EZ Water: A New Quantitative Approach Applied - Many Numerical Results Obtained

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Abstract

This study applies a new quantitative approach to explain behaviors of Exclusion Zone (EZ) water, and explore some closely related technological issues. The approach is computationally simple enough to be implemented using only a hand calculator. It is based on readily available data about ionization potentials of elements, plus a rational model to help interpolate and extrapolate to cover situations for which data about ionization potentials are not readily available. It allows one to assess all the plausible ionic configurations for any chemical species. Applied to EZ water, the approach gives insight about why EZ water forms its ion and its larger hexagonal structure, why EZ water is probably ubiquitous on our planet (and other planets too, if they have water), and how such knowledge about EZ water could help us solve some important engineering problems.

Introduction

I was introduced to the subject of EZ Water by a talk that Gerald Pollack gave at the 2013 meeting of the Natural Philosophy Alliance at College Park, MD. I was im- mediately attracted to the problem. The talk included dramatic evidence of real physical phenomena, and plausible qual- itative explanations of the phenomena, but it also suggested to me a real need for a more quantitative theory to explain the phenomena more fully. And I already had in hand a candidate theory, ready to try out on EZ water. This paper is a brief report on the origin of this theory, its application to EZ water, and the results obtained so far.

The Theory for Application to EZ Water

My theoretical approach is detailed in Whitney (2013). It is called 'Algebraic Che- mistry' (AC) because it has no integrals, or other math operations, that would demand computations beyond the capabilities of a hand calculator. The worst operation in AC is a square root.

The origin for AC lies with issues deep in Special Relativity Theory (SRT). Members of an applications-oriented audience may embrace or ignore SRT, however they are inclined. But either way, results are results, and, so long as results from AC do not conflict with some observable effect, the match cannot be denied, and should be

pursued further.

Whitney (2013) is full of example asse-ssments of chemical species, and the assessments do indeed comport with observable effects. Example species inves-tigated include unusual elements like Helium, Gallium, Mercury, *etc.*; molecules of importance to humans, such as water, atmospheric gasses, hydrocarbons, *etc.*; various important chemical reactions, species involved in chemical catalysis; and species involved in the much-doubted phenomenon of Cold Fusion (CF). This latter problem involves water again, this time with heavy isotopes of Hydrogen.

The issue of isotopes is important in AC because nuclear mass is important in AC. The initial observation from which AC developed is this: when first-order ioniz-ation potentials for all elements are scaled by the factor M/Z, where M is the nuclear mass and Z is the nuclear charge, then the scaled first-order ionization potentials (called $IP_{1,z}$) fall into a *very* regular pattern: the rise on *every* period in the Periodic Table is *the same factor*, 7/2.

The consistency of the 7/2 rise on every period suggests that the IP values are not just about individual elements; they are following a pattern that relates *all* elements, and because of the pattern, each $IP_{1,z}$ contains information about all *other* elements. That is, $IP_{1,z}$ embodies *population generic information*.

The idea that suggests itself is hierarchical: each $IP_{1,z}$ contains a universal baseline contribution $IP_{1,1}$ about interaction bet-ween the nucleus and the population of electrons as a whole, and, for all elements beyond Hydrogen, a contribution $\Delta IP_{1,z}$ about interactions just among the electrons by themselves.

The electron-electron contribution can be dramatic. Consider Helium: $\Delta IP_{1,2}$ is huge, meaning that two electrons make a very strong bond between themselves. And consider Lithium: $\Delta IP_{1,3}$ is negative, meaning that two electrons actively work together to try to exclude a third electron.

Over the periods, there is obvious detail about the electron-electron interactions. Within each period, there are obvious sub-periods keyed to the nominal angular-momentum quantum number that is being filled. Plotted on a log scale, all sub-period rises are straight lines. The slopes all appear to be rational fractions. We can display these as follows:

period	N	l	fraction	l	fraction	l	fraction	l	fraction
1	1	0	1						
2	2	0	1/2	1	3/4				
3	2	0	1/2	1	3/4				
4	3	0	1/4	2	5/18	1	2/3		
5	3	0	1/4	2	5/18	1	2/3		
6	4	0	1/4	3	7/48	2	5/16	1	9/16
7	4	0	1/4	3	7/48	2	5/16	1	9/16

Table 1

A non-traditional parameter N is included in the display because, for $l > O$, it is possible to write a simple formula for fraction:

(1) $fraction = [(2l+1)/N^2][(N-l)/l]$

Also, all periods in the Periodic Table have length $2N^2$.

All this numerical regularity is highly suggestive that there really is a reliable pattern here, and we can reasonably seek to exploit it. Here is the first exploitation that suggests itself. Given first-order ionization potentials of many elements, we can make reasonable estimates of the additional ene-rgy required to remove a second electron from each, and then a third, and so on.

Please note: estimating the energy to remove a second electron, or a third, and so on, is not the same thing as estimating the so-called 'second-order ionization potential', 'third-order ionization potential', and so

on. Look up those energies, and you will see that they are very large. The implication is that the numbers are about events that are very *violent*: ripping two, or three, or more, electrons off an atom *all at once*.

Just as for the first-order ionization potentials, there is a great deal of numerical regularity in the higher-order ionization potentials. You can read about it in Whitney (2013). But the numerical analysis of EZ water does not require this information. That is because violent events occur only when some really heavy-duty equipment, like a molecular beam generator, is used, or dangerous operations, like ignition of rocket engines, or explosion of bombs, are conducted. The study of EZ water involves none of this. The study of EZ water is just normal lab-bench chemistry; it is about events that occur gently, one at a time.

We need to consider not only the events themselves, but also the internal adjustments of atoms that occur after the events. For example, suppose we remove an electron from a neutral atom with nuclear charge Z. The atom started with an electron population of size Z, but ended up with an electron population of size Z-1. It will have to adjust to this change.

The difference between the removal event and the adjustment process is something like the distinction between work and heat in thermodynamics. We control work; Nature controls heat. We do work to remove an electron from the nuclear field of an atom; the remaining electron population absorbs or releases heat while adjusting in response.

Given an atom of the element with nuclear charge Z, the work to remove one electron just from the nuclear field is:

(2) $\qquad W_{\text{removing } e_1} = IP_{1,1}(Z/M_Z)$

This is energy that has to be supplied to get the removal process started: energy to get over a potential wall. Note the factor of Z/M. It restores *population-generic* information, *IP*'s, to *element-specific* information, W here, or H below.

