Comment on 'Ultradense protium p(0) and deuterium D(0) and their relation to ordinary Rydberg matter: a review' 2019 Physica Scripta 94, 075005

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Abstract. The article by Holmlid and Zeiner-Gundersen (2019 *Physica Scripta* **94** 075005) contains a number of claims that explicitly or implicitly contradict fundamental knowledge of modern science. Some can only be true if long held conservation laws are broken. One such is baryon number conservation. A second fatal mistake is the treatment of the structure of molecules that disregard fundamental quantum mechanical aspects, such as the concept of kinetic energy operators and the Heisenberg indeterminacy relations.
Keywords: baryon number conservation, hydrogen phase diagram, quantum mechanics

1   Introduction

The article we comment on, which takes the form of a review, contains a large number of egregious statements and inferences beyond those explicitly addressed here. For the sake of space we address in this comment only those that deal with the violation of baryon number conservation, and with the treatment of aspects of molecular structure that completely ignore the laws of quantum mechanics that govern the structure of matter at this scale. We also include comments on the experimental work used by the authors.

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2   Baryon number conservation

Perhaps the most remarkable claim regarding the properties imputed to ultradense hydrogen (UDH) is the induction and even spontaneous occurence of nuclear reactions. Besides the claim of 'cold fusion' of deuterons in ultra-dense deuterium, protons (p) in the UDH are supposed to undergo the reaction

$$pp \rightarrow 3K \tag{1}$$

'K' here stands for 'kaon', a hadron, which can be either charged or neutral. The reaction is energetically possible. The mass of a proton is roughly 1 GeV/c^2, that of a K roughly 0.5 GeV/c^2, so there would be a surplus of 0.5 GeV/c^2 carried away as kinetic energy that is ultimately transferred to the decay products of the K-mesons, notably muons.

But the reaction violates a very fundamental law, namely that of the conservation of baryon number or, roughly speaking, that of the conservation of the total number of protons and neutrons in the universe. A violation of this conservation law has never been observed. Not in high energy particle physics experiments, nor in another other type of experiment. It has been the objective of dedicated experiments in large underground facilities (shielded from cosmic rays). They have all shown no proton decay and have established a lower limit of the proton lifetime of 3.6 10^{29} years. That means that no proton was seen to decay in one ton of protons during one year.

The authors suggest that the reaction above can occur as a rearrangement of the quarks in the two protons (six in total) into three sets of two quarks (the kaons). This is completely missing the point that kaons like all other mesons do not consist of a quark-quark pair but of a quark-antiquark pair. In other words, their suggested explanation completely disregards the difference between matter and antimatter. Moreover, kaons contain a type of quark with a property called strangeness and named strange quarks. Protons do not, and where the strange quarks in the reaction scheme all of sudden come from remains unexplained.

Summarizing this part, these claims by the authors are based on words 'borrowed' from well the well established field of high energy physics, and used completely out of context, with no justification and in violation of fundamental laws of nature.

3   Molecular structure of H$_2$

As another example of the disregard of well established facts, we want to mention the authors' treatment of the structure of the hydrogen molecule. This important molecule has been investigated in great detail, both experimentally and theoretically. A number of properties are listed, for example, in the NIST chemistry databook. The molecule has a ground state bond length of 0.74 Å. Holmlid and Zeiner-Gundersen (in the following HZG) claim the existence of another species of the hydrogen molecule with bond length 2.3 pm. In their Fig.1 the authors provide their understanding of how this very short bond length can come about. Their argument is that the molecule has six Coulomb interactions, the two e-e and nucleus-nucleus repulsions, and the four e-nucleus interactions (in passing we note that the HZG Eq. 1 is incorrect). The sum of these six interactions is then claimed to amount to

a binding, and that due to the increase of the Coulomb interaction with reduced distances, it will render smaller structures more stable than bigger structures.

This explanation begs the question of why there are any normal H_2 molecules. Somehow there must be a repulsive force at work. The answer is very well known and is of course the presence of the kinetic energy term for the electrons. This is what defines the size of the normal and, we can safely add, to date the only observed form of the H_2 molecule.

This can be illustrated without going into extensive calculations, even at the level of a particle in a box. Confining an electron will introduce a kinetic energy that varies with the inverse square of the size of the box. The kinetic energy term will therefore grow faster than the Coulomb terms will decrease (go more negative) when the molecular length scale is reduced. The two terms strike a balance at one value, and this is at the measured and generally accepted 0.74 Å bond length. Although simple, this argument against the simple counting argument of HZG is incontrovertible. It is based on scaling properties of the potential energy operator, in close parallel to the arguments used to derive the virial theorem. The counting of potential energy contributions of HZG is therefore irrelevant.

The bond length of 0.74 Å can even be understood simpler, as resulting from the uncertainty principle, or more specifically as the result of minimizing the total energy, which is the sum of the two types of terms: the kinetic energy of the electrons, and the Coulomb interactions. (The nuclear kinetic energy can be ignored here). The Coulomb interactions are the attractive electron-nucleus interactions, and the repulsive electron-electron and nucleus-nucleus interactions. Balancing these two then proceeds along the line of the above argument.

