Verification of the law of conservation of electric charge

I. R. Barabanov, E. P. Veretenkin, V. N. Gavrin, Yu. I. Zakharov, G. T. Zatsepin, G. Ya. Novikova, I. V. Orekhov, and M. I. Churmaeva
Institute of Nuclear Studies, USSR Academy of Sciences

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A search for the $^{71}\text{Ga}\to{}^{71}\text{Ge}+\gamma$ decay was undertaken to investigate the law of conservation of electric charge. An upper limit of $T\geqslant 2.3\times 10^{23}$ yr was determined for the lifetime of Ga.

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At present, preparations for a gallium-germanium radiochemical experiment for detection of solar neutrinos are being made in several laboratories. The use of gallium for this purpose was initially proposed by Kuz'min[1] in view of the fact that ^{71}Ga has a low threshold for recording neutrinos in the process

$$^{71}\text{Ga} + \nu \to {}^{71}\text{Ge} + e^- . \tag{1}$$

The low threshold for recording neutrinos is due to the fact that the mass of a ^{71}Ga nucleus is larger than that of a ^{71}Ge nucleus; however, a β decay of ^{71}Ga into ^{71}Ge is impossible because the mass difference between the ^{71}Ga and ^{71}Ge nuclei is smaller than the electron mass.

In 1959, Goldhaber and Feinberg[2] pointed out that such a nuclear pair can be used to verify the law of conservation of electric charge. For example, in the process,

$$^{71}\text{Ga} \to {}^{71}\text{Ge} + \gamma . \tag{2}$$

The process (2) can have a $\nu\bar{\nu}$ pair, a pseudoscalar particle, etc., instead of a γ-ray quantum.

In 1960, Goldhaber and Sunyar performed an experiment in search of such a decay of ^{87}Rb into ^{87}Sr* and found the upper limit for the lifetime of ^{87}Rb for this process, $T\geqslant 1.8\times 10^{16}$ yr.[3] Recently, the accuracy of this experiment was increased,[4] and a higher limit $T\geqslant 1.9\times 10^{18}$ yr for the lifetime of ^{87}Rb was obtained.

In this paper we report the preliminary results of an investigation of the possibility for the transition (2) in a detector containing 300 kg of Ga. This detector was designed for perfecting a method of extracting trace amounts of Ge from Ga in a multiton, gallium-germanium facility for recording solar neutrinos, which is currently being designed.

The experiment involves the following procedure: 300 kg of Ga is exposed in an underground location at a depth of 20 meters of water equivalent (mwe) to eliminate the effect of formation of ^{71}Ge from ^{71}Ga as a result of the action of a nuclear-active, cosmic-ray component. Gallium must be exposed for approximately three half-lives of ^{71}Ge ($T_{1/2} = 11.3$ days) in order to reach the saturation point of ^{71}Ge. The produced

^{71}Ge is subsequently extracted from Ga using an method analogous to that described elsewhere.[5] The extraction method will be described in detail in a future report; here we give only its schematic diagram.

After vigorous mixing of liquid Ga in an acid-peroxide solution, the Ge is converted from Ga in the acid-peroxide solution in the form of a $GeCl_4$ compound. Then the solution is saturated by a stream of dry HCl to an acidity of ≈ 9 N. After this, the $GeCl_4$ is blown out of the solution by an He stream and captured by a trap. The extracted $GeCl_4$ is converted into a gaseous GeH_4 compound, which, as shown earlier,[6] is a fairly good working gas for a proportional counter. The produced batch of GeH_4 is pumped into a 5-mm-diam proportional counter which is used to measure the activity of the extracted ^{71}Ge. The quantity of Ge extracted during the entire cycle was equal to 80%. This quantity was determined from a known portion of the Ge carrier that was dissolved in Ga in advance. The ^{71}Ge activity was measured during a time equal to its three half-lives.

The recorded radioactivity in the region of the energy release of ^{71}Ge, corrected for the recording efficiency (40%), and after subtraction of the background, was

$$N = (18 \pm 18) \text{ decays per half-life} \cdot T_{1/2}. \tag{3}$$

We note that, according to our estimates, the number of ^{71}Ge atoms corresponding to $N \approx 16$ decays should be produced in the detector as a result of the interaction of muons with Ga.

After the introduction of all the corrections, and taking into account the amount of extracted Ge, the elapsed time between the moment of its extraction and the beginning of counting, etc., we obtain for the upper limit of the lifetime of ^{71}Ga relative to its decay with charge nonconservation,

$$T \gtrsim 2.3 \times 10^{23} \text{ yr}$$

with a 90% confidence interval.

This result can also be physically explained in the following way. According to Bahcall,[7] if we assume that the weak interaction contains a small component in which the electron in the lepton current is replaced by a neutrino, then the decays such as

$$n \to p + \nu_e + \bar{\nu}_e$$

in which the charge is not conserved, can occur in this case.

Therefore, the ratio of the probability of such a channel to that of ordinary decay, according to Bahcall,[7] is

$$\frac{\Gamma(n \to p + \nu_e + \bar{\nu}_e)}{\Gamma(n \to p + e^- + \bar{\nu})} = \frac{\tau(n)}{\tau(\mathrm{Ga})}\left[\left(\frac{W(n)}{W(\mathrm{Ge})}\right)^5 \frac{ft(^{71}\mathrm{Ge})}{ft(n)}\right],$$

where $\tau(n)$ is the neutron lifetime, τ(Ga) is the Ga lifetime in the investigated decay in which the charge is not conserved, $W(n)$ is the mass difference between a neutron and a proton, and $W(^{71}\text{Ge})$ is the mass difference between ^{71}Ga and ^{71}Ge.

Using the limit determined by us, we obtain

$$\frac{\Gamma(n \rightarrow p + \nu_e + \bar{\nu}_e)}{\Gamma\,(n \rightarrow p + e^- + \bar{\nu}_e)} \lesssim 9 \times 10^{-24},$$

which is a factor of 3×10^4 better than that obtained by Norman and Seamster.[4]

The physical consequences associated with the experimental limit for this process were also discussed by Ignatiev *et al.*[8]

The counter used by us for recording the decay of ^{71}Ge atoms had a relatively large background produced due to poor purification of GeH_4 from ^{222}Rn and also due to possible activity of a ^{68}Ga isotope which could have entered the detector during the calibration measurements. After removing these background sources, we hope to determine the reported limit more accurately.

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