ON THE POSSIBILITY OF DETECTING SUPERHEAVY HYDROGEN THROUGH CENTRIFUGATION AND ATOMIC SPECTROSCOPY

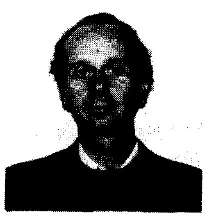
(presented by M. SPIRO)

B. Pichard, J. Rich, M. Spiro,
DPhPE, CEN-Saclay, 91191 Gif-sur-Yvette Cedex, France

F. Biraben, G. Grynberg, P. Verkerk,
Laboratoire de Spectroscopie Hertzienne de l'E.N.S.
Université P. et M. Curie,
4 Place Jussieu, 75252 Paris Cedex 05, France

M.E. Goldberg,
Unité de Biochimie des Régulations Cellulaires
Institut Pasteur
28 rue du Docteur Roux, 75015 Paris, France

P.Fayet,
Laboratoire de Physique Théorique de l'E.N.S.
24 Rue Lhomond, 75231 Paris Cedex 05, France



ABSTRACT

We discuss a theoretical[1] framework in which superheavy hydrogen atoms could exist and propose an experiment to search for such atoms through centrifugation of water followed by atomic spectroscopy. The experiment should be able to observe heavy atoms in the mass range 10^4 - 10^8 a.m.u. provided that their concentration relative to ordinary hydrogen is greater than $\sim 10^{-25}$. This should improve by at least 5 orders of magnitude the sensitivity of the detection compared to previous results in this mass range.

Particle physics theories, such as supersymmetric theories, suggest the possible existence of heavy stable charged X^+ particles. Superheavy hydrogen atoms could then be formed with these particles as nuclei. Early on during the Big-Bang, these particles would have been in thermodynamical equilibrium with other particle species. As long as the temperature was well above the energy threshold corresponding to their mass, their density would have been of the same order as the density of photons. Upon cooling, most of them should annihilate with their antiparticles, and surviving X^+ particles would trap electrons to produce superheavy hydrogen atoms with about the same binding energy and chemical properties as ordinary hydrogen atoms. On Earth, hydrogen atoms are mostly found in water. It is reasonable to expect that this should also be the case for superheavy hydrogen atoms, as long as their masses are lower than $\sim 10^8$ amu (or GeV/c^2) [1]. Note that X^- particles could also exist in the Universe. They would combine with He^{++} particles through electromagnetic or possibly strong forces, and form very small quasiparticles X^-He^{++} (radius $\lesssim$ 4 fermis) with about the same properties as X^+ particles.

In this letter we establish the possibility of detecting stable superheavy isotopes of hydrogen with masses between 10^4 and 10^8 a.m.u.. They would be identified, provided their relative abundance in water is greater than $\sim 10^{-25}$ compared to ordinary hydrogen. This should improve present detection limits for this mass range by more than five orders of magnitude, complementing the limits of $\sim 10^{-29}$ to $\sim 10^{-24}$ which already apply for masses smaller than 10^4 a.m.u. [1].

The experimental approach we shall use will consist of the following two main steps:

i) 20 liters of water will be centrifuged to provide at the end a 20 mm^3 water sample with an enrichment factor of nearly 10^6 in heavy hydrogen ($>10^4$ amu). We hope to gain a further factor of $\sim 10^3$ through centrifugation in a gaseous phase. Furthermore, by starting with heavy water, we could have an additional gain of $\sim 2\ 10^4$, provided that the heavy water production process is at least as efficient for superheavy hydrogen atoms as it actually is for the tritium content.

ii) After water reduction, the hydrogen molecules will be dissociated by a radiofrequency discharge and the superheavy hydrogen atoms will be excited with lasers by a resonant two-step process, the same process being non-resonant for ordinary hydrogen atoms because of the isotopic mass shift. The detection of the excited atoms will be done through the fluorescent light emitted some 100 ns after the laser pulse. The expected overall sensitivity of the detection in this last step is of the order of one superheavy hydrogen atom per 10^{16} ordinary hydrogen atoms.

