Chromospheric Emission Lines: 
Rules of Formation 

Spring 2018 Meeting of the APS Ohio Section 
March 23-24, 2018 
Michigan State University 
East Lansing, MI 

Pierre-Marie Robitaille 
Department of Radiology 
The Ohio State University 
Columbus, Ohio 43210
This spectrum is a collaboration between Lorenzo Comolli and Emmanuele Sordini; processing Paolo Berardi
http://www.astrosurf.com/comolli/ecl17-11a.png
1. Emission lines in the chromosphere have always been viewed as randomly produced, manifesting only local temperature.

2. Use of the Saha equation in the chromosphere can lead to errors of 100 trillion times in the ratio of ions observed (H. Zirin, The Solar Atmosphere, Blaisdell Publishing, Waltham, MA, 1966, p. 72).

3. The emission lines in the chromosphere do not result from processes in thermal equilibrium. Therefore, they cannot be used to set chromospheric temperatures and the Saha equation should not be applied.

4. Infrared carbon monoxide (CO) absorption lines in the chromosphere indicate that this region of the Sun is cooling with elevation, not heating. These lines are much more likely to be in thermal equilibrium.
The intense emission lines in the chromosphere are not a product of random absorption and emission. They are indicative of condensation reactions involving metal hydrides!

Such reactions are exothermic in nature. Since no conductive path is available to dissipate heat, photons are emitted.

\[
\text{Ca}^+ (3p^63d^1) + \text{H} \rightarrow \text{CaH}^+ \\
\text{OR} \\
\text{Ca}^+ (3p^64s^1) + \text{H} \rightarrow \text{CaH}^+
\]

It is the ground state of the transition which matters because the metal returns to that state after the delivery of the hydrogen atom or proton!

\[
\text{CaH}^+ + \text{CHS} \rightarrow \text{CHS-H-Ca}^{+*} \rightarrow \text{CHS-H} + \text{Ca}^{+*} \\
\text{Ca}^{+*} \rightarrow \text{Ca}^+ + \text{hv}
\]

In this way, protons and hydrogen atoms can be recaptured by the Sun!

<table>
<thead>
<tr>
<th>Species</th>
<th>$\lambda$ Sun (nm)</th>
<th>$\lambda$ NIST (nm)</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca II</td>
<td>393.39</td>
<td>393.39</td>
<td>3p6 4s $\rightarrow$ 3p6 4p</td>
</tr>
<tr>
<td>Ca II</td>
<td>397.03</td>
<td>396.87</td>
<td>3p6 4s $\rightarrow$ 3p6 4p</td>
</tr>
<tr>
<td>Mg I</td>
<td>516.73</td>
<td>516.73</td>
<td>3s 3p $\rightarrow$ 3s 4s</td>
</tr>
<tr>
<td>Mg I</td>
<td>517.27</td>
<td>517.27</td>
<td>3s 3p $\rightarrow$ 3s 4s</td>
</tr>
<tr>
<td>Mg I</td>
<td>518.36</td>
<td>518.36</td>
<td>3s 3p $\rightarrow$ 3s 4s</td>
</tr>
<tr>
<td>Na I</td>
<td>588.95</td>
<td>588.99</td>
<td>3p6 3s $\rightarrow$ 3p6 3p</td>
</tr>
<tr>
<td>Na I</td>
<td>589.6</td>
<td>589.59</td>
<td>3p6 3s $\rightarrow$ 3p6 3p</td>
</tr>
<tr>
<td>O I</td>
<td>777.19</td>
<td>777.19</td>
<td>2s2 2p3 3s $\rightarrow$ 2s2 2p3 3p Spec II</td>
</tr>
<tr>
<td>O I</td>
<td>777.41</td>
<td>777.41</td>
<td>2s2 2p3 3s $\rightarrow$ 2s2 2p3 3p Spec II</td>
</tr>
<tr>
<td>O I</td>
<td>777.54</td>
<td>777.54</td>
<td>2s2 2p3 3s $\rightarrow$ 2s2 2p3 3p Spec II</td>
</tr>
<tr>
<td>O I</td>
<td>844.63</td>
<td>844.63</td>
<td>2s2 2p3 3s $\rightarrow$ 2s2 2p3 3p Spec II</td>
</tr>
<tr>
<td>O I</td>
<td>844.66</td>
<td>844.66</td>
<td>2s2 2p3 3s $\rightarrow$ 2s2 2p3 3p Spec II</td>
</tr>
<tr>
<td>O I</td>
<td>844.68</td>
<td>844.68</td>
<td>2s2 2p3 3s $\rightarrow$ 2s2 2p3 3p Spec II</td>
</tr>
<tr>
<td>Ca II</td>
<td>849.8</td>
<td>849.8</td>
<td>3p6 3d $\rightarrow$ 3p6 4p Spec II</td>
</tr>
<tr>
<td>Ca II</td>
<td>854.21</td>
<td>854.21</td>
<td>3p6 3d $\rightarrow$ 3p6 4p Spec II</td>
</tr>
<tr>
<td>Ca II</td>
<td>866.14</td>
<td>866.14</td>
<td>3p6 3d $\rightarrow$ 3p6 4p Spec II</td>
</tr>
</tbody>
</table>
Now, you have to be a little bit of a detective:

