CALCIUM IN THE SOLAR ATMOSPHERE

Link to: physicspages home page.

To leave a comment or report an error, please use the auxiliary blog and include the title or URL of this post in your comment.

Post date: 23 Jun 2023.

We can use the Saha equation to calculate the ratios of calcium in its first three ionization stages (that is, neutral, first ionization and second ionization, Ca, Ca_I and Ca_{II}) in the solar atmosphere. We use the data provided in Carroll & Ostlie Example 8.1.5. The Saha equation is

$$\frac{N_{i+1}}{N_i} = \frac{2kTZ_{i+1}}{P_e Z_i}\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi_i/kT} \tag{1}$$

Here Z_i is the partition function for ionization stage i, P_e is the electron pressure and χ_i is the ionization energy required to take an ion in the ground state of stage i to the ground state of stage $i+1$.

In Carroll & Ostlie's example 8.1.5, they calculate the ratio of singly ionized calcium to neutral calcium, N_{II}/N_I. Here we'll investigate the ratio of doubly ionized to singly ionized calcium, N_{III}/N_{II}.

The required data are

$$\begin{aligned} Z_{II} &= 2.3 \\ Z_{III} &= 1 \\ P_e &= 1.5 \text{ N m}^{-2} \\ \chi_{II} &= 11.9 \text{ eV} \\ T &= 5777 \text{ K} \end{aligned} \tag{2}$$

The physical constants are

$$\begin{aligned} k &= 1.38\times 10^{-23} \text{ J K}^{-1} \\ m_e &= 9.11\times 10^{-31}\text{kg} \\ h &= 6.626\times 10^{-34} \text{ J s} \\ 1 \text{ eV} &= 1.6\times 10^{-19} \text{ J} \end{aligned} \tag{3}$$

Plugging in all these values gives us

$$\left[\frac{N_{III}}{N_{II}}\right]_{\text{Ca}} = 2.02 \times 10^{-3} \tag{4}$$

That is, at the temperture $T = 5777$ K of the solar atmosphere, very little calcium is in the doubly ionized state. This is consistent with the observation that the calcium Ca II H and K absorption lines, formed when a singly ionized calcium atom in its ground state absorbs a photon of the energy required to bump an electron into an excited state, are quite strong in the solar spectrum.

As with our study of the helium star, we can produce plots of the fraction of calcium atoms in the various ionization stages. The equations are

$$\frac{N_I}{N_t} = \frac{N_I}{N_I + N_{II} + N_{III}} \tag{5}$$

$$= \frac{1}{1 + N_{II}/N_I + N_{III}/N_I} \tag{6}$$

$$= \frac{1}{1 + N_{II}/N_I + (N_{III}/N_{II})(N_{II}/N_I)} \tag{7}$$

$$\frac{N_{II}}{N_t} = \frac{N_{II}/N_I}{1 + N_{II}/N_I + (N_{III}/N_{II})(N_{II}/N_I)} \tag{8}$$

The fraction of unionized calcium is shown in Fig. 1.

Singly ionized calcium peaks around the temperature of the solar atmosphere, as shown in Fig. 2.

We might be tempted to produce a plot of doubly ionized calcium, in the same way as we did for doubly ionized helium in the helium star. The equation we used for helium was

$$\frac{N_{III}}{N_t} = \frac{(N_{III}/N_{II})(N_{II}/N_I)}{1 + N_{II}/N_I + (N_{III}/N_{II})(N_{II}/N_I)} \tag{9}$$

If we plot this, we get Fig. 3, which shows that above about $T = 8000$ K, all the calcium is in the doubly ionized state. However, this isn't true, since calcium, with atomic number 20, has more electrons than helium, and thus has a number of ionization stages above Ca_{III}. In the case of helium, we can remove at most two electrons, so He_{III} is the highest ionization stage possible. For calcium, we would expect the curve for N_{III}/N_{total} to look somewhat like Fig. 2 with the peak shifted towards a higher temperature.

