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SHORT COMMUNICATION

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Are claims of cheap muon production correct?

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Abstract

Background Muon catalyzed fusion is a process, whereby isotopes of hydrogen undergo nuclear fusion thanks to a muon replacing an electron bringing the nuclei within fusion distance. The muon is then ejected and can facilitate a next fusion process. 'Break even' has not been achieved yet in spite of the optimization of isotope mixtures and initial muon energy. A main limiting factor is the muon lifetime and the cost in energy of accelerator-based muon production. The possibilities would receive an immense boost toward practical applications if a cheap muon source could be constructed. We challenge a recent publication claiming to have constructed a very intense, yet very 'cheap' muon source.

Main text A recent publication in this journal (Holmlid in Energ Sustain 12:14, 2022, 10.1186/s13705-022-00338-4) promotes the idea that such a source has been constructed and demonstrated. The suggestion is based on a long series of articles by the same author as main investigator. They all center around a spectacular new aggregation state of hydrogen, so called ultra-dense hydrogen (UDH). The claims in the article (Holmlid in Energ Sustain 12:14, 2022, 10.1186/s13705-022-00338-4), as well as in the previous articles, are based on speculations going far beyond the experiments they purport to explain, and on a striking disregard of very well-established facts, both concerning conservation laws, elementary quantum mechanics and the phase diagrams of hydrogen. There are strong arguments why the claimed muon production does not occur and that the suggested evidence for it is a collection of instrumental artefacts.

Conclusion The muon source suggested by Holmlid (Energ Sustain 12:14, 2022, 10.1186/s13705-022-00338-4) does not produce any muons.

Keywords Muon catalyzed fusion, Muon source, Energy non-conservation

Background

The question of a reliable and non-polluting energy supply has been a major issue for a number of decades, and has acquired renewed importance in view of recent considerable geopolitical changes. Every technologically feasible proposal to contribute to the long-term goal of secure and clean energy production can only be welcomed. One long-term effort is the creation of the technology needed for controlled nuclear fusion. Several strategic venues are being or have been pursued in this quest; magnetic confinement, inertial confinement and muon catalyzed fusion, with the latter being the one relevant here. For a review, see, e.g. [2], and for recent work, we refer to [3].

From the outset, we would like to emphasize that this comment is not intended as a critique of muon catalyzed fusion per se. Neither is it a comprehensive review of the

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status of present knowledge and research in this field. We merely want to emphasize that the muon source that has been advertised in a recent publication [1] is not based on solid and credible experimental results, and it is no realistic avenue for furthering the field of muon catalyzed fusion.

Muon catalyzed fusion refers to the process in which a negative muon (μ^-) is injected into a mixture of hydrogen isotopes and through a series of steps forms a diatomic ion with the μ^- replacing the electron as the binding particle. Due to the large mass of the muon, about 200 times that of the electron, the distance between the nuclei is reduced to the extent that fusion can occur. The most promising reaction involving muon catalyzed fusion utilizes mixtures of deuterium and tritium resulting in the reaction $(t^+d^+\mu^-) \rightarrow {}^4He^{2+} + n + \mu^-$ The released energy is 17.6 MeV.

Muon catalyzed fusion was first observed in 1956 in a serendipitous discovery [4, 5] in a bubble chamber filled with liquid hydrogen, contaminated by small amounts of deuterium. From the point of view of fundamental physics, the involved phenomena are all well-understood and well-established. The main problem with the use of this method for a practical source of energy is the limited number of fusion reactions that a muon can catalyze (currently calculated to be about 150), primarily due to the muon sticking to the alpha particle about once every 200 reactions. An intense and cheap source of muons would go a long way to making muon catalyzed fusion practical.

A recent publication [1] claims experimental proof of principle of a high intensity muon source that operates at practically no energy cost, of 0.25 MeV per produced muon (calculated below). The source is based on a postulated new aggregation state of hydrogen, so-called ultra-dense hydrogen (UDH), claimed to have been discovered in 2009 (for deuterons) [6] and 2013 (for protons) [7].

Main text

To be technologically interesting, ideas must by necessity be scientifically sound. This is where ref. [1] fails. The postulated source is based on reactions in the so-called ultra-dense hydrogen, located on a surface in the experimental chamber. The claims on the properties of ultra-dense hydrogen would imply revolutionary new physics, if true, and it is worth listing some of the most important ones. The properties of UDH reported by Holmlid and collaborators vary a little over time, but can be summarized as:

- The interatomic (proton–proton or deuteron–deuteron) distance is 2.3 pm (2.3×10^{-12} m), although values down to 0.56 pm are also mentioned.
- The stated density is 1000 kg/cm^3 for some types.
- UDH is claimed to be superconducting and superfluid not only at but also several hundred kelvin above room temperature.
- UDH is claimed to be the most stable material that exists.
- It is claimed that it is easy to start nuclear reactions in UDH using a standard nanosecond (0.4 J/pulse) laser. In addition, spontaneous multi-MeV particle production is claimed to occur.
- It is claimed that UDH is a prolific muon source operating at almost no cost in energy.
- Muons are supposedly produced through the decay of K-mesons and π-mesons; these in turn are postulated to result from proton-antiproton annihilation; also proton–proton annihilation is mentioned as a possible mechanism for muon production. In [8], for example, the reaction $pp \rightarrow 3K$, two protons give three kaons, the kaons subsequently decaying to muons, is claimed to be the source of muon production. This reaction violates the very well-established experimental fact of baryon number conservation.