Al I 394.403 nm \(3s^23p^1 \rightarrow 3s^24s^1\)
(note: Al II lines \((3s^2)\) are not visible even though ionization requires only 5.9 eV, whereas Ca II \((3p^64s)\) which requires \(\sim 6.11\) eV are prominent! Mn II (e.g. 348.868 nm \(3d^6\)) and Mg II (e.g 438.464 nm \(3p^64p\)) are seen and require \(\sim 7.34\) and \(\sim 7.64\) eV)

NIII 409.736 nm \(2s^23s^1 \rightarrow 2s^23p^1\)
Fe I 483.955 nm \(3d^74s^1 \rightarrow 3d^74p^1\) (ground state for Fe I in lab is \(3d^64s^2\))
Fe I 516.227 nm \(3d^74p^1 \rightarrow 3d^74d^1\)
Cr I 425.435 nm \(3d^54s^1 \rightarrow 3d^54p^1\) (Strong! Leaving from the lab ground state!)

The intensity of an emission line is related to the ability to form the hydride and deliver a hydrogen atom, molecule, or proton. It is not proportional to the concentration of a given element in the chromosphere.

He I, He II, Ca II, O Triplet, Mg I lines are intense because they most readily form the hydrides.
An example of a condensation reaction in the laboratory:

silver clusters @ 10 K, Neon environment

\[ \text{Ag}_4 + \text{Ag}_4 \rightarrow \text{Ag}_8^* \rightarrow \text{Ag}_7 + \text{Ag}^* \]

\[ \text{Ag}^* \rightarrow \text{Ag} + h\nu \]

Photons are emitted in the ultra violet in this case. But the thermal bath is at 10K!

When He captures a proton, it leads to an activated HeH$^{+*}$, which must emit light to enter the ground state (see Eq. 1, in ApJ, 1982, 255, 489-496). Assuming it does not relax back before it can react, you could have the following:

Two electron transitions should not occur in random processes. They are suggesting the bonding of a hydrogen molecule known in inorganic chemistry.

Titanium

\[
\text{Ti-H}_2
\]

Hydrogen molecule

\[
\begin{align*}
\text{σ-donation} & \\
\text{π-back donation} & \\
\text{σ-anti-bonding} & \\
\text{σ-bonding} & 
\end{align*}
\]

Ti I @ 415.964 nm in ApJSS, 1968, 150(17), 1-364, if as recorded, originates from \(3d^3(2D)4s \rightarrow 3d4s^24p\)