Experimental test of a possible violation of the Pauli principle

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A method of isotopic analysis of elements is proposed for testing for a possible violation of the Pauli principle. Analysis of the isotopic composition of boron yields a limitation on the lifetime with respect to a violation of the Pauli principle by atomic electrons: $T \geqslant 10^{25}$ yr.

The question of a violation of the Pauli principle for the electrons in an atom was originally raised in a paper by Reines and Sobel.[1] In that paper they found a limitation $T \geqslant 10^{20}$ yr on the lifetime with respect to a violation of the Pauli principle in iodine atoms on the basis of data from an experiment carried out to test the conservation of electric charge. A corresponding experiment[2] subsequently yielded[3] the stricter limitation $T \geqslant 3.0 \times 10^{22}$ yr. In the same study, Gavrin *et al.*[3] suggested an integral method for testing the validity of the Pauli principle. That method is essentially one of searching in a sample of an element with an atomic number z for anomalous atoms ("monsters") of the same substance, which are chemically masked by atoms of an element with an atomic number $z-1$ due to the "dumping" (in violation of the Pauli principle) of a valence electron to a lower-lying atomic shell. As one particular search, they suggested a geochemical experiment with 100 metric tons of the natural salt NaCl. Chemically, anomalous ^{23}Na atoms would behave in the same way as ^{23}Ne atoms. If the salt has an age $\tau \sim 10^8$ yr, and if the lifetime of an atomic electron with respect to a violation of the Pauli principle is $T \sim 10^{30}$ yr, the relative number of anomalous ^{23}Na atoms would be

$$C \approx \tau/T = 10^{-22}. \tag{1}$$

A neutron-activation analysis was proposed for counting the anomalous atoms. The product of the reaction $^{23}\mathrm{Na}(n\gamma)\,^{24}\mathrm{Na}$ is subject to β^- decay with $T_{1/2} = 14.96$ h and $E^{\beta}_{\max} = 1.39$ MeV; the activation cross section of ^{23}Na is[4] 0.53 b. It is obvious, however, that the presence of even a microscopic impurity of individual elements in the working gas of the counter would be a serious complication in the effort to achieve the maximum sensitivity of the experiment. For example, analysis shows that argon at a level $\approx 10^{-6}$ or krypton at a level $\approx 10^{-12}$ would reduce the expected result by several orders of magnitude, since the products of the reactions $^{40}\mathrm{Ar}(n\gamma)^{41}\mathrm{Ar}$ and $^{78}\mathrm{Kr}(n\gamma)^{79}\mathrm{Kr}$ obtained as a result of activation could simulate useful events. Furthermore, creating a high vacuum in 100 metric tons of salt and completely degassing the water used as a solvent would be extremely complicated procedures.

In the present letter we suggest searching for anomalous atoms which arose in the universe during the stage of nucleosynthesis. According to the present understanding of the origin of the elements,[5] nucleosynthesis began about 11×10^9 yr ago and ended about 4.5×10^9 yr ago; i.e., it lasted about 6.5×10^9 yr. It has also been suggested that the rate of nucleosynthesis was higher in its initial stage than at its end.[5] An estimate of $(4\text{–}5) \times 10^9$ yr would then be a realistic estimate of the time interval during which anomalous atoms were formed, with an effective mass of the matter of the mother element equal to its mass at the end of the nucleosynthesis. During the formation of the solar system, a differentiation of the originally homogeneous protomatter occurred, according to the chemical properties of the elements. If the Pauli principle is violated, each element with an atomic element z contains an impurity of anomalous atoms of an element which has, in the simplest case, an atomic number $(z+1)$. The concentration of anomalous atoms in the host substance would be, instead of (1),

$$C = \frac{\tau}{T} \frac{P(z+1)}{P(z)}, \tag{2}$$

where $P(z+1)$ and $P(z)$ are the cosmic abundances of the elements with atomic numbers $z+1$ and z. We see from (2) that the concentration of anomalous atoms in the host matter is maximized when the cosmic abundance of the mother element, $z+1$, is large, while that of element z is small. Furthermore, it is important that there be no isotopes with identical masses in the elements z and $z+1$.