The subsequent re-adjustment among electrons within the atom involves heat

(3) $\quad H_{\text{removing } e_1} = (\Delta IP_{1,Z} - \Delta IP_{1,Z-1})(Z/M_Z)$

This is energy that might be recovered by, or extorted from, the environment because of a rock pile, or a ditch, on the other side of the potential wall. (Note: for the special case $Z = 1$, $\Delta IP_{1,Z-1}$ does not exist and $\Delta IP_{1,Z} = 0$. And for $Z = 2$, $\Delta IP_{1,Z-1} = \Delta IP_{1,1} = 0$.)

The total energy involved in the removal of one electron is then:

(4)

$(W+H)_{\text{removing } e_1} = [IP_{1,1}Z + \Delta IP_{1,Z}Z - \Delta IP_{1,Z-1}(Z\text{-}1)]/M_Z$

Now suppose that we remove a second electron. The work that has to be supplied because of the nuclear field is:

(5) $\qquad W_{\text{removing } e_2} = IP_{1,1}\sqrt{Z(Z-1)}/M_Z$

Observe the $\sqrt{Z(Z-1)}$ instead of just Z; it takes account of the difference between nuclear charge and electron count. The reason for this form of accommodation, rather than some other form, lies deep in the Physics theory, rather than in the Chemistry application, and so is summarized separately in the Appendix to this paper.

The heat then involved in electron readjustment is:

(6)

$H_{\text{removing } e_2} = \Delta IP_{1,Z-1}(Z\text{-}1)/M_Z - \Delta IP_{1,Z-2}(Z\text{-}2)/M_Z$

The total energy involved in this step is then:

(7) $(W+H)_{\text{removing e}_2} = IP_{1,1}\sqrt{Z(Z-1)}/M_Z$
$\quad + \Delta IP_{1,Z-1}(Z-1)/M_Z - \Delta IP_{1,Z-2}(Z-2)/M_Z$

Now put both steps together. The grand total energy involved in removing two electrons is then:

(8)

$(W+H)_{\text{removing e}_1 \& \text{e}_2} = IP_{1,1}[Z+\sqrt{Z(Z-1)}]/M_Z$
$\quad + [\Delta IP_{1,Z}Z - \Delta IP_{1,Z-2}(Z-2)]/M_Z$

You can see the pattern developing. The grand total energy involved in removing three electrons will be:

(9)

$(W+H)_{\text{removing e}_1, \text{ e}_2 \& \text{e}_3} =$
$\quad IP_{1,1}[Z+\sqrt{Z(Z-1)}+\sqrt{Z(Z-2)}]/M_Z$
$\quad + [\Delta IP_{1,Z}Z - \Delta IP_{1,Z-3}(Z-3)]/M_Z$

and so on like that.

Now let us go in the other direction, *adding* electrons. First, rewrite (4) for the singly charged negative ion of element Z, which has $Z+1$ electrons to start with:

$(W+H)_{\text{removing e}_1 \text{ from negative ion}} =$
$[IP_{1,1}\sqrt{Z(Z+1)} + \Delta IP_{1,Z+1}(Z+1) - \Delta IP_{1,Z}Z]/M_Z$

or, just reversing the direction of the operation:

$(W+H)_{\text{adding e}_1 \text{ to neutral atom}} = -[IP_{1,1}\sqrt{Z(Z+1)}$
$\quad + \Delta IP_{1,Z+1}(Z+1) - \Delta IP_{1,Z}Z]/M_Z$

That is, the work involved in adding the one electron into the nuclear field is:

(10) $\quad W_{\text{adding e}_1} = -IP_{1,1}\sqrt{Z(Z+1)}/M_Z$

And the heat involved in re-adjusting the electron population is:

(11)

$H_{\text{adding e}_1} = -\Delta IP_{1,Z+1}(Z+1)/M_Z + \Delta IP_{1,Z}Z/M_Z$

And the total energy involved in adding one electron is:

(12)

$(W+H)_{\text{adding e}_1} = -IP_{1,1}\sqrt{Z(Z+1)}/M_Z$
$\quad - \Delta IP_{1,Z+1}(Z+1)/M_Z + \Delta IP_{1,Z}Z/M_Z$

We can pause here to address some reviewer comments. Compare the summary Equations (4) and (12). The comparison shows the difference between adding an electron to, *vs.* removing an electron from, a particular neutral atom. There is clear asymmetry, with different Z factors and different ΔIP data items being involved. I thank an anonymous reviewer for mentioning the existence of much data showing such clear asymmetry, and I suggest that AC can help to interpret that data.

Another reviewer wondered if the formulae in AC could imply possible perpetual-motion processes based on cycling through different ionization states of an atom. Certainly they do not. Energies for transitions between ionization states are only state-dependent, not path-dependent, so no closed cycle of ionization state transitions can yield any net energy. The above derivations of formulae for adding *vs.* subtracting an electron use this principle.

Now we can proceed to add more electrons. If we add a second one to the singly charged ion, it will require additional work:

(13) $\quad W_{\text{adding e}_2} = -IP_{1,1}\sqrt{Z(Z+2)}/M_Z$

And it will cause a further heat adjustment:

(14) $H_{\text{adding e}_2} = -\Delta IP_{1,Z+2}(Z+2)/M_Z$
$\quad + \Delta IP_{1,Z+1}(Z+1)/M_Z$

Putting both steps together, the grand total energy involved in adding two electrons is:

$$(15) \quad (W+H)_{\text{adding } e_1 \& e_2} =$$
$$-IP_{1,1}[\sqrt{Z(Z+1)} + \sqrt{Z(Z+2)}]/M_Z$$
$$+[\Delta IP_{1,Z}Z - \Delta IP_{1,Z+2}(Z+2)]/M_Z$$

Similarly, the total energy involved in adding three electrons is:

$$(16) \quad (W+H)_{\text{adding } e_1, e_2 \& e_3} =$$
$$-IP_{1,1}[\sqrt{Z(Z+1)} + \sqrt{Z(Z+2)} + \sqrt{Z(Z+3)}]/M_Z$$
$$+[\Delta IP_{1,Z}Z - \Delta IP_{1,Z+3}(Z+3)]/M_Z$$

And so it goes on from there.

Equations (9) and (16) represent a consolidation and simplification over the approach in Whitney (2013). There, individual steps in ionization were each evaluated numerically, and then added together as numbers. Here, individual steps are added together as formulae, and then the consolidated formulae are evaluated numerically. This way, canceling terms are never evaluated, so a little less numerical error may accumulate.

