The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere VIII. ‘Futile’ Processes in the Chromosphere

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In the liquid metallic hydrogen solar model (LMHSM), the chromosphere is the site of hydrogen condensation (P.M. Robitaille. The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere IV. On the Nature of the Chromosphere. *Progr. Phys.*, 2013, v. 3, L15-L21). Line emission is associated with the dissipation of energy from condensed hydrogen structures, CHS. Previously considered reactions resulted in hydrogen atom or cluster addition to the site of condensation. In this work, an additional mechanism is presented, wherein atomic or molecular species interact with CHS, but do not deposit hydrogen. These reactions channel heat away from CHS, enabling them to cool even more rapidly. As a result, this new class of processes could complement true hydrogen condensation reactions by providing an auxiliary mechanism for the removal of heat. Such ‘futile’ reactions lead to the formation of activated atoms, ions, or molecules and might contribute to line emission from such species. Evidence that complimentary ‘futile’ reactions might be important in the chromosphere can be extracted from lineshape analysis.

In order to explain the occurrence of the dark lines in the solar spectrum, we must assume that the solar atmosphere incloses a luminous nucleus, producing a continuous spectrum, the brightness of which exceeds a certain limit. The most probable supposition which can be made respecting the Sun’s constitution is, that it consists of a solid or liquid nucleus, heated to a temperature of the brightest whiteness, surrounded by an atmosphere of somewhat lower temperature.

Gustav Robert Kirchhoff, 1862 [1]

1 Introduction

During a solar eclipse, the flash spectrum associated with the chromosphere of the Sun becomes readily visible [2–5]. This spectrum is dominated by emission lines from hydrogen, most notably H-α, which gives rise to its characteristic color. However, the flash spectrum also contains a wide array of emission lines generated from neutral atoms, ions, or molecules [2–5]. Within the context of the Standard Solar Models (SSM) [6], these emission lines are produced by random temperature related excitation processes in this region of the Sun. Because the SSM adopt a gaseous solar body, the chromosphere is devoid of function and line emission does not help to account for structure.

In sharp contrast, within the Liquid Metallic Hydrogen Solar Model (LMHSM) [7, 8], the chromosphere is a site of hydrogen and proton capture, while the corona is responsible for harvesting electrons [8–12]. Condensation reactions have therefore been advanced to account for the production of emission lines in the chromosphere. These reactions facilitate the deposit of atomic hydrogen onto condensed hydrogen structures, CHS [9, 11, 12]. Line emission in the chromosphere is fundamentally linked to the dissipation of heat associated with exothermic condensation reactions. The role of condensation reactions in the chromosphere of the Sun has previously been presented in substantial detail [9, 11, 12]. For the sake of clarity, it is briefly readdressed herein.

One can consider an atom, A, reacting with hydrogen, H, to give rise to a molecular species, AH [8, 9, 11]. It should be possible for AH and CHS in the chromosphere to form an activated complex, CHS + AH → CHS-HA*. This would then be followed by an exothermic step involving the expulsion of an activated atom, CHS-HA* → CHS–H + A*, followed by the line emission from A*, A* → A + hv. In such a manner, a viable scheme is presented to account for line emission from neutral atoms, including those from hydrogen itself.

An analogous process could also be applied to a cation, A^{+n}, reacting with hydrogen, H, to give rise to a molecular species, AH^{+n}, where n=1, 2, etc [8, 9, 11]. Reaction of AH^{+n} with a condensed hydrogen structure (CHS) in the chromosphere leads to an activated complex, CHS + AH^{+n} → CHS-HA^{+n*}. This would then be followed by an exothermic step involving the expulsion of an activated ion, CHS-HA^{+n*} → CHS–H + A^{+n*}, followed by the line emission from the cation, A^{+n*}, A^{+n*} → A^+ + hv. Such reactions have been postulated to play an important role in the chromosphere and can explain the HeII lines, if HeH^+ triggers the condensation [8, 11]. When Ca^+ acts as the initial cation, such a mechanism can account for the strong CaII lines in the Sun [9].

2 'Futile' Reactions

There is another class of reactions which may play a role in the Sun, but has previously been overlooked. It is possible for interactions to take place with condensed hydrogen structures, but without the net transfer of a hydrogen atom. This new set of 'futile' reactions is important for three reasons: 1) it offers new insight relative to line emission arising from neutral atoms and molecules, 2) it adds an important new mechanism, which can complement previous reactions [9, 11, 12], in describing spectroscopic linewidths in the chromosphere, and 3) it provides a mechanism which can facilitate condensation reactions in the chromosphere by offering yet another means to dissipate heat.

In biochemistry, futile reactions tend to be cyclic in nature. They involve chemical processes which do not lead to any useful work, but which are exothermic.

A classic example of a futile cycle would involve the reactions of fructose-6-phosphate in glycolysis and gluconeogenesis. During glycolysis, we have a reaction catalyzed by phosphofructokinase: fructose-6-phosphate + ATP → fructose-1,6-bisphosphate + ADP. The reaction is reversed in gluconeogenesis using fructose-1,6-bisphosphatase: fructose-1,6-bisphosphate + H_2O → fructose-6-phosphate + P_i. The overall reaction involves the simple wastage of ATP and energy dissipation without net work: ATP → ADP + P_i + H_2O. The cell, of course, had to work to make the ATP and as a result, such a cycle is truly futile.

Let us consider the simplest futile reaction in the chromosphere. A hydrogen atom, H, interacts directly with a condensed hydrogen structure to form a weak activated complex, CHS + H → CHS–H^*. But this time, the reaction is reversed and no hydrogen is deposited: CHS–H^* → CHS + H^*. This would then be followed by line emission from activated hydrogen H^*, H^* → H + hv, as hydrogen is allowed to relax back to the ground state. The reaction appears futile, as no net change has taken place. But on closer examination, it is noted that heat has been removed from the condensed hydrogen structure. As a result, though no additional condensation has occurred, such a futile process can cool the condensing structure, thereby facilitating its growth when other true condensation reactions [8–12] are occurring in parallel.

It is now readily apparent that a wide array of 'futile' processes may exist in the chromosphere. For instance, an atom, A, could react with hydrogen, H, to give rise to a molecular species, AH [8, 9, 11]. AH could interact with CHS in the chromosphere to form an activated complex, CHS + AH → CHS–HA^*. The reaction is reversed and no hydrogen is deposited: CHS–HA^* → CHS + AH^*. This would then be followed by line emission from the molecular species AH^*, AH^* → AH + hv. In such a manner, a viable scheme is presented to account for line emission from small neutral molecules, such as H_2, CaH, LiH, etc. Similar reactions could also be invoked which involve small molecules such as H_2O or NH_3. The result would be line emission from these molecular species.

The analysis of spectroscopic lineshapes in the Sun is an area of considerable complexity for current models. The wings and cores of many lines appear to change with altitude above the solar surface (see [3, 4, 8, 13] and references therein). Such findings suggest that the mechanism involved in line production might well involve both true condensation reactions and futile processes. As previously stated [8], it is unlikely that Stark mechanisms are truly responsible for the lineshapes we observe in the Sun.

Dedication

Dedicated to past, present, and future astronomers.

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