: The Most Abundant Elements in the Solar Photosphere

The relative abundance of an element is given by \( \log_{10}(N_{el}/N_H) + 12 \). (Data from Grevesse and Sauval, *Space Science Reviews*, 85, 161, 1998.)

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Log Relative Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>12.00</td>
</tr>
<tr>
<td>Helium</td>
<td>2</td>
<td>10.93 ± 0.004</td>
</tr>
<tr>
<td>Oxygen</td>
<td>8</td>
<td>8.83 ± 0.06</td>
</tr>
<tr>
<td>Carbon</td>
<td>6</td>
<td>8.52 ± 0.06</td>
</tr>
<tr>
<td>Neon</td>
<td>10</td>
<td>8.08 ± 0.06</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>7</td>
<td>7.92 ± 0.06</td>
</tr>
<tr>
<td>Magnesium</td>
<td>12</td>
<td>7.58 ± 0.05</td>
</tr>
<tr>
<td>Silicon</td>
<td>14</td>
<td>7.55 ± 0.05</td>
</tr>
<tr>
<td>Iron</td>
<td>26</td>
<td>7.50 ± 0.05</td>
</tr>
<tr>
<td>Sulfur</td>
<td>16</td>
<td>7.33 ± 0.11</td>
</tr>
<tr>
<td>Aluminum</td>
<td>13</td>
<td>6.47 ± 0.07</td>
</tr>
<tr>
<td>Argon</td>
<td>18</td>
<td>6.40 ± 0.06</td>
</tr>
<tr>
<td>Calcium</td>
<td>20</td>
<td>6.36 ± 0.02</td>
</tr>
<tr>
<td>Sodium</td>
<td>11</td>
<td>6.33 ± 0.03</td>
</tr>
<tr>
<td>Nickel</td>
<td>28</td>
<td>6.25 ± 0.04</td>
</tr>
</tbody>
</table>

Relative abundance by number:
- 8.5% \( N_H \)
- 0.068% \( N_H \)
- 0.033% \( N_H \)
- 0.012% \( N_H \)
- 0.00023% \( N_H \)
### Isotope Composition

<table>
<thead>
<tr>
<th>Isotope</th>
<th>A</th>
<th>Mass Fraction</th>
<th>Number Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen-1</td>
<td>1</td>
<td>705,700</td>
<td>909,964</td>
</tr>
<tr>
<td>Hydrogen-2</td>
<td>2</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>Helium-3</td>
<td>3</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>Helium-4</td>
<td>4</td>
<td>275,200</td>
<td>88,714</td>
</tr>
<tr>
<td>Carbon-12</td>
<td>12</td>
<td>3,032</td>
<td>325</td>
</tr>
<tr>
<td>Carbon-13</td>
<td>13</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td>Nitrogen-14</td>
<td>14</td>
<td>1,105</td>
<td>102</td>
</tr>
<tr>
<td>Oxygen-16</td>
<td>16</td>
<td>5,920</td>
<td>477</td>
</tr>
<tr>
<td>Neon-20</td>
<td>20</td>
<td>1,548</td>
<td>100</td>
</tr>
<tr>
<td>Neon-22</td>
<td>22</td>
<td>208</td>
<td>12</td>
</tr>
<tr>
<td>Sodium-23</td>
<td>23</td>
<td>33</td>
<td>2</td>
</tr>
<tr>
<td>Magnesium-24</td>
<td>24</td>
<td>513</td>
<td>28</td>
</tr>
<tr>
<td>Magnesium-25</td>
<td>25</td>
<td>69</td>
<td>4</td>
</tr>
<tr>
<td>Magnesium-26</td>
<td>26</td>
<td>79</td>
<td>4</td>
</tr>
<tr>
<td>Aluminum-27</td>
<td>27</td>
<td>58</td>
<td>3</td>
</tr>
<tr>
<td>Silicon-28</td>
<td>28</td>
<td>653</td>
<td>30</td>
</tr>
<tr>
<td>Silicon-29</td>
<td>29</td>
<td>34</td>
<td>2</td>
</tr>
<tr>
<td>Silicon-30</td>
<td>30</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Sulfur-32</td>
<td>32</td>
<td>396</td>
<td>16</td>
</tr>
<tr>
<td>Argon-36</td>
<td>36</td>
<td>77</td>
<td>3</td>
</tr>
<tr>
<td>Calcium-40</td>
<td>40</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>Iron-54</td>
<td>54</td>
<td>72</td>
<td>2</td>
</tr>
<tr>
<td>Iron-56</td>
<td>56</td>
<td>1,169</td>
<td>27</td>
</tr>
<tr>
<td>Iron-57</td>
<td>57</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>Nickel-58</td>
<td>58</td>
<td>49</td>
<td>1</td>
</tr>
<tr>
<td>Other elements</td>
<td>3,879</td>
<td>149</td>
<td></td>
</tr>
</tbody>
</table>

\[
A \frac{N_{\text{elem}}}{N_{H}} \frac{1}{1 + A \frac{N_{\text{elem}}}{N_{H}}}
\]

H-1: \( \frac{705700}{1000000} = 0.7057 = 70.6\% \)

He-4: \( \frac{275200}{1000000} = 0.2752 = 27.5\% \)

Metals: \( \frac{198100}{1000000} = 0.0191 = 1.9\% \)

A = mass number
Abundance of Si is normalized to $10^5$. 

The graph shows the logarithm of the abundance of various elements as a function of their atomic number ($Z$). The abundance is given in units of the logarithm base 10 of the abundance ratio. The elements are plotted along the horizontal axis, with their atomic numbers increasing from left to right. The abundance is represented by the vertical axis, with higher values indicating greater abundance. The elements are labeled with their symbols, and the graph illustrates the periodic variation of abundance across the periodic table.
NUCLEOSYNTHESIS:

- Nucleosynthesis occurs in the natural evolution of stars
- The initial H and He are fused into heavier nuclei, dispersed in the ISM in the terminal phases of stellar evolution
- During the first 3 minutes after the Big Bang, H (75% by mass), He (25%) and traces of D, $^3\text{He}$, Li, Be, B were produced (primordial nucleosynthesis)
- $^{12}\text{C}$, $^{16}\text{O}$, $^{20}\text{Ne}$ most abundant elements after H and He (produced by He fusion)
- $^{56}\text{Fe}$: nuclear binding energy per nucleon has a maximum at $^{56}\text{Fe}$, i.e., successive nuclear fusion reactions cease to liberate energy when all light nuclei have been fused into $^{56}\text{Fe}$. Farther fusion requires energy, hence the termination of energy-generating stages of nuclear fusion.
- Very heavy elements can be formed efficiently by the capture of free neutrons liberated as a by product of reactions between light charged particles.
Stellar Atmosphere

Reading assignment
TUESDAY 10/20: Chapter 10.1 / 10.2 / 16.3

Homework Assignment #3 due by:
TUESDAY 10/27 before beginning of class