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On the idea of low-energy nuclear reactions in metallic lattices by producing neutrons from protons capturing "heavy" electrons

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Abstract. The present article is a critical comment on Widom and Larsens speculations concerning low-energy nuclear reactions (LENR) based on spontaneous collective motion of protons in a room temperature metallic hydride lattice producing oscillating electric fields that renormalize the electron self-energy, adding significantly to the effective electron mass and enabling production of low-energy neutrons. The frequency and mean proton displacement estimated on the basis of neutron scattering from protons in palladium and applied to the Widom and Larsens model of the proton oscillations yield an electron mass enhancement less than one percent, far below the threshold for the proposed neutron production and even farther below the mass enhancement obtained by Widom and Larsen assuming a high charge density. Neutrons are not stopped by the Coulomb barrier, but the energy required for the neutron production is not low.

1 Introduction

The present article is a critical comment on an article by Widom and Larsen [1], where the authors suggest the possibility of low-energy nuclear reactions (LENR) on metallic hydrid lattice surfaces by producing low-momentum neutrons from protons that capture "heavy" electrons. The electron mass enhancement is obtained from electromagnetic field fluctuations produced by collective motions of the surface metallic hydride protons.

The local electronic mass enhancement factor threshold for neutron production is $\beta > 2.531$. It corresponds to an electron energy increase of 0.78 MeV and is related to the oscillating electric field as

$$\beta(\mathbf{r}) = \sqrt{1 + \frac{\overline{|\mathbf{E}(\mathbf{r},t)|^2}}{\mathcal{E}^2}}\,, \qquad \text{where} \qquad \mathcal{E} = \frac{M_\mathrm{e} c\tilde{\Omega}}{e} \tag{1}$$

and $\tilde{\Omega}$ is the oscillation frequency scale. The fluctuating electric field is related to the electron velocity through $e|\mathbf{E}(\mathbf{r},t)| = \beta M_\mathrm{e}\tilde{\Omega}|\mathbf{v}_\mathrm{e}(\mathbf{r},t)|$, leading to

$$\beta(\mathbf{r}) = \frac{1}{\sqrt{1 - \frac{\overline{|\mathbf{v}_\mathrm{e}(\mathbf{r},t)|^2}}{c^2}}}\,. \tag{2}$$

A characteristic frequency $\tilde{\Omega} = e\mathcal{E}/M_\mathrm{e}c \approx 8.2 \times 10^{13}\,\mathrm{s}^{-1}$ was estimated on the basis of neutron scattering from protons in palladium yielding the characteristic electric field in (1),

$$\mathcal{E} \approx 1.4 \times 10^{11}\,\mathrm{V/m}. \tag{3}$$

The neutron scattering data also provided an estimate of the mean proton displacement

$$\sqrt{\overline{|\mathbf{u}(\mathbf{r},t)|^2}} \approx 4.2a \approx 2.2 \times 10^{-10}\,\mathrm{m} = 2.2\,\text{Å}. \tag{4}$$

The protons also oscillate with the fluctuating field, according to their equation of motion,

$$\mathbf{E}(\mathbf{r},t) = \frac{M_\mathrm{p}}{e}\ddot{\mathbf{u}}(\mathbf{r},t) = -\frac{M_\mathrm{p}}{e}\tilde{\Omega}^2\mathbf{u}(\mathbf{r},t), \tag{5}$$

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which gives the electric field in terms of the measured quantities. This field acts on all involved oscillating particles and may be used to evaluate the electron mass enhancement β.

Equation (5) is similar to an equation describing proton oscillations in a stationary electric field inside a sphere of constant charge density,

$$\mathbf{E}(\mathbf{u}[t]) = \frac{M_\mathrm{p}}{e}\ddot{\mathbf{u}}(t) = -\frac{M_\mathrm{p}}{e}\tilde{\Omega}^2\mathbf{u}(t), \tag{6}$$

which is specific for each proton. It represents oscillations of one proton with all other charges fixed! With the correct choice of charge density, the magnitude of this field may coincide with the field relevant to eq. (1).