Taking into account the previous enrichment factor, the sensitivity of detection we can expect is very roughly one superheavy hydrogen atom per 10^{25} ordinary hydrogen atoms.

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[1] While too heavy hydrogen atoms would fall down on the ocean floor, we estimate, given the self-diffusion coefficient of water, that atoms lighter than $\sim 10^8$ a.m.u., which should in principle fall at $v \lesssim 5\ 10^{-5}$ cm/s, would be mixed by ocean currents [2] and therefore remain present in sea water.

We now describe in more detail the centrifugation and laser spectroscopy. More details as well as the theoretical motivations will be published elsewhere [3].

1 - The centrifugation process: from 20 liters to 20 mm^3

The self-diffusion coefficient of heavy water (HDO, HTO) in water is measured to be $D= 2.5\ 10^{-5}\ cm^2\ s^{-1}$ at 20° C [4]. The speed limit v due to a drag force F is related to this coefficient by $v = FD/kT$ [1]. The sedimentation speed limit can then be calculated, as a function of the distance r to the axis of the rotor:

$$v \sim 1.7\ \text{cm hr}^{-1}\ \frac{m_X}{10^4 \text{GeV}/c^2}\ \frac{r}{10\ \text{cm}}\ \left\{\frac{\nu}{20{,}000\ \text{rpm}}\right\}^2$$

With a swinging-bucket rotor spinning at 20,000 r.p.m., the clearing time, i.e. the time needed to sediment from the meniscus to the bottom of the tube, is less than 8h for $M_X > 10^4\ GeV/c^2$. We therefore plan to centrifuge 20 liters of sea water, in 200 cm^3 aliquots, at 20,000 r.p.m. for about 12 hours, and to repeat this step on the concentrated fractions.

The ultimate equilibrium distribution is given by the Boltzmann formula : $n \sim \exp(-h/h_0)$, where h is the distance to the bottom of the centrifugation tube. h_0 is equal to $kT/(M_X \omega^2 r_{max})$, where r_{max} is the distance from the bottom of the centrifugation tube to the axis of the rotor. At 20,000 r.p.m., and with r_{max}=16 cm, we obtain $h_0 \simeq 0.3$ mm for $M_X = 10^4\ GeV/c^2$, and $h_0 \simeq 300$ Å for $M_X = 10^8\ GeV/c^2$. We can obtain an enrichment factor of about 20 at each centrifugation by just keeping the last 5 mm's of solution, while still avoiding significant insertions of the heavy particles in the bottom wall of the tube.

To minimize the diffusion during the slowing down of the rotor, we plan, as this is usually done by biologists, to introduce a 10% sucrose solution at the bottom of the tube. The heavy particles are expected to be trapped in this solution, avoiding diffusion during the slowing down of the rotor because of the high viscosity of the sucrose solution.

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[1] This formula gives the same speed limit as the Stokes formula $F = 6\pi\eta r_0 v$, where η is the water viscosity (.01 g $cm^{-1}\ s^{-1}$), provided that the radius of the molecule, r_0, is about 1 Å. This radius is about what one expects for a water molecule. This means that hydrogen bonds between water molecules do not significantly interfere with the diffusion of individual molecules and therefore should not affect centrifugation.

The whole method was tested with Radium ions (A = 226) dissolved in 0.1 M sodium phosphate buffer at pH 7.4. The solution was centrifuged at 45,000 r.p.m. for 50 hours. This time is longer that the clearing time we can determine for Radium ions (and other radioactive elements produced in their decays) from the calculation of their speed limits. However, in this case $h_0 \simeq 5$mm, which limits the sedimentation at equilibrium. The results are shown in fig. 1 . They were obtained by measuring the α radioactivity of different samples of the solution at various depths. This is an experimental evidence that the centrifugation process is an efficient way of accumulating heavy elements at the bottom of the tube.