The purported properties of the ultra-dense hydrogen are all based on measurements of flight times of charged particles emitted from hydrogen-covered surfaces. The time-of-flight spectra produced in these experiments are poorly resolved, with a resolution on the order of $\Delta m/m \sim 1$, and it is difficult to make strong conclusions even about the identity of the emitted particle. It does seem to be closer to a mass of two u than the one u claimed by Holmlid, however. It is consistent with a deuterium nucleus or an H_2^+ molecule emitted from a charged surface. For details, please see ref. [9]. Similar hyperthermal emissions appear frequently from poorly grounded surfaces in laser desorption experiments. The charging of such surfaces occurs by electron emission caused by the extremely strong electric fields in a laser pulse, and are the most likely explanation for the observed fast ions.

The explanation suggested by Holmlid is that the kinetic energy can be identified with the Coulomb energy 'of Coulomb explosions' of two very nearby hydrogen nuclei that have been stripped of both electrons in some unspecified ionization process, and which thereby gives a measure of the internuclear distance.

Apart from being built on a very shaky experimental ground, this suggestion is contradicted by the fact that this, the postulated most stable allotrope of hydrogen, is completely absent from the phase diagram of the element. Likewise, the conjectured properties of the UDH, such as the minuscule bond lengths, have no resemblance to the solutions of the Schrödinger equation for the hydrogen molecule, which displays usual chemical bond lengths and strengths and excitation energies.

The UDH is postulated to be needed for the operating muon source. Strikingly, no property of the postulated UDH is invoked to explain the postulated muon production scheme. The energy required for driving the muon production is given as provided by a proton-antiproton annihilation process (the earlier proton–proton annihilation seems to have been abandoned). There is no suggestion about the origin of the antiproton. Either it is generated by the laser pulse in an unspecified process and in violation of baryon number conservation. Or, alternatively, the process is driven by a proton–antiproton creation process. This first and crucial step is simply postulated to have happened without any indication of how.

In either case, the process is also violating energy conservation or at least extracting energy from the UHD in a completely unexplained way. With a laser pulse of 0.4 J and a production of 10^{13} muons of mass 106 MeV/c^2 per pulse (where c is the speed of light), the output exceeds the input by a factor of 400, if the muons would be produced at rest (they are claimed to have momenta up to 100 MeV/c). Therefore, in reality, the factor of 400 is even larger. The energy conservation principle would correspond to the total energy cost of production of a single muon at rest of 106 MeV/400 $\approx$ 0.25 MeV. Moreover, it does not take into account the energy of unobserved escaping neutrinos.

An obvious suggestion for the signal Holmlid measures in his detector and assigns to muon detection is electronic noise. A good candidate for this noise is the laser. The Q-switch of lasers with 0.4 J pulses gives a very clear electric noise signal when triggered. The duration of these noise pulses is typically on the order of 10 ns, with a sharp onset in time. Similar to the signal observed by Holmlid, such noise signals are predominantly but not entirely exponentially decreasing. The fitted lifetime curves are, therefore, no proof of the production scheme. The same concern has already led to the retraction of one paper by L. Holmlid (see ref. [10]).

We note that the muon production, which is claimed to have a rate up to 10^{14} s^{-1}, is operated without any radiation protection measures in place. The absence of serious radiation damage to people and equipment by this extremely high amount of ionizing radiation is perhaps best explained by the author himself. In [11] the author states that a Geiger–Müller counter held close to the source does not register any radiation. We remind the reader that this counter detects single high energy particles, and we find that this statement makes a very good argument that the putative source does not in fact produce muons.

The explanation for the signal seen in the detector and interpreted as high energy particles by Holmlid appears not only when a laser is triggered. As claimed in [12], nuclear reactions (not 'just' fusion but also and in particular meson production) can be ignited by switching on a fluorescent lamp. This is in our mind a very good indication that the measured signal is an instrumental artefact, i.e., noise.

Conclusions

We have commented on a recent paper [1] containing claims on a practical solution for industrial energy production through muon catalyzed fusion of hydrogen isotopes. Although its appeal is understandable, the results in the paper are untenable.

Arguments for the existence of UDH take the form of unsubstantiated conjectures about interpretations of rather sparse and very low quality experimental results, in addition to theoretical conjectures based on cartoons of simplistic geometric shapes, without a beginning of a quantitative model. No logical or in any way compelling or convincing connection exists between the experimental results and the conclusions drawn. This holds for the UDH and the muon production separately, and for the connection between the two. The experimental evidence for the existence of either of these aspects of the source is flimsy at best and bears the hallmark of instrumental artefacts. The suggested violation of very well-established conservation laws and the complete disregard of a century of physical chemistry and quantum mechanics does little to bolster confidence in the claims made in [1].

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