Widom and Larsen used eq. (6) with an estimated electron number density $\tilde{n} = 1/\pi a^3$, where $a \approx 0.5292\,\text{Å}$ is the Bohr radius, and arrived at

$$\sqrt{\overline{|\mathbf{E}|^2}} \approx 2.9 \times 10^{12}\,\mathrm{V/m} \qquad \text{and} \qquad \beta \approx 20.6, \tag{7}$$

corresponding to an electron kinetic energy of $\approx 10\,\mathrm{MeV}$! The threshold for neutron production appears to be satisfied with margin.

However, eqs. (5) and (6) both give the electric field in terms of proton displacement and oscillation frequency, yielding

$$\sqrt{\overline{|\mathbf{E}|^2}} \approx 1.5 \times 10^{10}\,\mathrm{V/m} \qquad \text{and} \qquad \beta \approx 1.005 \tag{8}$$

and $v_\mathrm{e} \approx 3 \times 10^7\,\mathrm{m/s}$, very far below the threshold for neutron production! The charge density chosen by Widom and Larsen cannot be correct!

2 Proton oscillations

The fluctuating electric field can be determined from the measurements of the proton oscillations according to eq. (5), but Widom and Larsen chose to model it with a proton oscillating in the stationary electric field described by eq. (6). They argued that their eq. (21) holds true in the fully quantum mechanical theory if the electron density $\tilde{n}$ represents the electron density at the proton position [1]. In that model, the electric field is given by the estimated charge density and Coulombs law (in SI units),

$$\mathbf{E}(\mathbf{u}) = -\left(\frac{e\tilde{n}}{3\varepsilon_0}\right)\mathbf{u}, \tag{9}$$

and thus their eq. (21) becomes

$$\tilde{\Omega}^2 = \frac{e^2\tilde{n}}{3M_\mathrm{p}\varepsilon_0}\,. \tag{10}$$

Their choice of charge number density $\tilde{n} = 1/\pi a^3 = 2.26 \times 10^{30}\,\mathrm{m}^{-3}$ yields $\tilde{\Omega} \approx 1.14 \times 10^{15}\,\mathrm{s}^{-1}$, far from the measured frequency.

The normal palladium lattice configuration is face-centered cubic with a density of $6.78 \times 10^{28}\,\mathrm{m}^{-3}$, a lattice spacing of 3.89 Å, and a distance to the nearest neighbour 2.75 Å. With 46 electrons per atom, the average electron density is $\approx 3.1 \times 10^{30}\,\mathrm{m}^{-3}$, including the hydrogen electrons, it is somewhat higher. The average electron density is of the same order of magnitude as the choice of the authors, but the sphere enclosing the proton displacement also contains a large number of protons, in the palladium nuclei and the oscillating protons. The electrostatic force on a single proton would have a lowest-order contribution from the total charge $-e$!

From eq. (10) we may instead evaluate the charge number density corresponding to the observed oscillation frequency, yielding $\tilde{n} \approx 1.16 \times 10^{28}\,\mathrm{m}^{-3}$, corresponding to a charge in an $r = \sqrt{\overline{|\mathbf{u}(\mathbf{r},t)|^2}} \approx 4.2a$ sphere of $\approx -0.5e$ and $-1.4e$ in a $r = 6a$ sphere covering the full oscillation orbit.

We may conclude that the electrostatic approach may give results close to reality, but as eq. (5) gives the fluctuating field directly, the electrostatic approach has little to add but confusion.

Combining (1) with (5) yields the neutron production threshold in terms of the measured quantities $\tilde{\Omega}$ and $\sqrt{\overline{|\mathbf{u}|^2}}$,

$$\frac{\sqrt{\overline{|\mathbf{E}(\mathbf{r})|^2}}}{\mathcal{E}} = \frac{M_\mathrm{p}}{M_\mathrm{e}c}\tilde{\Omega}\sqrt{\overline{|\mathbf{u}|^2}} = \sqrt{\beta^2 - 1} > 2.325, \tag{11}$$

leading to a threshold for the mean proton velocity,

$$v_\mathrm{p} = \tilde{\Omega}\sqrt{\overline{|\mathbf{u}|^2}} > 3.8 \times 10^5\,\mathrm{m/s}, \tag{12}$$

corresponding to $\approx 750\,\mathrm{eV}$ mean proton energy.