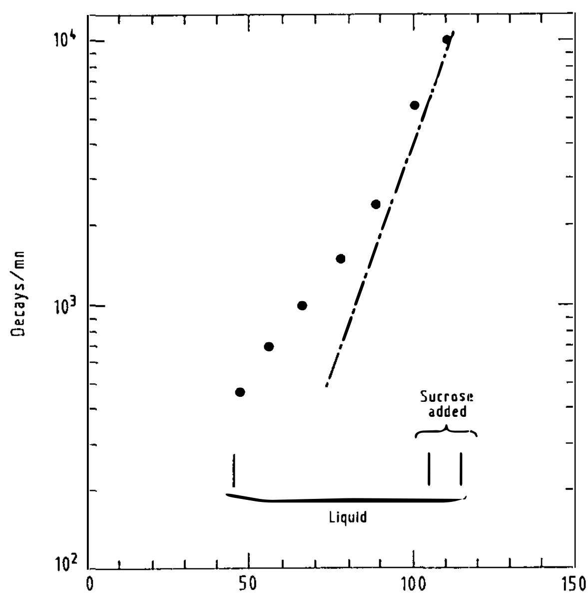

Figure 1
Density of radioactive elements versus the distance to the axis of the rotor. The points correspond to measurements of the radioactivity of samples taken from the Radium solution after the slowing-down of the rotor. The dashed line indicates approximately the asymptotic theoretical equilibrium curve during the rotation.

2 - Detection of superheavy hydrogen atoms by atomic spectroscopy

The energy levels of atomic hydrogen are proportional to the reduced mass of the electron:

$$m_r = m_e \frac{1}{1 + m_e/m_n}$$

for a nucleus of mass m_n. If we assume that the mass of the nucleus is larger than 10^4 GeV/c^2, the isotopic mass shift between the superheavy hydrogen atom and the usual hydrogen atom is of the order of 44.8 cm^{-1} for Lyman α and 8.3 cm^{-1} for Balmer α. An optical excitation resonant for the superheavy hydrogen atom is thus non-resonant for a usual hydrogen atom. The same property has already been used in sodium [5] to search for anomalously heavy isotopes. More precisely in the present proposal, we consider the two-step excitation from 1S to 3S of the superheavy hydrogen atom (fig. 2a). The same wavelengths correspond to a doubly non-resonant process for the hydrogen atom (fig. 2b). We can thus excite with a high selectivity the upper level of the superheavy atom.

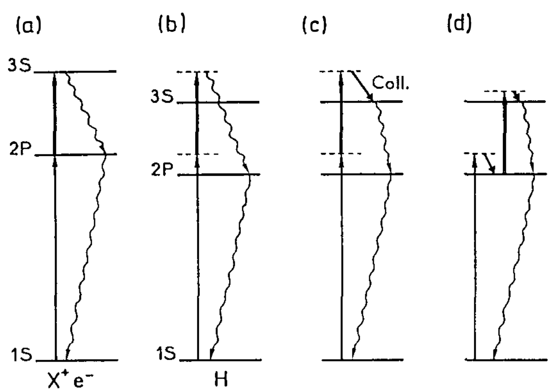

Figure 2
Scheme of the excitation process:
a) Two-step excitation of X^+e^-.
b) Hyper Raman process in hydrogen.
c) and d) Background due to collision-aided excitations of hydrogen.

Furthermore, if we consider two pulsed light sources of 10 ns duration, we can temporaly separate the spontaneous emission from the 3S state of the superheavy atom, from the hyper Raman scattering in hydrogen, because the spontaneous emission comes on average 160 ns after the pulse while the Rayleigh and hyper Raman scatterings follow adiabatically the pulse excitation. If we detect the Balmer α photons emitted after the pulse, we can thus suppress most of the parasitic light.