The above is an elementary textbook argument, but if more reason is needed to understand it, one can consider the hydrogen atom for an even clearer demonstration. In this atom, there is one potential energy and it is attractive. By the argument of HZG, there is therefore nothing to prevent this atom from collapsing to a structure where the electron is located on top of the nuclear charge. It should not be necessary to explain in any detail why such a suggestion is in disagreement with all we have learned about the structure of atoms and molecules the last 100+ years. Clearly, the same arguments also raise the question why the 2.3 pm molecules brought up by HZG should have any finite bond length at all.

The treatment of total molecular energies by HZG also includes an argument derived from considerations of the quantum mechanical wave function. The claim is that the counting of potential energy contributions is even more favorable than the simple picture in their Fig.1 is suggesting, because the electron-electron repulsion supposedly cancels. The argument of HZG is best given with a quote from their article (p.4, top of right column): 'With different spin states for the two electrons, they may fill the same space and one of the repulsive terms (−) disappears effectively.' What HZG seem to be saying here is that if the two electrons have opposite spins, the Hamiltonian will be changed as:

$$H \rightarrow H - \frac{e^2}{4\pi r_{1,2}} \qquad (2)$$

That is effectively a postulated interaction of the two electrons based on their spin projection that will completely cancel the Coulomb interaction between the two. It should not be

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necessary to point out that such interaction has never been observed, although if present it would be abundantly manifested in atoms, molecules and solid matter. A simple consequence of this suggestion is that the helium atom would have a ground state energy of exactly 8 times that of the hydrogen atom. The suggestion seems to be based on a simple misunderstanding of the nature of a multi-particle wave function (and notably of the Pauli principle). The claim is even implicitly contradicted by the authors themselves, who elsewhere claim that the postulated H(0) has a spin of 2. With a total of four elementary particles in the molecule (two protons and two electrons), each of spin 1/2, it is impossible for any pairs of those spins, and in particular the spins of the electrons, not to be aligned. This will render their postulated cancellation of the Coulomb interaction inoperative.

4   Experiments, measurements

Above we have concentrated on some of the extreme claims of the production and properties of so called ultra-dense hydrogen. These claims are disproportionate, compared to the experimental evidence given. The production of UDH is supposed to proceed through a catalytic process employing a standard, potassium doped, iron oxide catalyst producing clusters of various sizes of UDH. The UDH is then supposed to drip down on a metal surface. A common laser [1] then induces the explosive breakup of these clusters. The 'reaction products', both charged and neutral, are observed through measurements of their time-of-flight. The detectors are thin and thick scintillators, some covered with a 'catcher foil' ('to detect neutrals') placed at two distances from the target. A dynode at -7 kV accelerates the positively charged reaction products towards a scintillator in front of a photo-multiplier. Disentangling the peaks, assigning a mass and a kinetic energy to them is not straightforward, very hard to understand and not convincing. The postulated bond length of a few picometers, in particular, is calculated from the observation of flight times in mass spectra. The peaks which, noted in passing, have extremely poor resolution, are assigned without any argument to the protons emitted in a Coulomb explosion of the putatively extremely strongly bound new form of hydrogen. No attempt has been documented of any attempt to rule out any other explanation, for example the obvious suggestion that the spectra are due to charging up of the sample.

Finally, we want to address the stated numbers for the production rates of the ionizing radiation. The claim on meson production is based on 'Time-of-flight current muon signal to two collectors'. The analysis of the signal is reported with scant details. The interpretation in terms of kaon and pion production and subsequent decay into pions, however, is given with great certainty. Reactions are even claimed to be also taking place spontaneously, i.e. without exposure of the sample to laser light. Reaction yields are quantified as: 'The number of mesons observed in each laser pulse is as large as 10^{15}, which seems to be the highest meson intensity used anywhere in the world.' This is a truly astonishing statement for at least two reasons. One is that this production rate corresponds to an energy output of close to 240 kW with an input of 5 W laser light. Another is that it is made without

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[1]We quote: 'the laser most often used in our experiments here being a <0.5 J Q-switched laser with pulse length in the 5 ns range.'

any reference to radiation protection measures that should have been taken. This type of intensities will cause serious damage to living biological matter in the surroundings and even to the experimental equipment used.

5　Final comments

The paper of Holmlid and Zeiner-Gundersen makes claims that would be truly revolutionary if they were true. We have shown that they violate some fundamental and very well established laws in a rather direct manner. We believe we share this scepticism with most of the scientific community. The response to the theories of Holmlid is perhaps most clearly reflected in the reference list of their article. Out of 114 references, 36 are not coauthored by Holmlid. And of these 36, none address the claims made by him and his co-authors. This is so much more remarkable because the claims, if correct, would revolutionize quantum science, add at least two new forms of hydrogen, of which one is supposedly the ground state of the element, discover an extremely dense form of matter, discover processes that violate baryon number conservation, in addition to solving humanities need for energy practically in perpetuity.

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