LETTERS TO PROGRESS IN PHYSICS

The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere V. On the Nature of the Corona

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The E-corona is the site of numerous emission lines associated with high ionization states (i.e. FeXIV-FeXXV). Modern gaseous models of the Sun require that these states are produced by atomic irradiation, requiring the sequential removal of electrons to infinity, without an associated electron acceptor. This can lead to computed temperatures in the corona which are unrealistic (i.e. ∼30–100 MK contrasted to solar core values of ∼16 MK). In order to understand the emission lines of the E-corona, it is vital to recognize that they are superimposed upon the K-corona, which produces a continuous spectrum, devoid of Fraunhofer lines, arising from this same region of the Sun. It has been advanced that the K-corona harbors self-luminous condensed matter (Robitaille P.M. The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere II. Continuous Emission and Condensed Matter Within the Corona. *Progr. Phys.*, 2013, v. 3, L8–L10; Robitaille P.M. The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere III. Importance of Continuous Emission Spectra from Flares, Coronal Mass Ejections, Prominences, and Other Coronal Structures. *Progr. Phys.*, 2013, v. 3, L11–L14). Condensed matter can possess elevated electron affinities which may strip nearby atoms of their electrons. Such a scenario accounts for the high ionization states observed in the corona: condensed matter acts to harness electrons, ensuring the electrical neutrality of the Sun, despite the flow of electrons and ions in the solar winds. Elevated ionization states reflect the presence of materials with high electron affinities in the corona, which is likely to be a form of metallic hydrogen, and does not translate into elevated temperatures in this region of the solar atmosphere. As a result, the many mechanisms advanced to account for coronal heating in the gaseous models of the Sun are superfluous, given that electron affinity, not temperature, governs the resulting spectra. In this regard, the presence of highly ionized species in the corona constitutes the thirty-first line of evidence that the Sun is composed of condensed matter.

> *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]

Superimposed on the continuous spectrum of the inner K-corona are emission lines, including one at 5303.3 Å, the famous line from coronium, first discovered by Harkness and Young [2, 3], photographed by Evershed [4], and eventually identified as FeXIV by Bengt Edlén [5–7]. Walter Grotian suggested that this line originated from highly ionized atoms, supported by early reports of similar findings from Bengt Edlén in such atoms [5–8]. The wonderful story of coronium [5, 6], along with the roles played by Walter Grotian and Bengt Edlén has been presented by Edward A. Milne [7].

Milne's account provides a key fact relative to coronium: the formation of FeXIV requires energy in the soft X-ray range of the electromagnetic spectrum [7], but the Sun emits very few of these rays. As such, how does one produce ions with such elevated ionization states in the corona?

Today, X-ray spectroscopy reveals that the Sun can produce emission lines from ions with ionization states as high as FeXXV [9]. Within the context of the gaseous models [10–12], the formation of such species calls for the removal of electrons from electronic shells to infinity, requiring energies associated with temperatures of ∼30 MK [9, p. 26]. It has also been postulated that superhot thermal components ($>10^8$ K) can be generated above the limb in association with some flares [13] and radio studies initially called for temperatures of 10^8–10^{10} K in the corona [14, p. 128].

In 2000, the Bastille Day flare produced FeXII lines, but with a spine emmiting FeXXIV lines [9, p. 19]. If such findings are to be explained within the context of a gaseous solar model [10–12], it is not surprising that extreme temperatures must be invoked. A gaseous Sun has no other means of producing highly ionized species.

At the same time, the extreme temperatures currently associated with the corona must be viewed with caution, given that the core of the Sun has been postulated to harbor temperatures of only ∼16 MK [10, p. 9]. In addition, it is claimed that the energy source driving such extremes in temperature *"must be magnetic since all the other possible sources are completely inadequate"* [13]. Such statements, and the computed temperatures from which they stem, directly reflect the shortcomings of the gaseous solar models [10–12]. The need to explain the synthesis of highly ionized ions in the corona within a gaseous context is so acute that numerous schemes have been advanced to heat the chromosphere and corona [15, 16]. Ulmschneider states that *"The chromosphere and corona are thus characterized as layers which require large amounts of mechanical heating"* [15, p, 235] and further *"To clarify the zoo of coronal heating processes much further work remains to be done"* [15, p. 278].