Input Data for Analysis of EZ Water

Numerical data about all elements up to number 118 (some not even discovered in Nature or synthesized in a high-energy lab yet) are given in Whitney (2013). For the numerical analysis of EZ water, we need at most the data for the first ten elements. These numerical data, expressed in electron volts, eV, are as follows:

Hydrogen:

Z=1, M=1.008, $IP_{1,1}$=14.250 eV, $\Delta IP_{1,1}$= 0 eV

Helium:

Z=2, M=4.003, $IP_{1,2}$=49.875 eV, $\Delta IP_{1,2}$= 35.625 eV

Lithium:

Z=3, M=6.941, $IP_{1,3}$=12.469 eV, $\Delta IP_{1,3}$= -1.781 eV

Beryllium:

Z=4, M=9.012, $IP_{1,4}$=23.327 eV, $\Delta IP_{1,4}$= 9.077 eV

Boron:

Z=5, M=10.811, $IP_{1,5}$=17.055 eV, $\Delta IP_{1,5}$= 2.805 eV

Carbon:

Z=6, M=12.011, $IP_{1,6}$=21.570 eV, $\Delta IP_{1,6}$= 7.320 eV

Nitrogen:

Z=7, M=14.007, $IP_{1,7}$=27.281 eV, $\Delta IP_{1,7}$= 13.031 eV

Oxygen:

Z=8, M=15.999, $IP_{1,8}$=27.281 eV, $\Delta IP_{1,8}$= 13.031 eV

Fluorine:

Z=9, M=18.998, $IP_{1,9}$=34.504 eV, $\Delta IP_{1,9}$= 20.254 eV

Neon:

Z=10, M=20.180, $IP_{1,10}$=43.641 eV, $\Delta IP_{1,10}$= 29.391 eV

This glimpse of the overall data set illustrates and important point. The *IP* numbers come from a semi-empirical model, and not from a super-accurate theory. Observe that the *IP* numbers are the same for Nitrogen and Oxygen. These numbers come at a transition where the spin quantum number being filled is switching sign. There is no presently known fact to guide the model to different numbers before and after this switch. So, for now, the numbers are the same.

The implication of the semi-empirical nat-

ure of the model is that not all of the four or five digits given are actually significant. Extra digits are given mainly to help readers recognize the data items, and reproduce the calculations using them.

Following are some example calculations concerning possible ionic configurations for ordinary, normal water.

One possible ionic configuration for water is $2H^+ + O^{2-}$, and most people believe this is what ordinary water is. Let us now check that belief.

By Eq. (4), the transition $H \to H^+$ takes:

$$(IP_{1,1} + \Delta IP_{1,Z-1})(Z / M_Z) = (IP_{1,1} + 0) \times 1 / M_1$$

$$= (14.250 + 0) \times 1 / 1.008 = 14.1369 eV$$

So $2H^+$ takes:

$$2 \times 14.1369 = 28.2738 eV$$

By Eq. (15), the transition $O \to O^{2-}$ takes:

(17)

$$-IP_{1,1}[\sqrt{Z(Z+1)} + \sqrt{Z(Z+2)}] / M_Z$$

$$+[\Delta IP_{1,Z}Z - \Delta IP_{1,Z+2}(Z+2)] / M_Z =$$

$$-14.250[\sqrt{8 \times 9} + \sqrt{8 \times 10}] / 15.999$$

$$+[\Delta IP_{1,8} \times 8 - \Delta IP_{1,10} \times 10] / 15.999 =$$

$$-14.250[\sqrt{72} + \sqrt{80}] / 15.999$$

$$+[13.031 \times 8 - 29.391 \times 10] / 15.999 =$$

$$-14.250[8.4853 + 8.9443] / 15.999$$

$$+[104.248 - 293.910] / 15.999 =$$

$$-14.250[17.4296] / 15.999 + [-189.662] / 15.999$$

$$-15.5242 - 11.8546 = -27.3788 eV$$

So the creation of a water molecule in the

ionic configuration $2H^+ + O^{2-}$ takes 28.2738 - 27.3788 = 0.8950 eV.

This is a positive energy requirement, and it implies that some external assistance is needed to fulfill the requirement. So normal water may not be in this ionic configuration after all.

But another possibility exists. The ionic configuration for normal water could be $2H^- + O^{2+}$. By Eq. (12), the transition $H \to H^-$ takes:

(18)

$$-IP_{1,1}\sqrt{Z(Z+1)} / M_Z - \Delta IP_{1,Z+1}(Z+1) / M_Z$$

$$+\Delta IP_{1,Z}Z / M_Z =$$

$$-IP_{1,1}\sqrt{1 \times 2} / M_1 - \Delta IP_{1,2} \times 2 / M_1$$

$$+\Delta IP_{1,1} \times 1 / M_1 =$$

$$-14.250 \times 1.4142 / 1.008 - 35.625 \times 2 / 1.008$$

$$+0 \times 1 / 1.008 =$$

$$-19.9924 - 70.6845 + 0 = -90.6769 eV$$

So $2H^-$ takes:

(19) $$2 \times (-90.6769) = -181.3538 eV$$

Please pause here and take notice: this is a *huge* negative energy. It reflects the fact that electrons *really* like to make pairs. They do it everywhere in Chemistry. Their propensity to do it motivated the invention of the so-called 'spin' quantum number. Without spin, many electrons in atoms would be violating the 'Pauli Exclusion Principle', which says that only one electron can be in any particular quantum state. Electron pairs are famous in Condensed Matter Physics too, under the name 'Cooper pairs'.

By Eq. (8), the transition $O \to O^{2+}$ takes:

(20)

$$IP_{1,1}[Z + \sqrt{Z(Z-1)}]/M_Z$$
$$+[\Delta IP_{1,Z}Z - \Delta IP_{1,Z-2}(Z-2)]/M_Z =$$

$$IP_{1,1}[8 + \sqrt{8 \times 7}]/M_8$$
$$+[\Delta IP_{1,8} \times 8 - \Delta IP_{1,6} \times 6]/M_8 =$$

$$14.250[8 + \sqrt{56}]/15.999$$
$$+[13.031 \times 8 - 7.320 \times 6]/15.999 =$$

$$14.250[8 + 7.4833]/15.999$$
$$+[104.248 - 43.920]/15.999 =$$

$$14.250 \times 15.4833/15.999 + 60.328/15.999 =$$

$$13.7907 + 3.7707 = 17.5614 eV$$

So the creation of the water molecule in the ionic configuration $2H^- + O^{2+}$ takes:

$$-181.3538 + 17.5614 = -163.7924 eV$$

This is a solidly negative energy. It means that ordinary water is overwhelmingly in the unexpected ionic configuration $2H^- + O^{2+}$. This *is* normal water.