From the neutron scattering data we get

$$v_\mathrm{p} = 1.8 \times 10^4\,\mathrm{m/s}, \tag{13}$$

which is clearly far too low and still significantly higher than thermal velocity at room temperature. The corresponding electron velocity is $v_\mathrm{e} = 3.3 \times 10^7\,\mathrm{m/s} \approx 0.11c$.

3 Low-energy nuclear reactions

The title of Widom and Larsens article reads "Ultra low momentum neutron catalyzed nuclear reactions". Such reactions have been known for 80 years. They are utilized in fission reactors where the neutrons really acts as catalysts, since each reaction produces new neutrons enabling a chain reaction.

The authors speculate about spontaneous collective motion in a room temperature metallic lattice of surface metallic hydride protons producing oscillating electric fields that renormalize the electron self-energy, adding significantly to the effective mass and enabling production of low-energy neutrons.

A number of objections can be raised against their treatment of the subject:

1) While proton oscillations and surface plasmon polaritons can exist in metal lattices, they need energy to grow! To reach the necessary electron mass enhancement, each oscillating electron needs 0.78 MeV, which is not readily available in a room temperature metal lattice.
2) The fluctuating electric field evaluated from the neutron scattering data on proton oscillation frequency and displacement is far from adequate for reaching the threshold for neutron production. In the neutron scattering experiment, the proton energy appears to be higher than room temperature thermal. The energy in this case most likely is provided by the diagnostic neutron beam.
3) The authors point out the importance of avoiding the Coulomb barrier, but they provide no discussion of the energy needed. The electrons will lose energy by competing interactions in the metal lattice. Only a small fraction of the electrons may produce neutrons and we must take all competing mechanisms into account. Reaching the threshold probably requires a substantial energy input by particle beams or infrared lasers.
4) Widom and Larsens exercise with the stationary electric field could have led to the correct electric field strength using the measured frequency and displacement in eq. (6), but they failed to realize that. They referred to violation of the Born-Oppenheimer approximation to explain the lack of Coulomb screening needed to get the high charge densities assumed. However, the positive charges in the lattice nuclei and the protons cannot be neglected to the extent the wish, as demonstrated by the neutron scattering data. The stationary field approach also caused confusion since they omitted the time dependence in their eq. (16), which obscured the relation between the electric field and the electron oscillation energy.
5) They referred to violation of the Born-Oppenheimer approximation to explain the lack of Coulomb screening needed to get the high charge densities assumed. However, the positive charges in the lattice nuclei and the protons cannot be neglected to the extent they wish, as demonstrated by the neutron scattering data.
6) They do not disclose the measured frequency explicitly, in these comments it is evaluated from eqs. (1) and (3). In a later publication [2] the authors note that "for metallic hydride surfaces upon which plasma oscillations exist, typical values for the surface plasmon polariton frequencies are in the range $(\hbar\Omega/e) \approx (5-6) \times 10^{-2}\,\mathrm{V}$". This yields $\Omega \approx (8-10) \times 10^{13}\,\mathrm{s}^{-1}$.
7) Their habit of mixing SI and Gaussian units in the equations in the equations obscures the evaluation process.
8) In addition to the energy threshold for neutron production, we must look at the cross-section for the reaction. This is not discussed in [1], but in [2]; the authors provide an estimate of $v\sigma$ in the limit of vanishing initial relative velocity. However, with relativistic electrons the reaction rate would be severely reduced. A relativistic electron must come very close to a proton to be captured. At larger distances the electron will transfer energy to the proton.

The behaviour of beta decay of a neutron and the reverse process $\tilde{e} + p \to n + \nu_e$, due to the weak interaction, in the presence of an electric field has been considered in detail in the literature [3,4]. A compact expression for the total probability for a process perturbed by a laser field was investigated as a function of the field intensity and frequency. The main conclusion is that even in strong laser fields the effects are negligible.

4 Conclusions

It is very unlikely the electron energy threshold for neutron production can be reached in a metal lattice system without a substantial energy input. Even if the threshold field is reached the high velocities of the relativistic electrons will severely reduce the reaction rate and make the reverse beta decay reaction very rare.

The neutron scattering data used by the authors to demonstrate the concept rather demonstrate its failure. Their claim of obtaining low-energy nuclear reactions in metallic lattices and their other conclusions are based on a number of fallacies and an obscuring way of handling the equations.

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