Since the corona must be excessively hot to produce such ions in a gaseous context, the continuous spectrum of the K-corona has been dismissed as a strange artifact, produced by electronic scattering of photospheric light [17]. Otherwise, the coronal continuous spectrum would be indicating that *apparent coronal temperatures are no warmer than those of the photosphere*. It would be impossible for the gaseous models [10–12] to account for the presence of highly ionized species within the outer solar atmosphere. Consequently, sufficient electron densities are inferred to exist in the corona to support the idea that the spectrum of the K-corona is being produced by the scattering of photospheric light: *"The reason we see the corona in white, or integrated, light is that the photospheric light is scattered by coronal electrons: we see the light that does not get through but is scattered towards us. This scattered light is about 10^{-6} as intense as the photospheric light, which means it has been scattered by 10^{19} electrons; these are distributed along a path about equal to the diameter of the sun, or 1.4 x 10^{11} cm, so the average coronal density close to the surface must be 10^8 electrons/cm^3"* [14, p. 75]. Much like the solar surface [18], the relevance of a thermal spectrum in the K-corona has been rejected as little more than an optical illusion [17].

In the end, all extreme temperatures obtained from line emission should be dismissed as erroneous. Discovery of FeXXV within X-ray flares suggests that we do not properly understand the formation of emission lines with high ionization levels in the corona. Current temperature estimates are flirting with violations of both the first and second laws of thermodynamics: it is difficult to conceive that localized temperatures within flares and the corona could greatly *exceed* the temperature of the solar core.

Instead, line emission spectra from highly ionized ions might best be viewed as direct evidence that materials with elevated electron affinities exist within the corona. Such a solution can be readily associated with the condensed nature of the Sun [19–23].

In this regard, the continuous spectrum of the K-corona must be regarded as genuine [17]. The slight reddening of the K-corona, reported long ago by Allen [24], indicates that *apparent* coronal temperatures are gently decreasing with increasing distance above the solar surface. The corona seems to contain condensed matter of the same nature as found on the photosphere, since the spectrum of the K-corona, though devoid of Fraunhofer lines, is essentially identical to that produced by the solar surface [18]. This proposal is compelling, given that the Sun is expelling material into its corona which is also known to emit continuous visible spectra [25].

By extension, *apparent* coronal temperatures, which are likely to represent vibrational lattice phenomena [26–29], can be no greater than those found on the surface of the Sun. Therefore, contrary to popular scientific belief [15, 16], the corona of the Sun is *not* being heated. Rather, free atoms in the corona are being stripped of their electrons, as they interact with condensed matter which possesses much higher electron affinity. Neutral atoms have limited electron affinities, but molecules can have higher values.* However, condensed matter can develop enormous attractive forces for electrons.

This lesson is well manifested on Earth, as lightning attempts to equalize charge imbalance between separate regions of condensed matter [31–33]. Typically, lightning forms in clouds containing solid or liquid water particles. But it can also occur *"above volcanoes, in sandstorms, and in nuclear explosions"* [33, p. 67]. Usually, lightning forms between different cloud regions, or between clouds and the Earth's surface [31–33]. Lightning represents the longest standing example of the power of electron affinity in condensed matter. In this respect, while temperatures in the tens of thousands of degrees could be inferred from Hα line analysis during lightning activity,† scientists do not claim that the atmosphere of the Earth exists at these temperatures.

Thunderhead clouds can generate substantial steady electric fields on the order of 100 kVm^{-1} [33, p. 494]. Such fields have have been associated with runaway electrons capable of generating X-rays with energies of 100 KeV or more [33, p. 493-495]. Nonetheless, these energies are not translated into associated temperatures, as values in excess of 10^9 K would be derived. Still, for the purpose of this discussion, it is important to note that the presence of condensed matter in the atmosphere of the Earth can lead to amazing phenomena, when electric potentials are eliminated through charge transfer.