This little exercise about water illustrates the value of having additional quantitative approaches available for use in Chemistry. Many people imagine that a quantitative approach to Chemistry ought to come from traditional Quantum Mechanics. One would start with something fundamental, or '*ab initio*', like Schrödinger's equation. Then one would compute ... and compute ... and compute. Requiring so much computation, this approach has not yet helped enough in addressing the practical needs of Chemists[1].

Because of its emphasis on the theoretical foundation, one might call the *ab initio* ap-

1) Chaplin M. (2009) remarks on *ab initio* calculations being limited to a few molecules at most. And his subject of interest is the macroscopic water surface, a much larger scenario indeed!

proach a 'bottom-up' approach. That terminology suggests the possibility to have also a 'top-down'[2] approach: something that starts with the existing big empirical knowledge base and drills down to particular cases. That is where AC comes in.

The above exercise about water also illustrates something about numerical accuracy. When the calculations were first done in the old order 'evaluate ionization steps first, then add', as opposed to the new order 'combine ionization steps first, then evaluate', the 17.5614eV above was 17.5613eV, and the -163.7924eV above was -163.7925 eV. This means: don't take lots of decimal places too seriously; in a multi-step calculation, they can accumulate detectable rounding error. The numbers just provide a tool; the real focus should be on the big conceptual ideas that the tool produces.

Here is one big conceptual idea. The numerical analysis helps explain some things known about the normal water molecule: that it is tetrahedral in shape, that it is polarized, and that, when frozen, it floats.

Consider what surrounds the O^{2+} in $2H^- + O^{2+}$: two naked protons, and two tight little electron pairs. That makes four distinct items, and of course that makes the normal water molecule a tetrahedron. Note that the shape has nothing to do with Oxygen *per se*; it has to do with the number of items *attached* to the Oxygen. The lesson is: we should think less about 'bond angles' of host atoms, and more about attachments *on* host atoms.

With two of the attached items being positively charged, and two of the attached items being negatively charged, of course

2) The terminology 'bottom-up' and 'top-down' occurs also in Pavuna D, Jurendic T (2013). There is another deep connection to the present work too; the vortex structures that Pavuna and Jurendic study and the Periodic Table that I study both display fractal behavior!

the resulting tetrahedral normal water molecule is polarized.

But this water molecule cannot be static. The two electron pairs have got to rotate about their respective naked protons. So the whole molecule has to rotate about an axis slightly offset from the Oxygen nucleus. It occupies a volume in space something like two Hershey-kiss candies attached bottom-to-bottom. And though polarized, its polarization vector is not steady in time.

This description helps explain the strange fact about water that its solid form floats over its liquid form. That is because water cannot form a typical space-efficient +/- cubic crystal array. The best it can do is some type of hexagonal array, which will have hexagonal holes in it. So frozen water occupies more total volume than liquid water does. Therefore, it is less dense than liquid water is. Therefore, it floats.

Here is another big conceptual idea. The other ionic configuration for water, the $2H^+ + O^{2-}$, that everyone has believed was normal water, is not normal water. But it may be something else instead. Experimenters doing electrochemistry for applications such as fine welding have created something called 'Brown's gas'. See Sackstedt (2009).

Brown's gas is both potentially useful and not at all well understood, and that situation creates a lot of secrecy, hype and doubt around the subject. The most scientifically oriented work I have seen is by Eckman (2009). He views the subject in terms of traditional quantum states of atoms and molecular orbitals. This is a conceptually sound but computationally intensive way to go, involving integrals of functions of spatial coordinates.

My goal here is to complement Eckman's view with a view based on the positive-energy ionic configuration $2H^+ + O^{2-}$. Observe that the O^{2-} ion has ten electrons, complete like neutral noble Neon is. There are only two items attached to this O^{2-}, and they are identical: two naked protons. So of course this ionic configuration has to be a linear molecule. And Eckman does indeed show 'Brown's gas' as a linear molecule. The linear molecule is also un-polarized, and Eckman does indeed call it 'non-polar'.

About energy: recall that $2H^+ + O^{2-}$ carries a dose of energy, not unlike the energy that a methane molecule carries [see Whitney (2013)]. But of course the $2H^+ + O^{2-}$ molecule does not burn; it releases energy by just reverting to the normal ionic configuration for water, $2H^- + O^{2+}$. So it produces energy without consuming O_2, or releasing CO_2, or presenting a burn risk to exposed human flesh, as Eckman notes.

Here is another big conceptual idea about Brown's gas. Suppose the molecule $2H^+ + O^{2-}$ were made with at least one heavier Hydrogen isotope – with a Deuterium nucleus, or a Tritium nucleus. With no electron shield around it, that heavy nucleus would be in a very exposed position. Given enough such molecules, the scene would be set for a possible CF reaction.

Like the subject of Brown's gas, the subject of CF is surrounded with secrecy, hype, and doubt. There are three prime reasons for doubt: 1) Lack of neutrons produced; 2) Variability of excess heat produced; 3) Lack of a credible theory. There are also three corresponding reasons for hope: 1) Lack of neutron production is not a valid reason for doubt: *fission* reactions release excess neutrons but fusion reactions *require* extra neutrons; that is why they start with heavy isotopes. 2) Variable results are to be expected when a process is not yet well understood. 3) Lack of credible theory can be remedied; for example, with AC.

Having planted a seed of doubt *about* all the doubt, I will return to the subject of CF later. The treatment of CF first needs the following information about EZ water.

The Numerical Analysis of EZ Water

The following transition is proposed for analysis of EZ water:

3 normal water molecules → 1 EZ water ion + 1 hydronium ion

That is,

$$3(H_2O) \rightarrow (H_3O_2)^- + (H_3O)^+$$

Observe the notation: parentheses are used to avoid any prejudice about what charge the individual atoms within any chemical species may carry. We want to consider all possible, or at least all plausible, ionic configurations of every chemical species mentioned, including all ions.

