A Search for Anomalously Heavy Isotopes of Low Z Nuclei

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ABSTRACT

We present preliminary results of a search for anomalously heavy isotopes of certain light elements using an electrostatic charged particle spectrometer in conjunction with the MP tandem accelerator facility at the Nuclear Structure Research Laboratory of the University of Rochester. New limits for the existence of anomalous, heavy isotopes (100–10,000 amu) in ordinary, terrestrial Li, Be, B and F samples and enriched H^2, C^{13}, and O^{18} samples are reported.

INTRODUCTION

It is a curious fact that, in spite of the large variety of elementary particles that have been observed and hypothesized during the past 40 years, it appears that all stable matter can be explained as various combinations of neutrons, protons, and electrons – particles well known to physicists since the 1930's. Big-Bang cosmology implies that all types of particles were present in large numbers during the earliest moments of creation. Thus, particles of virtually any mass that have lifetimes comparable to the age of the universe ($\approx 10^{10}$ years) should exist today as remnants of the Big-Bang. Various calculations have been performed[1,2] which yield estimates of 10^{-12}–10^{-10} for the concentration of anomalously heavy isotopes in nature. There are a several potential candidates among the particles that are commonly considered in high energy physics possessing the required level of stability. In technicolor theories[3], for example, the lightest "techni-baryon", a technicolor singlet state of 3 technicolor quarks, is expected to have a lifetime of $\approx 10^{16}$ years. Supersymmetric theories[4] predict that all fermions have bosonic partners and vice versa; the lightest of these is expected to be stable. Particles of these types, if charged, should be observable in matter. Positively charged particles would have similar chemical properties to hydrogen and would appear in nature as an isotope of hydrogen with an anomalous mass. Negatively charged particles would bind to ordinary nuclei, changing a nucleus of atomic number Z into one with atomic number Z-1 and anomalous mass.

We have constructed an all-electrostatic beam line for the University of Rochester Nuclear Structure Research Laboratory (NSRL) MP tandem electrostatic accelerator to search systematically for such components of matter. An electrostatic beam line transports ions independently of their masses, an essential feature since the masses of the ions for which we are searching are not known. We can enhance the relative selection of these ions by tuning the beam and appropriately configuring the detector.

Searches for massive isotopes of hydrogen have been reported[5,6,7], the most sensitive being that by Smith and co-workers[8]. Using electrolysis followed by analysis in a time-of-flight mass spectrometer, they were able to establish concentration limits of $<10^{-28}$ per nucleon in ordinary water for isotopes in the mass range 8–1200 amu. Searches for anomalous mass isotopes of heavier nuclei have had less sensitivity. One of the most sensitive to date is that of Turkevich et al.[9], which places limits on the natural abundance of >100 amu carbon-like nuclei at less than 1 per 10^{15} nucleons. Other less sensitive searches covering more limited mass regions have been reported for helium[10], lithium[10], beryllium[10], oxygen[11], and sodium[12].

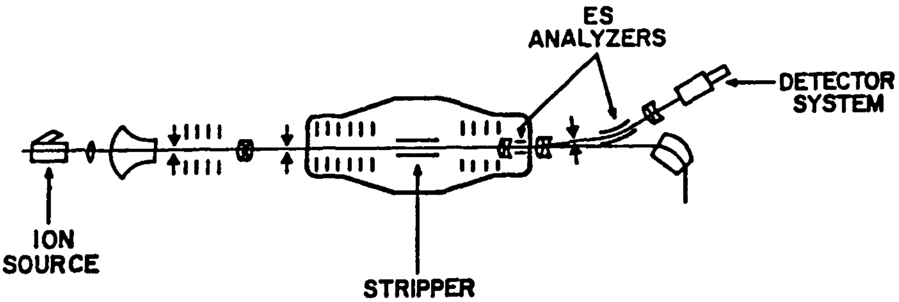

Fig. 1. A plan view of the apparatus including the injection system into the accelerator.

THE ELECTROSTATIC SPECTROMETER

A diagram of the accelerator, spectrometer, and detection system is shown in Fig. 1. It has been described in detail in ref. 13. A cesium ion source, which can be used to sample virtually any type of solid material and many gasses, feeds into the accelerator directly through electrostatic lenses. The sample beam is accelerated to 5 MeV in charge state 1^- to the terminal where it is stripped to charge state 1^+ in a 5 μg/cm^2 carbon foil. At the high energy end of the accelerator, the 10 MeV beam is focused with an electrostatic quadrupole doublet and deflected 1.3° off axis by a pair of electrostatic plates within the accelerator pressure vessel. Outside the machine, the beam passes through a removable 5 μg/cm^2 foil stripper and a set of adjustable slits at the focus of the quadrupole. This is followed by a high resolution 20° electrostatic analyzer, an electrostatic quadrupole doublet, and a small magnet that can be energized to sweep out low mass (<100 amu) ions. A slit located at the focus of the second quadrupole system is followed by a microchannel plate time-of-flight transmission detector, a gas pressure cell to range out unwanted ions, and a gas ionization counter to measure the $\delta E/\delta x$, range, and total energy of the ions.

We periodically verified the mass independence of the beam transport by measuring the yields from a specially prepared BeCuAu alloy. Small variations in the optimum beam tunes for the three elements were identified as being due to small differences in the energy losses in the two stripper foils and to small residual magnetic fields at the low energy end of the accelerator. These effects, while significant for masses of a few amu, have little effect for the high mass, low-Z ions that are the subject of the search reported here.

For the hydrogen search we introduced a small magnetic field just downstream of the ion source. This eliminated light particles from the beam but had negligible effects on particles with masses ≥100 amu.

