Comment on "Hydrogen-Antihydrogen Collisions"

For the prototype of matter/antimatter interactions (1a)

\[ H + H \rightarrow [HH] \rightarrow \text{pp} + e^e \]  

(1a)

Froelich et al. found [1] that HH, like an atom molecule [2], can survive longer than expected. Unfortunately, they did not calculate the PEC (potential energy curve) of intermediate 4-fermion complex HH, which is very close to that of \( H \) [3]. This places constraints on matter/antimatter reactions in general and on \( HHH \) in (1a) in particular. A perfect Babel of tongues on conventional "matter" results when considering matter/antimatter reactions like

\[ \text{Ps} + \text{Ps} \rightarrow \text{PsPs} \]  

(1b)

CP-symmetries in neutral N-particle systems (N=2,3,4), with centers of mass \( c_M \) and of charges \( c_C \), illustrate this:

(i) \( N=2; \) short living \( (10^{-12} \text{ sec}) \) charge-conjugated pairs \( \text{Ps} \) (positronium Ps, protonium Pn); \( c_M \) and \( c_C \) coincide. Pseudo atom \( \text{Ps} \) is stable, energy and spectrum derive from Bohr theory. \( \text{Ps} \) belongs to the "matter" domain, although it consists of equal amounts of matter and antimatter (eqg). By symmetry, \( \text{Ps} \) may be classified as antimatter. But if \( \text{Ps} \) is "matter", \( \text{antispositronium Ps} \) is "antimatter" (see below). Mass-asymmetrical pairs \( \text{p}e \) in \( H \) are stable.

(ii) \( N=3; \) charge-conjugated pairs in atom molecules; \( c_M \) near \( c_C \). Antiprotonic helium \( \text{He}^\text{p} \) has a lifetime of \( \mu \text{sec} \), longer than \( \text{Ps} \). It is new "matter" [2]. Antiparticle \( \text{He}^\text{p} \) is not (yet) observed. In (i)-(ii), "matter" is a matter/antimatter pair.

(iii) \( N=4; \) atom/antiatom pairs as in (1); \( c_M \) and \( c_C \) do not coincide. Molecules \( XX \), if stable, are "matter" and building blocks are matter/antimatter pairs. C-symmetry in atom and antiatom is broken by lepton/nucleon mass difference. Annihilation is hampered and lifetimes may equal or exceed that in (ii). Even mass symmetrical \( N=4 \) systems like \( \text{Ps}_2 \) in (1b) are believed to be stable [4] (see also below).

If, in reality, "matter" consists of matter/antimatter pairs, this leads to confusion. Neutrality requires 1/1 contributions in terms of charges not of masses. Short lifetimes apply if \( N=2 \) and \( c_M \) coincides with \( c_C \). But simply rotating \( \text{Ps} \) gives \( \text{Ps} \) due to mass symmetry. Comparing all forms as in (1c)

\[ \text{Ps}_2(\uparrow\downarrow) + \text{Ps}_2(\downarrow\uparrow) \rightarrow \text{PsPs}(\uparrow\downarrow) + \text{PsPs}(\downarrow\uparrow) \]  

(1c)

gives symmetric/asymmetric parallel dipole alignments. Internal C-symmetry in \( \text{Ps} \), becomes a P-symmetry effect, \( \text{PsPs} \). By mirror-symmetry and with respect to the \( \text{PsPs} \), \( \text{Ps} \) is left- \( \text{Ps} \) and \( \text{Ps} \) right-handed \( \text{Ps} \) (or vice versa). As with \( \text{Ps} \), \( \text{PsPs} \) is either matter or antimatter. Is it also stable "matter"? If \( R \) separates the centers of mass (or charge) and if \( a \) is the \( \text{Ps} \)-radius, interactions V(R) in (1c) for \( R >> a \) are

\[ V_{+\downarrow}(R) = -2e^2/R + 2e^2/\sqrt{R^2 + 2a^2} = -2e^2/R^3 \]  

(2a)

\[ V_{-\uparrow}(R) = -V_{+\downarrow}(R) = (-1)^3V_{+\downarrow}(R) = +2e^2/R^3 \]  

(2b)

if parity operator \( p=1 \). With (2a), stable "matter" \( \text{Ps} \) [4], not yet observed [5], is matter/antimatter pair \( \text{PsPs} \).

Operator \( p \) in 4-fermion Hamiltonians leads generically to singlet-triplet splitting [3]. The drastic effect of Coulomb interactions (2) applies to 4-fermion complexes in (1), not to the threshold 2-fermion systems. But, unlike in \( \text{Ps}_2 \), rotation has a different effect on energy than inversion of charges if \( c_M \) and \( c_C \) do not coincide, as in \( HHH \) [3]. In cold atom region \( R/r_c = 20 \), difference is 0.01 cm\(^{-1} \) in favor of a charge-inverted state [3]. Matter/antimatter pair \( HHH \) in (1a) can also be "matter" with not too short a lifetime [1]. This might explain why an \( HHH \)-PEC matches the observed \( HHH \)-PEC [3]. Chemical gaps \( a^2\mu c^2 \). Coulomb thresholds \( \varepsilon/R \) for mass asymmetrical charge-conjugated ion pairs \( XX \), are \( 10^7 \) times annihilation gaps \( m_NS^0 \) [3].

The 4 different particles \( p, p, e \) and \( e \) in \( HH \) secure its \( c_M \) is prochiral, which explains generally why chirality/left-right asymmetry is so important when complex matter is formed from diatomic bonds (bio-molecules, DNA...). With \( H \), this 2\(^\text{nd} \) order stereo-directing effect can only show in \( \text{intermolecular HH} (H_2^+) \) reactions leading to liquid, solid and, eventually, metallic hydrogen.

Nature prefers unconventional charge distributions in \( N=4 \) neutral positive mass systems, which result in anti-symmetric matter/antimatter interactions in a generic way and, finally, in stable "matter" [3]. More [3,4] or less [1,2] stable micro-scale antimatter-domains exist close to matter-domains. The universe consists mainly of hydrogen. Stable micro-scale "matter" \( HH \) gives matter/antimatter symmetry for the universe on the macro-scale [3]. This avoids having to look for large-scale antimatter-domains at large distances (Mpc) from matter-domains [6] to conserve this symmetry.

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[1] P. Froelich et al., Phys. Rev. Lett., 84, 4577 (2000)
[2] T. Yamazaki et al., Nature, 361, 238 (1993)
[3] G. Van Hooydonk, Spectrochim. Acta A, in press, astro-ph/0003285
[4] E. A. Hylleraas, A. Ore, Phys. Rev., 71, 493 (1947); J.-M. Richard, Phys. Rev. A, 49, 3573 (1994)
[5] but see J. Usukura et al., Phys. Rev. A, 58, 1918 (1998)
[6] A. G. Cohen et al., Astrophys. J., 495, 539 (1998), astro-ph/9707087; M.Y. Khlopov et al., Phys. Rev. D, in press, hep-ph/0003285