The EZ water ion $(H_3O_2)^-$ could have the ionic configuration $3H^+ + 2O^{2-}$. From Eq. (4), $3H^+$ takes total energy:

(21)

$$3 \times IP_{1,1} / M_Z = 3 \times 14.250 / 1.008 = 42.4107 eV$$

From Eq. (17), $2O^{2-}$ takes total energy:

$$2 \times (-27.3788) = -54.7576 eV$$

So the ionic configuration $3H^+ + 2O^{2-}$ takes:

(22) $$42.4107 - 54.7576 = -12.3469 eV$$

This is a negative energy, so this ionic configuration certainly can occur.

But there is another possibility too. The EZ water ion $(H_3O_2)^-$ could have the ionic configuration $3H^- + 2O^{2+}$. From Eq. (18), H^- takes -90.6769eV, so $3H^-$ takes:

(23) $$3 \times (-90.6769) = -272.0307 eV$$

From Eq. (4), the O^+ takes total energy:

(24)

$$(IP_{1,1} \times 8 + \Delta IP_{1,8} \times 8 - \Delta IP_{1,7} \times 7) / M_8 =$$

$$14.250 \times 8 + 13.031 \times 8 - 13.031 \times 7) / 15.999 =$$

$$114.000 + 104.248 - 91.217) / 15.999 = 7.9399 eV$$

So $2O^+$ takes $2 \times 7.9399 = 15.8798$ eV. Thus the ionic configuration $3H^- + 2O^+$ takes:

(25) $$-272.0307 + 15.8798 = -256.1509 eV$$

This is an energy much more negative than the first ionic configuration for EZ water, $3H^+ + 2O^{2-}$, gave. It means that EZ water is nearly always in this second ionic configuration, $3H^- + 2O^+$.

However, since both energies are negative, both species must exist. In situations where two versions of anything *can* exist, they generally both *do* exist, in proportions determined by their so-called Boltzmann factors, exp(-energy/*kT*), where *k* is Boltzmann's constant and *T* is absolute temperature.

The hydronium ion $(H_3O)^+$ could have the ionic configuration $3H^+ + O^{2-}$. This, I believe, is what most people would expect, given that most people would have expected (wrongly, as it turned out) that normal water had the ionic configuration $2H^+ + O^{2-}$.

From Eq. (21), the $3H^+$ would take 42.4107 eV, and from Eq. (17) the O^{2-} would take -27.3788 eV, so the ionic configuration $3H^+ + O^{2-}$ takes:

$$42.4107 - 27.3788 = 15.0319 eV$$

This is a solidly positive energy, and so the ionic configuration $3H^+ + O^{2-}$ for the hydronium ion $(H_3O)^+$ is not likely to occur.

But the hydronium ion $(H_3O)^+$ could also have the ionic configuration $3H^- + O^{4+}$. From Eq. (18), the $3H^-$ takes:

(26) $$3 \times (-90.6769) = -272.0307 eV$$

Following the pattern introduced at Eq (9), the O^{4+} takes:

$$IP_{1,1}[Z + \sqrt{Z(Z-1)} + \sqrt{Z(Z-2)} + \sqrt{Z(Z-3)}] / M_Z$$
$$+ [\Delta IP_{1,Z} Z - \Delta IP_{1,Z-4}(Z-4)] / M_Z =$$

$$14.250 \times [8 + \sqrt{8 \times 7} + \sqrt{8 \times 6} + \sqrt{8 \times 5}] / 15.999 +$$
$$[\Delta IP_{1,8} \times 8 - \Delta IP_{1,4} \times 4] / 15.999 =$$

$$14.250 \times [8 + \sqrt{56} + \sqrt{48} + \sqrt{40}] / 15.999 +$$
$$[13.031 \times 8 - 9.077 \times 4] / 15.999 =$$

$$14.250 \times [8 + 7.4833 + 6.9282 + 6.3246] / 15.999$$
$$+ [104.248 - 36.308] / 15.999 =$$

$$14.250 \times 28.7361 / 15.999 + 67.940 / 15.999 =$$
$$25.5947 + 4.2465 = 29.8411 \text{eV}$$

So the ionic configuration $3H^- + O^{4+}$ for the hydronium ion $(H_3O)^+$ takes:

$$-272.0307 + 29.8411 = -242.1895 \text{eV}$$

This is a robustly negative energy. It explains why the reaction product that accompanies EZ water *is* a hydronium ion, rather than a naked proton (14.1369 eV) next to a normal water molecule (-163.7925 eV), which would add up to -149.6556 eV, which, though negative, is not anywhere near as robustly so.

Together, the EZ water ion and the hydronium ion take:

$$-268.6204 - 242.1895 = -510.8099 \text{eV}$$

Compare this to three normal water molecules at -491.3775 eV. The EZ water ion together with the hydronium ion is favored over the three normal water molecules. That means nature stands poised to make EZ water ions and hydronium ions whenever it has the opportunity to do so.

It looks like what creates the opportunity is a surface – just about any surface – plus a little energy to separate the ions. Any planet with some gravity, and some energy source, plus some normal water, will automatically create EZ water. Even an asteroid or a comet might be able to do it.

On the Geometry of Chemical Species

Normal water is a bent molecule, with an Oxygen atom at the bend, and two Hydrogen atoms at the extremities. If we stick with the usually assumed ionic configuration of $2H^+ + O^{2-}$, then we have no good explanation for the bend. We have to suppose that the Oxygen atom somehow imposes the bend. But if we adopt the proposed alternative ionic configuration for normal water, $2H^- + O^{2+}$, then we easily explain the bend. It exists because $2H^-$ has two naked protons and two tight electron pairs: *four items*. So the normal water molecule is a tetrahedron. The lesson is: ionic configuration controls the geometry of chemical species.

This lesson must hold for EZ water ions too. Because the water angle ~109° is close to the hexagon angle 120°, EZ water ions approximately form a hexagon. Given the preferred ionic configuration $3H^- + 2O^+$, the approximate hexagon has $6H^-$ on the sides, and $6O^+$ at the corners, each with another attachment to another H^- imagined. If the ions begin with their ~109° bend, this hexagon begins slightly out-of-flat, with the O^+ alternating between slightly up and slightly down, relative to the H^- ions. In short, it begins as a little ruffle. It probably then relaxes to flat.

What gives the exclusion property to this EZ water? The ionic configuration of the EZ water looks important for that. Consider that an H^- ion is significantly larger than the previously presumed naked proton H^+, and the O^+ ion is *not* so significantly smaller than the previously presumed O^{2-} ion. As a result, the preferred ionic configuration $3H^- + 2O^+$ may be what provides the 'E' for EZ water!