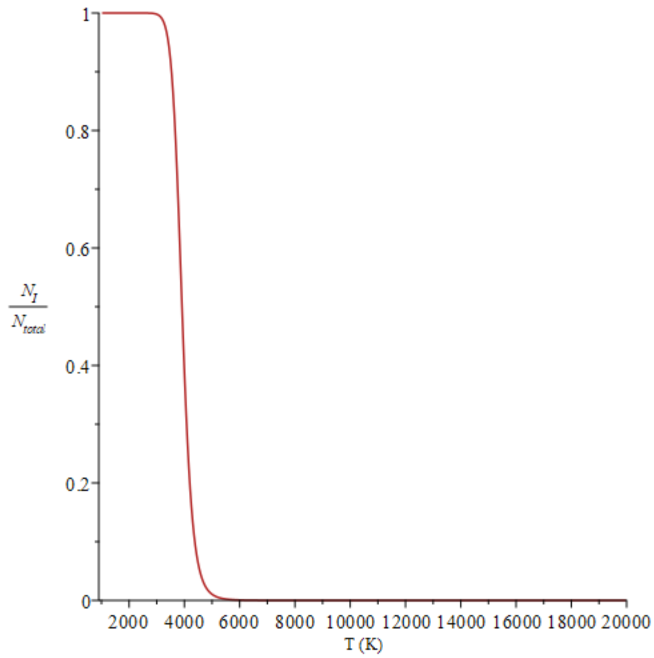

FIGURE 1. Unionized calcium in the solar atmosphere.

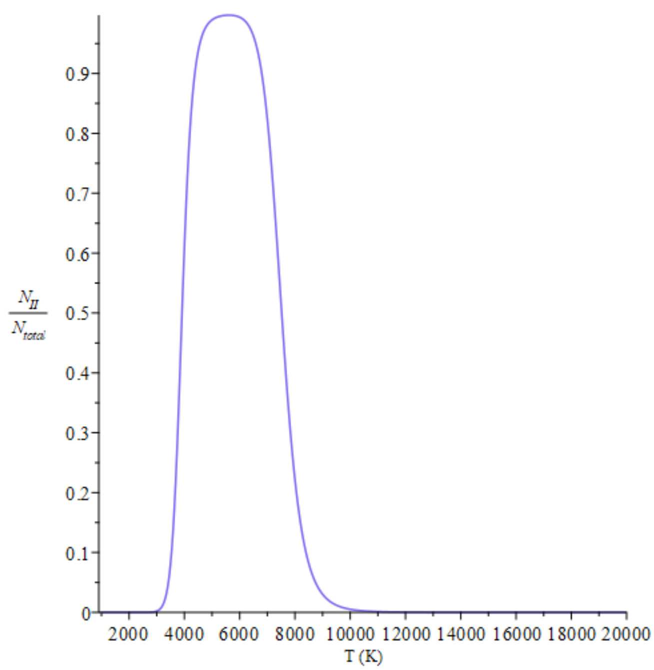

FIGURE 2. Singly ionized calcium in the solar atmosphere.

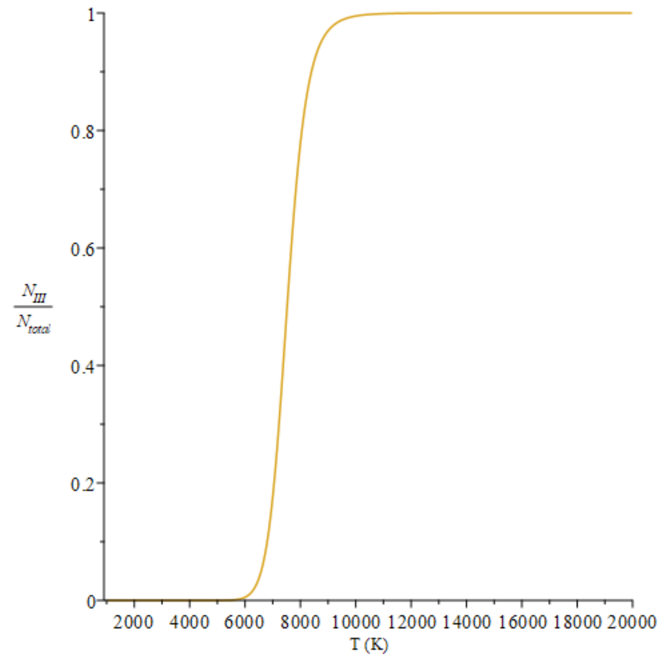

FIGURE 3. Doubly ionized calcium in the solar atmosphere (wrong!).