The author has advanced that the corona of the Sun is filled with sparse remnants of liquid metallic hydrogen [18] which have been expelled from the body of the Sun [25]. Such material is expected to have a highly conductive nature

*Of the elements, chlorine has the highest electron affinity at ∼3.6 eV, calcium has the lowest value at ∼0.02 eV; molecular RuF_6 has a value of ∼7.5 eV [30]

†Peak temperatures of ∼35,000 K have been reported [33, p. 163]

and could be used to harvest electrons from the corona, helping to ensure the continued neutrality of the solar body and solar winds. The presence of metallic hydrogen in the corona may then promote, through its elevated electron affinity, the creation of highly ionized species.

For instance, when iron comes in contact with metallic hydrogen, MH, it could initially form an activated complex, MH–Fe*, MH + Fe → MH–Fe*. This excited complex then relaxes by capturing *n* electrons from the iron atom. This could be accomplished with the simultaneous ejection of an activated iron species, Fe^{+n*}, leading to the following reaction: MH–Fe* → MH–$n\overline{e}$ + Fe^{+n*}. The resulting excited iron could then relax back to the ground state through line emission, $Fe^{+n*} \rightarrow Fe^{+n}$ + hv. Depending on the local electron affinity of metallic hydrogen, *n* could range from single digits to ~25 [9] in the case of iron. A similar process could be invoked to create the other highly ionized species of the corona. In this regard, it is interesting to note that most of the ions observed in the solar *"XUV spectrum are principally those with one or two valence electrons"* remaining [14, 173].

In this scenario, the electron affinity of metallic hydrogen in the outer atmosphere responds to charge imbalances, either in the corona itself or on the surface of the Sun, by capturing electrons locally. Metallic hydrogen in the corona thereby acts as a conductive medium surrounding the solar body, constantly ensuring overall charge neutrality for the Sun. The arrangement of coronal steamers is highly suggestive of such a role from these objects, though all coronal structures might be involved in the recapture of electrons from the outer solar atmosphere.

Outstanding images of the corona have been obtained using spectroscopic lines from highly ionized iron (e.g. FeX–FeXIV) [34–37]. The presence of FeX–FeXIV throughout the solar atmosphere strengthens the concept that interactions between atoms and metallic hydrogen in the corona act to maintain neutrality on the Sun by producing highly ionized atoms throughout this region.

Moreover, flare studies indicate that coronal structures can display highly organized local electron affinities. As mentioned earlier, the TRACE team has produced a flare image where central spine structures produce line emission from FeXXIV and CaXVII, while the exterior of the flare emits in FeXII [9, p. 19]. Such images would be nearly impossible to explain in the context of a gaseous model of the Sun. Instead, organized structures within the corona and its components are strongly supportive of the idea that the Sun is comprised of condensed matter.

In closing, the liquid metallic hydrogen model of the Sun [19–23] provides an elegant solution for the production of highly ionized species in the corona. The wide variety of oxidation states can be simply obtained by invoking regions of varying electron affinity within the condensed structures that comprise the corona. The complete, or significant, removal of electrons from atoms can be explained using a single interaction, namely the temporary contact between atoms and metallic hydrogen.

The production of such ions in the gaseous models [10–12] requires the repeated ejection of electrons from their orbitals in a multistage process, whereby up to two dozen events must logically follow one another. Studies indicate the existence of species such as C^{+6}, Fe^{+14} and Fe^{+16} in the solar wind [38, p. 114]. Such ions require multiple steps for production in a gaseous context [10–12] and would be the result of random processes.

Conversely, the synthesis of highly ionized atoms requires but a single step in the liquid metallic hydrogen model [19–23]. The generation of such ions is no longer a random act, but rather a direct manifestation of the function of the corona, *facilitation of electron capture in the outer atmosphere of the Sun in order to preserve solar neutrality*. The production of highly ionized species throughout the corona therefore constitutes the thirty-first line of evidence that the Sun is composed of condensed matter.

Dedication

Dedicated to the poor, who sleep, nearly forgotten, under the light of the Southern Cross.

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