Evidently, the EZ water hexagonal array can extend indefinitely, to macroscopic area. How can such *large-scale* spatial organization be understood electrically? Elia *et al.* (2013) expressed the opinion that short-range electrostatic interactions are not able to explain any form of spatial organization beyond the local scale of polar-molecule dissolution. And they were no doubt right about short-range electrostatic forces.

But AC looks at issues beyond electrostatic forces; it looks at the energy budget, including adjustments that electron populations make among themselves in forming ionic configurations. I believe that the full energy budget can speak to the issue of larger-scale spatial organization. The point is: every successive addition to the big hexagonal array lowers the total energy of the overall population of water species.

Evidently too, the EZ hexagonal array can form multiple layers, to make up an EZ of macroscopic thickness. Each EZ layer has net negative charge, and so must repel each other layer. But this effect is diminished if the hexagons in each layer are offset to those in neighboring layers. That way, there can be local attraction between layers.

Recall that the other ionic configuration for EZ water, $3H^+ + 2O^{2-}$, can also exist. It can stack in alternation with the preferred ionic configuration $3H^- + 2O^+$. But this stack will have the hexagon layers in registration, rather than offset. The resulting stack will have big hexagonal holes in it. So positive ions can re-penetrate, spoiling the EZ, and pushing the array toward zero net charge.

This other ionic configuration for EZ water, $3H^+ + 2O^{2-}$, has higher energy than $3H^- + 2O^+$, and so occurs more at higher temperatures. Its enhanced presence must correlate with normal water being in its liquid state, and its diminished presence must correlate with normal water being in its frozen state.

It is to be noted that, like EZ water, normal water in its frozen state also has some hexagonal structure to it. But normal water ice is charge-neutral, and it has its ions, whatever they are, such that the ratio of atoms is 2H to 1O . So normal water ice is actually quite different from EZ water.

One possible way to understand normal water ice is to go back to the little-ruffle image, but instead of imagining it to relax to a flat state, imagine it to stay ruffled. Let the ruf-fles stack with up corners out of synchrony to down corners, and let additional H^- ions cushion the resulting three tight spots. This plan makes the atom ratio correct, and makes the preferred ionic configuration for normal water $2H^- + O^{2+}$ work correctly for normal water ice too.

Technology Implications of Results

The next question in the present study is this: what if any of the molecules or ions discussed here had been created with some heavy nuclei included? That is, what happens to the ionic configurations if one Hydrogen atom H is replaced with a Deuterium D, or even a Tritium T?

To handle the issue of isotopes, we should recognize that the previously quoted Hydrogen mass $M_1 = 1.008$ is really an average over isotopes in the proportions that occur in Nature. To be more precise, we should distinguish between Hydrogen H with mass $M = 1$, and Deuterium D with mass $M = 2$, or even a Tritium T with mass $M = 3$. The basic information needed follows.

Where an H^+ ion takes:

$$IP_{1,1} \times 1 / M_H = IP_{1,1} \times 1 / 1 = 14.2500 \mathrm{eV}$$

a D^+ ion takes:

$$IP_{1,1} \times 1 / M_D = IP_{1,1} \times 1 / 2 = 14.250 / 2 = 7.1250 \mathrm{eV}$$

a T^+ ion takes:

$$IP_{1,1} \times 1 / M_T = IP_{1,1} \times 1 / 3 = 14.250 / 3 = 4.7500 \mathrm{eV}$$

The message is: heavier positive ions are easier to make.

Similarly, where an H^- ion takes:

$$-IP_{1,1} \sqrt{1 \times 2} / M_H - \Delta IP_{1,2} \times 2 / M_H =$$

$$-14.250 \times 1.4142 / 1 - 35.6250 \times 2 / 1 =$$

$$-20.1495 - 71.2500 = -91.3995 \mathrm{eV}$$

a D^- ion takes:

$$-IP_{1,1}\sqrt{1\times2}\,/\,M_D-\Delta IP_{1,2}\times2\,/\,M_D=$$

$$-14.2500\times1.4142\,/\,2-35.6250\times2\,/\,2=$$

$$-10.0762-35.6250=-45.7012\,\mathrm{eV}$$

a T^- ion takes:

$$-IP_{1,1}\sqrt{1\times2}\,/\,M_T-\Delta IP_{1,2}\times2\,/\,M_T=$$

$$-14.2500\times1.4142\,/\,3-35.6250\times2\,/\,3=$$

$$-6.7175-23.7500=-30.4675\,\mathrm{eV}$$

The message is: heavier negative ions are less rewarding to make.

That is all to the good, inasmuch as CF requires naked nuclei, *i.e.* positive ions, as reactants.

So can we get such reactants from water? In the case of normal water, we now know that the ionic configuration must be $2H^- + O^{2+}$, and not the previously presumed $2H^+ + O^{2-}$. The latter has a positive energy, and so does not occur naturally; it is probably what researchers call 'Brown's gas'.

But what about $D^+ + H^+ + O^{2-}$? We have above that D^+ takes 7.1250 eV, H^+ takes 14.250 eV, and from Eq. (17) O^{2-} takes -27.3788 eV. So $D^+ + H^+ + O^{2-}$ will take:

$$7.1250+14.2500-27.3788=-6.0038\,\mathrm{eV}$$

This energy is *negative*, unlike that for Brown's gas. So in heavy water, this ionic configuration *will* naturally occur.

Even better, we have above that T^+ takes 4.7500 eV, so $T^+ + H^+ + O^{2-}$ will take:

$$4.7500+14.2500-27.3788=-8.3788\,\mathrm{eV}$$

So in heavy water, this ionic configuration will occur naturally too.

In the case of EZ water, we know that, along with the more favored ionic configuration $3H^- + 2O^+$, the less favored $3H^+ + 2O^{2-}$ *can* exist naturally, and so probably *does* exist. So what about $D^+ + 2H^+ + 2O^{2-}$? That will take:

$$7.1250+2\times14.2500+2\times(-27.3788)=$$

$$7.1250+28.5000-54.7576=-19.1326\,\mathrm{eV}$$

Compare this to $3H^+ + 2O^{2-}$ with pure Hydrogen, at:

$$3\times14.250\,/\,1-54.7576=42.750-54.7576$$

$$=-12.0076\,\mathrm{eV}$$

The EZ ion with a Deuterium ion included is at *lower energy*, and so forms *more easily* than the one without Deuterium. This EZ ion will be preferred. So the action of forming EZ water can tend to concentrate the kind of reactant that CF requires.