These arguments lead us to the boron-carbon pair as the most suitable. The relative cosmic abundances of these elements [with $P(\mathrm{Si}) = 10^6$] are $P(\mathrm{B}) = 6.2$ and $P(\mathrm{C}) = 1.35 \times 10^7$ (Ref. 6). We then find from (2) that in a search for anomalous carbon atoms the concentration of these atoms in boron would be $C(\mathrm{C}) = 10^{-14}$ under the assumptions $\tau = 4.5 \times 10^9$ yr and $T = 10^{30}$ yr. By way of comparison we recall that the concentration of anomalous sodium atoms in the salt NaCl is $C(\mathrm{Na}) = 10^{-22}$ at $T = 10^{30}$ yr (Ref. 3).

Boron exists as two stable isotopes, $^{10}\mathrm{B}$ and $^{11}\mathrm{B}$, as we know. Carbon also has two isotopes ^{12}C ($\sim 99\%$) and ^{13}C ($\sim 1\%$). If we assume that in analyzing the isotopic composition of boron we do not detect the presence of atoms with a mass of 12 at the sensitivity level of the isotopic mass spectrometer ($\sim 10^{-9}$), we could then interpret this fact as a limitation on the concentration of anomalous carbon atoms: $C(^{12}\mathrm{C}) < 10^{-9}$. From (2) we would then find a limitation on the lifetime of the carbon atom with respect to the Pauli principle:

$$T > \frac{\tau\, \delta(^{12}\mathrm{C})}{C(^{12}\mathrm{C})} \frac{P(\mathrm{C})}{P(\mathrm{B})} = 10^{25}\ \mathrm{yr}, \tag{3}$$

where $\delta(^{12}\mathrm{C}) = 0.99$ is the relative amount of the isotope $^{12}\mathrm{C}$ in carbon. It has been possible to derive this result because there is no stable isotope $^{12}\mathrm{B}$ in nature. The value in (3) could be improved significantly by using accelerator mass spectrometry to count anomalous $^{12}\mathrm{C}$ atoms; that method makes it possible to distinguish $^{11}\mathrm{B}$ from anomalous $^{12}\mathrm{C}$ at a level of $10^{-(14-15)}$ (Ref. 7). In this case we could reach a value $T \sim 10^{31}$ yr. A further increase in sensitivity would be possible if the boron were enriched beforehand with the heavier isotope.

However, as the sensitivity of the experiment is increased, we might run into the problem of the presence of "normal" carbon in the boron. From this point of view, it would be better to use a pair of elements which differ greatly in chemical properties in experiments of this type. Apparently better candidates are the fluorine-neon pair. While having a fairly high ratio of cosmic abundances [$P(\mathrm{Ne})/P(\mathrm{F}) = 0.65\times10^3$; Ref. 6], the elements of this pair also have "good" isotopic ratios: $^{19}\mathrm{F} = 100\%$, $^{20}\mathrm{Ne} = 90.92\%$, and $^{21}\mathrm{Ne} + ^{22}\mathrm{Ne} = 9.08\%$. It would thus become possible to search for anomalous $^{20}\mathrm{Ne}$ atoms in fluorine.

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[1] F. Reines and H. Sobel, Phys. Rev. Lett. **32**, 954 (1974).
[2] E. Koval'chuk, A. Pomanskiĭ, and A. Smol'nikov, Pis'ma Zh. Eksp. Teor. Fiz. **29**, 163 (1979) [JETP Lett. **29**, 145 (1979)].
[3] V. Gavrin, A. Ignatiev, and V. Kuzmin, Phys. Lett. **206**, 343 (1988).
[4] I. Kikoin (editor), Handbook of Tables of Physical Quantities, Atomizdat, Moscow, 1976.
[5] R. Tayler and A. S. Everest, The Origin of the Chemical Elements (Wykeham Science Ser.: No. 23) Repr. of 1975 ed. Crane Russak Co. (Russ. transl. Mir, Moscow, 1975).
[6] A. Cameron, in: Origin of the Solar System. Introduction to Space (ed. W. H. Hess), Gordon and Breach, New York, 1965.
[7] H. Gove, D. Elmore, R. Ferraro, *et al.*, Nucl. Instrum. and Methods **168**, 425 (1980).

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