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On the formation of „quasi stable“ hollow atoms towards a high power electric energy storage

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Abstract:

In this paper we propose a possible way of forming long-living (quasi stable) multiply excited atoms or ions, where their decay is blocked or delayed by intra-ionic magnetic stabilisation. Specially selected ionic configurations with high internal magnetic fields shall capture only spin-polarized electrons in collisions with spin-aligned atomic hydrogen gas targets. It is expected that the so created spin-aligned configuration yields an extremely high internal magnetic field, which will delay the spin-flip transitions. Thus the life time of inner shell vacancies should strongly increase.

Hollow atoms or ions are frequently formed by the interaction of slow highly charged ions with matter. Since more than a decade numerous groups (1-8), who are working on the field of slow highly charged ions, have investigated their formation and their decay. It is well known that these multiply exited hollow atoms or ions, i.e. their inner shell vacancies, decay within fractions of a pico second by x-ray or Auger-electron emission. In nature and also so far under laboratory conditions no evidence has been found that long living metastable multiply inner-shell excited ionic or atomic systems exist, whose life time exceeds milli seconds or even seconds. Only in case of highly ionized few-electron ions, where only *one electron* is excited and its decay is highly forbidden, i.e. if this state can only decay by magnetic dipole or by two-photon transitions or by spin-flip, such ionic configurations can have life times of the order of micro seconds or even longer. Recently Ninomiya et al. (7) have found evidence for longer living „hollow atoms“, which were formed by penetration of highly charged ions through thin films. However, if many-electrons (where some have spin-up and some have spin down) are excited, fast Auger transitions become possible and the life time for such electronic configurations is shorter than pico seconds.

We propose in this letter a new method, where hollow ions or atoms might be formed, which have „unnatural“ long life times due to ***„intra-ionic magnetic stabilisation*“**. Using modern atomic physics techniques long living innershell hollow atoms might be producable with very exotic spin-aligned configurations. Such exotic spin-aligned excited systems might be creatable under laboratory conditions, if specially *selected „highly ferromagnetic“ highly charged ions* (e.g. Pb $^{59+}$ or U^{69+}) capture only spin-up or spin-down electrons. If all excited electrons (including all captured electrons) have parallel spins, this excited system can only decay if spin-flip occurs. If all outer electrons have parallel spins, the energy barrier for a spin-flip might strongly increase. In this case it might be possible *to block or delay spin-flip transitions due to the very strong internal magnetic field.* The multiple capture process should be fast enough (in the order of less than 1 microsec) that till the formation of the very high internal magnetic field the highly ecited ion has no time to decay. Due to such a strong internal magnetic field and the so achieved blocking of spin-flip transitions the life time of inner shell vacancies even in special neutral atoms might be strongly delayed and reach up to milli sec or even longer. For special ionic initial configurations thus an internal magnetic field strength may be achieved, which is much stronger than that of the strongest so far in nature observed ferromagnetic atoms or ions.

Modern ion source techniques allow the production of nearly any kind of ion in any charge state. Present EBIS or EBIT devices and even ECR ion sources can create high intensity low energy beams of all the interesting ionic configurations. Ions, with high internal magnetic fields are for example those, which have half-filled 3d, 4d, 4f etc. shells and when all lower shells are filled and form closed shells and when all higher shells are empty. According to Hund's rule in this configuration the ion's total L value should be zero and the total S value should be maximal. If one can experimentally achieve, that these ions capture now only electrons, whose spin s is parallel to S, these electrons can be captured only into higher orbitals. They can decay into the lower empty states only if they undergo a spin-flip. The crucial condition for formation and surviving of such hollow ions is: 1. During the filling of the outer staes by spin-aligned electrons (till the final very strong magnetic field strength is reached) the spin-flip transition rate must be smaller than the electron capture rate (to block spin-flip during increasing magnetic field) and 2. The strong internal magnetic field must block by many orders of magnitude the spin-flip of such ions. *If nature is gracious to physicists* one might indeed be able to form fast enough ions with very high intra-ionic magnetic fields. Thus the spin-flip barrier reaches so large values that the total spin-flip rate of all captured electrons might be strongly reduced. Whether this is finnally the case and long living hollow ions or atoms can be created depends on the here concurring transition rates.

Reviewing in the literature published live time (τ) data on ionic states with large S and L values one can see that indeed τ increases by orders of magnitude compared to spin-flip allowed transitions. Research has been started to calculate with relativistic multi-configuration codes live times of such exotic ionic systems (9). Presently it seems impossible to calculate with the existing computer codes for such exotic systems the relevant spin-flip transition rates (9). Therefore to obtain information on spin-flip rates we are preparing an experimental study on the capture of spin-aligned electrons by spin-aligned slow highly charged ions in selected charge states in spin-polarized thin hydrogen gas targets.

Using the Frankfurt EZR ion source and the Livermore EBIT slow highly charged ions in selected charge states will be extracted and magnetically separated which have partially filled d, f, or g shells. If q defines ions with half- filled d, f, or g shells than according to Hund's rule these ions should have strong internal magnetic fields. These charge state selected ions will penetrate a thin (milli Torr) hydrogen gas target, where the electrons are spin-aligned. During their penetration they will capture the spin-aligned electrons and will be slowed down to lower kinetic energies within about 1 microsec. For these ions the internal magnetic stabilization may get strong enough to ensure the formation of long living hollow ions or atoms. If innershell vacancies survive (about 10 microsec flight time from place of capture to beam stop) these vacancies will immediately decay when touching the beam stopper surface and Auger electrons will be emitted. The detection of these electrons is the proof for long living innershell vacancies. With this „simple“ experiment set up the existence of hollow atoms with inner shell life times bigger than 10 micro sec can be proven. In case the life times would exceed milli sec or being even longer, the life time can be determined by measuring the decay rate along the flight path of the neutral hollow atoms by normalizing the decay events to the total number of hollow atoms produced.

E.g. uranium ions with charge state 69+ provide an interesting initial configuration with high internal magnetic field. For U^{69+} one possible configuration is: $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $3d^5$ with a total angular momentum of L=0 and a total S=5/2. If these ions capture 69 electrons with spin-up into the lowest allowed orbitals (including fast cascading into the lowest allowed states) they form very exotic hollow atoms where above the initially present closed inner shells only spin-up electrons are orbiting. One possible hollow atom configuration would be: $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $3d^5$, $4s^1$, $4p^3$, $4d^5$, $4f^7$, $5s^1$, $5p^3$, $5d^5$, $5f^7$, $5g^9$, $6s^1$, $6p^3$, $6d^5$, $6f^7$, $7s^1$, $7p^3$, $7d^5$, $8s^1$, $8p^2$. The total maximal S value of this atom would be 34 and the internal magnetic field exceeds **Mega**-Tesla.

Such hollow spin-aligned atoms might provide a new kind of chemical binding and material with new magnetical properties. Last not least they would be very interesting atoms with exotic internal features (Fermi statistics, electron-electron correlations etc.) to investigate fundamental aspects of physics.

Furthermore calculating the amount of energy, which will be released by filling the empty states with spin-down electrons, one would gain in case of such uranium ions more than 30keV energy per hollow atom, which could be partially converted into electric energy. Such an electric energy storage of about 30keV is a hugh amount compared to conventional energy gains in chemical reactions.

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