But we should also look at the other ionic configuration for a deuterated EZ ion, $D^- + 2H^- + 2O^+$. From Eq. (12) the D^- takes:

$$-IP_{1,1}\sqrt{Z(Z+1)}\,/\,M_Z-\Delta IP_{1,Z+1}(Z+1)\,/\,M_Z$$

$$+\Delta IP_{1,Z}Z\,/\,M_Z$$

$$=-IP_{1,1}\sqrt{1\times2}\,/\,2-\Delta IP_{1,2}2\,/\,2+\Delta IP_{1,1}\,/\,2$$

$$=-14.250\times1.4142\,/\,2-35.625+0=-25.5486\,\mathrm{eV}$$

From Eq. (19), the $2H^-$ takes -181.8538 eV. From Eq. (24) the $2O^+$ takes $2\times7.9399=15.8798$ eV. So altogether, the ionic configuration $D^- + 2H^- + 2O^+$ takes:

$$-25.5486-181.8538+15.8798=-191.5226\,\mathrm{eV}$$

This is a solidly negative energy, so this ionic configuration would certainly dominate the EZ – until such time as an energy source is introduced. That source would be the electrodes that are inserted to start the CF attempt. The process is analogous to the process for making Brown's gas: electrochemistry. In the CF case, when the electrodes are introduced they supply some energy, and the EZ ions can then go to their less favored, higher-energy, ionic configuration, wherein the deuterons are exposed, and CF can then ensue.

This EZ story may play into a peculiar fact that is known about CF, but not yet understood: it generally goes better if the reactant heavy water is left to rest quietly for a long time before being used. This rest period was described as 'incubation' by Senior VP Frank Gordon at Global Energy Corporation, Annandale, VA, speaking at the 2010 Conference of the Natural Philosophy Alliance in Long Beach, CA. Since then, I have come to think that three important processes may characterize 'incubation': 1) Gravity sends water molecules with heavier isotopes to lower levels in the water container, thus concentrating them; 2) The bottom of the water container has a surface, and that encourages EZ formation there, further concentrating the heavy isotopes. 3) The stage is then set, but nothing dramatic can happen until electrodes are inserted, and a little energy is supplied.

Conclusion

In the long run, the results in this paper may be most useful for prompting even more challenges to long-held assumptions. Recall, for example, that it uncovered energetically favored ionic configurations for the normal water molecule and for the hydronium ion that are not the ones that everyone had previously assumed. The message is: *everything* should be reviewed anew.

The quantitative approach illustrated in this paper works for analyzing all chemical species, in all imaginable ionic configurations, and in all proposed reactions. It bestows 'Power to the People'. Readers: you too can more easily analyze chemical situations, understand what can occur naturally, and what cannot occur without assistance, and uncover questionable assumptions that everyone else has unwittingly accepted as truth. You can do it all with a hand calculator. (Amusingly, my own hand calculator can run on sunlight, just like the process that makes EZ water can do!)

Here is one last batch of questions to ponder: What will the phenomenon of EZ water ultimately mean to our ideas about states of matter? Supposing that EZ water is a fourth phase of water, we may well wonder if Brown's gas constitutes a *fifth* phase of water. But what about a plasma state? Perhaps Brown's gas is the *plasma* state of water. And what about CF? The EZ phenomenon could help or hinder CF, depending on circumstances, so one might sometimes need to *prevent* the EZ from forming. If so, how would one best do that?

Appendix

One reviewer of this paper discussed the idea of a 'Convention', which in Philosophy of Science is something very different from the idea of a 'Hypothesis'. A 'Scientific Hypothesis' is a statement that can, in principle, be tested, and falsified, in some experiment. By contrast, a 'Scientific Convention' is a statement that does not conflict with any prior experiment, but probably cannot be falsified by any conceivable future experiment.

So are the formulae of AC 'conventional', or are they 'testable'? I think they are probably 'conventional', inasmuch as they do not conflict with any experimental fact presently known to me, but I am hard-put to see how to falsify them experimentally.

It is, however, possible to tell more about where the formulae of AC came from. It is a long story. I have to go back to the late nineteenth century, and the then-developing science of Electrodynamics. People knew Maxwell's four first-order coupled field equations, and from them derived two second-order uncoupled wave equations, and noted that the combination of electric permittivity ε_0 and magnetic permeability μ_0 implied a wave speed: $c = 1/\sqrt{\varepsilon_0\mu_0}$.

People assumed that a 'signal' traveling from a source charge to a receiver would arrive 'retarded' by a time equal to the

separation distance between the source at emission and the receiver at reception, divided by the wave speed *c*. This assumption seemed so obvious that it did not merit much discussion.

Enter Einstein. In 1905, he formalized the assumption as his Second Postulate for the development of Special Relativity Theory (SRT), saying that the speed of light has the same value *c* for any observer at rest in any inertial frame of reference. Highlighting this previously rather hidden assumption was definitely a big step forward.

Einstein's Second Postulate is today the most famous example of a Scientific Convention. It cannot be falsified experimentally, because any experiment would involve more than one spatial location, and the Postulate itself would be needed to correlate the data from the different locations.

Also in 1905, Einstein studied the photo-electric effect, and identified what we now understand as the photon, and thereby contributed to the development of Quantum Mechanics (QM). This was a development that he truly did not like! In later years, Einstein retreated to the study of gravity, and developed General Relativity Theory (GRT), which extends SRT and ignores QM.

To this day, we have a conceptual conflict between SRT / GRT, with their speed limit *c*, and QM, with its instantaneous distant correlations. This conflict is a continuing annoyance for Chemistry, inasmuch as QM is *the* science for atoms and molecules, and we want to believe it, but the conflict nags the mind.

Why have we got this nagging problem? Well, just look at the important words involved in the conflicting theories. We have the 'signal' in SRT/GRT, and we have 'uncertainty' in QM. These are words that are characteristic of Information Theory (IT). But Claude Shannon was not on the scene with IT until the middle of the twentieth

century. So Einstein did not have any inspiration from IT.

Whenever something new, like IT, becomes available, it is incumbent upon us to review everything older, like SRT and QM. There could always be some hidden assumption that is important to recognize, as in electrodynamics before SRT, and possibly update, as in SRT, I believe.