Let us now consider the Doppler widths of the transitions in the superheavy hydrogen atom. If its mass is larger than 10^4 GeV/c^2, the Doppler width is less than 10^{-2} cm^{-1} for Lyman α and 2 10^{-3} cm^{-1} for Balmer α. If the spectral widths of the exciting light beams are larger than these quantities, most of the superheavy atoms can be excited whatever their velocities are [3]. In the following, we shall consider that the widths are of the order of 10^{-2} cm^{-1}. Even in the case of the Lyman α line, this is actually possible as shown by Cabaret et al. [6]. The values of each beam intensity are adjusted so that the resonant Rabi frequencies are equal to the instrumental widths considered above. Here also, Wallenstein [7] and Cabaret et al. [6] show that this is possible with beams of transverse dimensions of the order of 1 mm.

If we consider systematic parasitic effects that have a signature similar to the signal, we have to calculate how many hydrogen atoms can be really excited in the 3S level through a collision-aided process (figs. 2c and 2d). At a hydrogen pressure equal to 0.3 Torr, the probability of such events can be estimated to be smaller than 10^{-17} (with the values of the beam intensities considered above) while the excitation probability for a superheavy atom is of the order of 0.2.

If we assume that there is one superheavy atom in 10^{16} hydrogen atoms, the probability to have an excitation in an interaction volume equal to 3 10^{-2} cm^3 at a pressure of 0.3 Torr during a pulse is 10^{-2}. In this example, the signal S is only slightly larger than the noise B (but one can increase the ratio S/B by decreasing the pressure). Given a detection efficiency of 10^{-2}, this is enough to get a significant signal in a few days at 10 Hz (frequency repetition of a commercial YAG laser), compared to the photomultiplier noise, provided that the background is well under control. This can be achieved, if we monitor the background through frequent changes of the excitation wavelength.

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[3] We consider here the case of one hyperfine sublevel. The hyperfine structure will of course depend on the spin of the X particle.

3 - Conclusion

We have shown that it is possible to single out superheavy hydrogen atoms from ordinary hydrogen atoms, through centrifugation followed by atomic spectroscopy, provided that their mass is in the 10^4 to 10^8 a. m. u. range and that their abundance in water, relative to ordinary hydrogen, is greater than about 10^{-25}. This should improve existing sensitivity limits for this very high mass range by at least 5 orders of magnitude (figure 3). If we want to be optimistic, a positive result would give a crucial indication for the existence of revolutionary new physics , not accessible at present accelerator energies. A negative result, on the other hand, would be more difficult to interpretate, due to the large uncertainties in the expected abundances of the various superelements inside terrestrial materials; nevertheless it could be taken as an indication against the existence of such stable particles.

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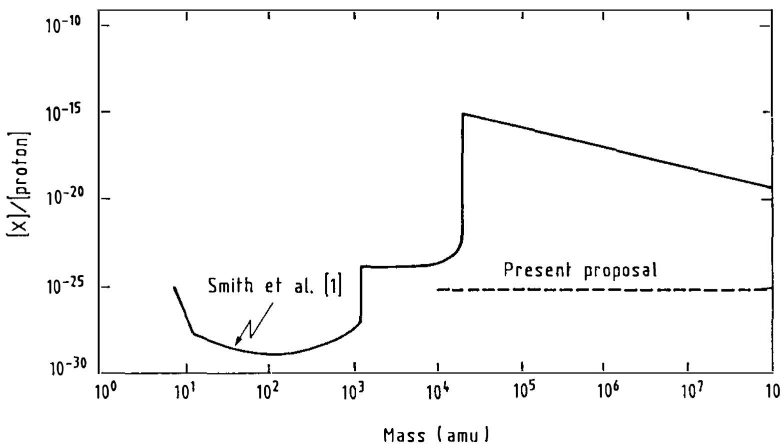

Figure 3
Limits on the relative abundance of superheavy hydrogen, as a function of its mass. The solid line corresponds to the experimental limit of Smith et al. and Nitz et al. [1]. The dashed line indicates the sensitivity level that should be attained with the present proposal.

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