For the other searches, we exploit the fact that heavy ions, in passing through a thin foil, don't have as many orbital electrons stripped as do light ions of the same energy. As a general rule, only those electrons that have orbital speeds less than that of the ion are stripped. This means, for example, that a 10 MeV 1000 amu "isotope" of beryllium will strip to charge state 1^+ ≈½ of the time, while normal Be^9 will usually strip completely to charge state 4^+, emerging in charge state 1^+ with a probability of 10^{-4}. By tuning for charge state 1^+ after both the terminal and high energy stripper foils, we achieve a rejection factor of $\approx 10^7$ for normal ions. Normal ions that do pass through the system are rejected in the detector, since a heavy version of any particular element will have a distinctly different $\delta E/\delta x$ and range.

RESULTS

We measured a variety of samples, including normal beryllium, lithium, boron, and fluorine, and specially enhanced samples of oxygen, carbon, and hydrogen. We used a commercially available sample of O^{18}, the preparation of which effectively enhances the concentration of heavy isotopes relative to O^{16} by a factor of 416, and a carbon sample prepared in the C^{13} separator at Los Alamos in which the concentration of possible heavier isotopes was enhanced by $\approx 10^5$.

In our searches for heavy hydrogen, we used several samples: sea water from a depth of 3 km (no enhancement), a commercially available deuterium sample (enhancement factor = 6600), and samples of lake water enriched at the Rutherford Laboratory (enhancement factor 10^6–10^9).

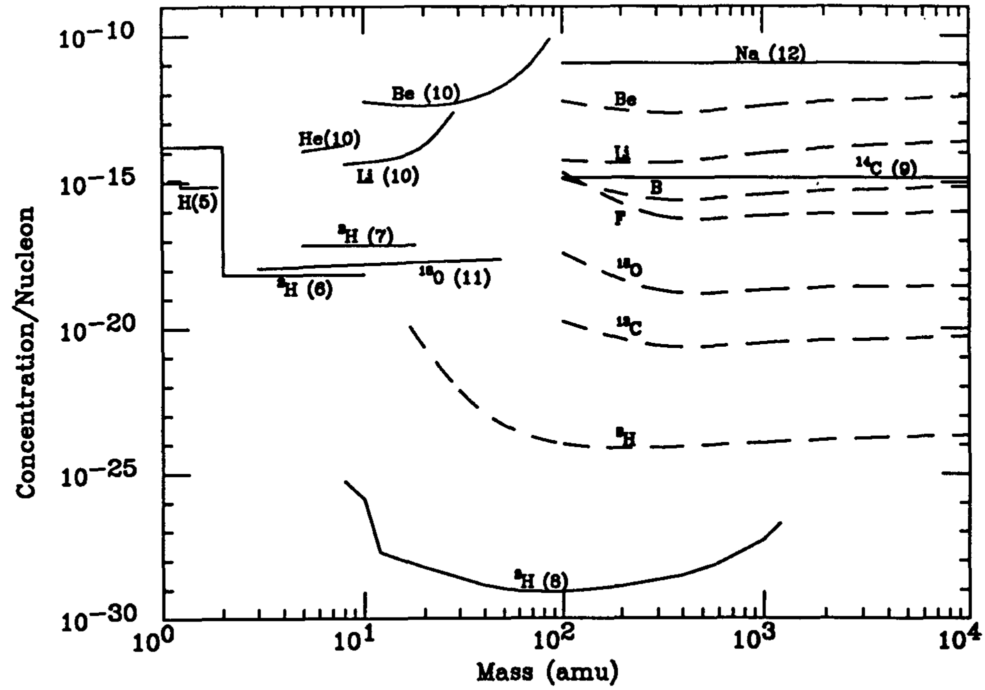

Fig. 2. Concentration limits (90% confidence level) for the existence of heavy isotopes in matter. Our preliminary results are shown as dashed lines, and previously published results as solid lines.

The sensitivity for detection of heavy isotopes is given by the expression:

$$S = \frac{n_0 \times \gamma_m}{Y_1 \times Y_2 \times \varepsilon_t \times \varepsilon_m \times I \times f \times \Delta t \times A \times \gamma_s} \tag{1}$$

Here S is the measured sensitivity, Y_1 and Y_2 are the stripping yields for the heavy isotope into charge state 1^+ at the first and second stripping foils, ε_t is the transmission efficiency of the heavy isotope, ε_m is the mass dependent correction for the magnetic sweeping, I is the average current from the ion source, f is the ratio of specific ion current to the total current, Δt is the total live time accumulated, A is the mass number of sample nuclei, γ_s is the enrichment of the sample, γ_m is a mass dependent enhancement factor due to molecules from the source, and n_0 is the minimum number of events required to define a signal. In the present preliminary analysis we have assumed ε_m=1, we have taken the heavy isotope transmission efficiency to be 10%, consistent with our measurements of the beam transmission for normal ions, and have considered only the masses ≥100 amu where the effect of the magnet sweeping is insignificant. We require ≥1 event (n_0=2.3 for 90% CL upper limit) to define a positive signal in the heavy hydrogen search. For the other samples, we require ≥3 events (n_0=5.3 for 90% CL upper limit) within a region taken to be ≥3 times wider than our FWHM resolution in the total ionization energy measurement and 4 $\delta E/\delta x$

measurements. In Fig. 2, we show our preliminary results as dashed lines, and previously published results as solid lines. We expect that further refinement of our analysis of these same data will enhance the concentration limits and extend our mass range.

CONCLUSIONS

It is not expected that geological fractionation processes will dramatically change the concentration of heavy isotopes in normal matter[14]. In light of the large discrepancy between these measurements and the predictions of refs. 1 and 2, it would appear safe to rule out the existence of stable charged particles in the mass range 100–10,000 amu.

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