One important thing that IT tells us is this: information cannot be conveyed by an infinite plane wave - any more than by a perpetual constant. Information transport requires structure; for example, pulses. So late nineteenth century electrodynamics and early twentieth century SRT used the worst possible model for signals. It simply cannot work.

Although nobody remarks on it, evidence that the infinite plane wave model does not work as a signal is plain for all to see in any modern textbook on electrodynamics. Look up the Liénard-Wiechert fields, electric **E** and magnetic **B**, created by a rapidly moving and accelerating charge. This is the so-called 'retarded' solution. Compare the direction of the Poynting vector, **E** × **B** of the $1/R$ radiation fields, to that of the $1/R^2$ Coulomb attraction/repulsion field. They do not align. Radiation comes from the retarded position of the source; Coulomb attraction/repulsion comes, approximately, from the *current* position of the source. In short, the 'torch' and the 'tug' conflict.

Once noticed, this conflict nags the mind. Can IT help us do any better? One way to construct a more IT-appropriate model is to look into using finite pulses instead of infinite plane waves as the signals. Einstein might have done this: signal = photon. But he didn't. We don't know why.

The first thing we learn is that pulses propagate undistorted with the second-order uncoupled wave equations, but not with Maxwell's first-order coupled field equations.

Instead, Gaussian pulses unfurl into higher- and higher-order Hermite polynomials multiplying Gaussians. There is a natural spread from original pulses into extended wavelets.

This natural spread means that the second-order equations are just not equivalent to the first-order equations; they allow additional solutions that are *not relevant* to our signal problem. It also means that the phrase 'propagation speed' becomes very ambiguous. What aspect of the waveform has the speed? The centroid? The median point? The peak?

The second thing we realize is that, with all the spreading that occurs, we need boundary conditions to avoid energy backflow at the source, and energy overflow at the receiver. We can, for example, make the E field always zero at the source and at the receiver. Then the energy is trapped, as if in a laser cavity; the propagation problem is well defined.

Note that in this vision of the signal problem, there is only one signal receiver; there is no multitude of equivalent inertial observers, each one receiving the same signal, each at speed c with respect to himself, as might be imagined in SRT. Extra observers all fall to Occam's razor.

With zero E at the source and at the receiver, the energy is trapped even if one, or the other, or both, boundaries will move relative to a stenographer-scientist describing the scenario. I believe it is possible to make some more precise statements about the signal speed. Near the source, the speed at which energy moves has to be c relative to the source; near the receiver, the speed at which energy moves has to be c relative to the receiver. And at the temporal midpoint of the scenario, the speed at which energy moves past that spatial midpoint has to be c relative to that mid point. The stated boundary conditions force all this behavior.

Having this clarifying role for boundary conditions means that standard nineteenth-century mathematics would have been relevant for SRT problems in the twentieth century, and will surely be recognized as relevant for such problems in the twenty-first century.

The third thing we realize is that the conventional assumption about retardation was too simple. The math reveals that the direction a signal travels in order to get from the source to the receiver aligns with the direction from the source to the receiver *at the temporal mid point of the scenario*. The math says this direction applies to both the Poynting vector of the radiation fields and the Coulomb attraction/repulsion. The formulae involved can be called the '*half*-retarded' solution.

This business about direction resolves the early twentieth-century worry that the Hydrogen atom ought to die of energy loss by radiation. There is not just one process going on in the Hydrogen atom; there are at least *three* processes going on. In addition to the familiar energy loss due to radiation from the accelerating electron, there is also torquing within the atomic system, electron plus nucleus, and this torquing provides energy gain. Also, there is an additional energy loss due to radiation because the whole system jitters about on account of zero-mean but instantaneously unbalanced forces (think of 'Zitterbewegung').

The balance between the two energy-loss mechanisms and the one energy-gain mechanism can explain the Hydrogen atom. Chapter 9 in Whitney (2013) works out the balance for the lightest isotope of Hydrogen. As a test, the result is checked for consistency with the known numerical value of Planck's constant h.

The formula given for the total energy loss rate due to radiation is:

$$(A1) \quad P_R = 2^5 e^6 / 3 m_e^2 c^3 (r_e + r_P)^4$$

where e is the electron charge, m_e is the electron mass, r_e is the electron orbit radius, r_P is the orbit radius for the pro-ton (with subscript capital P because the proton is so heavy compared to the electron). This formula is familiar except for a factor of 2^4, which arises from the center-of-mass Zitterbewegung, which was not traditionally considered. Yes, that means the main part of the radiation from a Hydrogen atom was not even known when people first worried that the atom ought to die of energy loss by radiation!

The formula given for the energy-gain rate due to torquing is:

$$(A2) \quad P_T = e^4 / m_P c (r_e + r_P)^3$$

where m_P is the mass of the proton. This formula is totally unfamiliar, because, with Einstein's Second Postulate, there can be no such torquing. That is the case because the Postulate leads to the Coulomb attraction/repulsion coming, approximately, from the *current* position of the source.

The formula then given for the electron-proton separation at the balance between energy loss and energy gain is:

$$(A3) \quad (r_e + r_P) \equiv 32 m_P e^2 / 3 m_e^2 c^2$$

The orbital energy of the electron is then:

$$(A4) \quad E_{\text{one electron in light Hydrogen}} = -e / (r_e + r_P)$$

For another element $Z \neq 1$, m_P in (A3) is replaced with the nuclear mass M_Z:

$$(A5)$$
$$(r_{\text{electron subsystem}} + r_{\text{nucleus}})_{\text{in element Z}} \equiv 32 M_Z e^2 / 3 m_e^2 c^2$$

The orbital energy of an individual electron is:

$$(A6) \quad E_{\text{one electron in element Z}} =$$
$$-e \times Z / (r_{\text{electron subsystem}} + r_{\text{nucleus}})_{\text{in element Z}}$$

which is then:

$$(A7)$$
$$E_{\text{one electron in element Z}} = (Z / M_Z) E_{\text{one electron in light Hydrogen}}$$

For ions, rather than neutral atoms, the one Z value in (A7) is replaced with the geometric mean of two Z values, one representing the nucleus, and the other representing the electron population as a whole. That is because the forces driving both the radiation and the torquing in the atomic system are Coulomb forces, and depend on the product of nuclear charge and electron-population charge. So the Z in (A7) is really $\sqrt{Z \times Z}$, and more generally it is $\sqrt{Z_{\text{nucleus}} Z_{\text{electrons}}}$.

Acknowledgments

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