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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Purification and purity control system for 2β-decay experiment with liquid Ar ionization chamber

A.S. Barabash and V.N. Stekhanov
Institute of Theoretical and Experimental Physics, B. Cheremushkinskaya 25, 117259 Moscow, Russian Federation

The low-background Ti-spong purification system and purity control detector were specially constructed for 2β-decay experiments with liquid Ar ionization chamber. A single passage of commercial Ar though the purification system at a rate of 0.6 m^3/h yields a gas of purity 1.9×10^{-9} eqv. O_2. The purification system was tested for Kr and Xe too. The measurement range of the purity control detector is 10^{-1}–10^{-12} eqv. O_2.

1. Introduction

In order to search for the 2β-decay of practically all interesting isotopes with sensitivity $(0.3–1)\times10^{24}$ yr for 0ν-decay and $(0.3–1)\times10^{22}$ yr for 2ν-decay, a multisection liquid ionization chamber was suggested [1–3]. We hope that the detector will be placed in the Gran Sasso Underground Laboratory (or in another underground laboratory) in a special passive shielding.

For the first step of the 2β-decay experiment we have selected nuclei with sufficiently large 2β-transition energy: ^{100}Mo($E_{2\beta}$ = 3033 keV) and ^{116}Cd($E_{2\beta}$ = 2808 keV). 2β (0ν)-decay limits for ^{100}Mo and ^{116}Cd will be obtained on the level $(5–7)\times10^{23}$ yr, which is two orders of magnitude higher than the present limits for these nuclei and is equivalent to 5×10^{24} yr for ^{76}Ge taking phase volume into account (that is higher than the modern ^{76}Ge result).

Liquid ionization chamber, gas system and electronics were constructed for this experiment. The gas system scheme is shown in fig. 1. A gaseous Ar is kept in the 18 40th liter stainless steel ballons. Six ballons are put into stainless steel dewars, owing to that it is possible to use them as a cryogenic pump for distilling Ar from the chamber to the ballons. The main part of the gas system is the purification and purity control system. There are many possibilities for purification of Ar (for example, see the review of ref. [4]) but Ti-sponge purification system was specially used here because this is a good material for the low-background experiment. For example, Oxysorb or molecular sieves will give a lot of radioactive ^{222}Rn because the contamina-

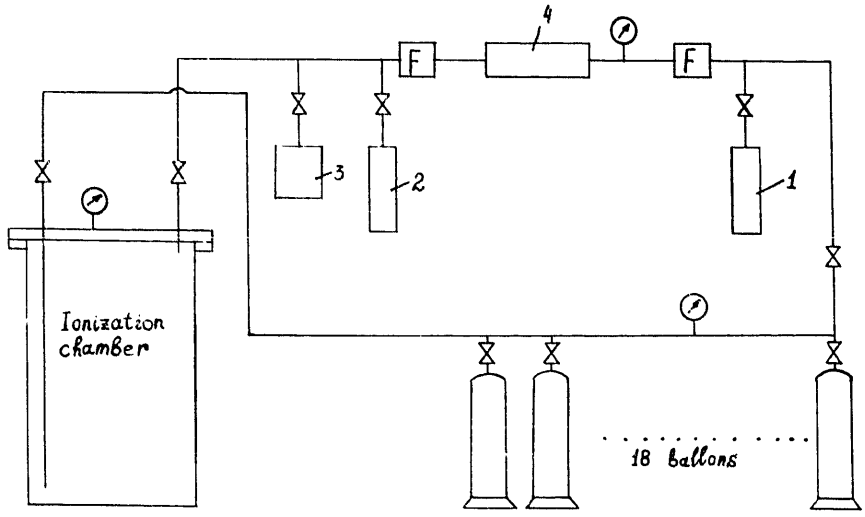

Fig. 1. Scheme of the gas system. 1,2–cryogenic pump; 3–purity control detector; 4–Ti-sponge purification system; F–filters.

tion of ^{238}U in these materials is $\sim 10^{-6}$ g/g. From this point of view Ti-spong is 10^2–10^3 times better.

2. Purification system

The scheme of the purification system is shown in fig. 2. A reactor (5) of high temperature steel 50 mm in diameter and 300 mm long is filled with Ti-spong (2). The reactor is heated by an electrical heater (3). The temperature regime is controled by a thermocouple. All these elements are covered with heat insulation. The outlet gas is cooled by water. Design of the purification system is symmetric: by this arrangement it is possible to pass gas in both directions. Thermocouple, electrical heater and a special electronics block hold the temperature within an accuracy of 0.1°C.

2.1. Purification of Ar

A single pass of the commercial Ar ($C = 2 \times 10^{-6}$ eqv. O_2) through the reactor at a temperature of 850°C provided a gas with an impurity content of 1.9×10^{-9} eqv. O_2. The output of the system is 0.6 m^3/h. The impurity content of the Ar (also Kr and Xe) was checked by an two-phase electro-negative impurities detector (see below).

2.2. Purification of Kr

This purification system was used for purification of Kr. The main results are shown in fig. 3. A single pass of the commercial Kr ($L = 0.4$ cm for $E = 100$–950 V/cm) through the reactor at a temperature 850°C provided a gas with $L = 1.3$ cm ($E = 250$–900 V/cm).

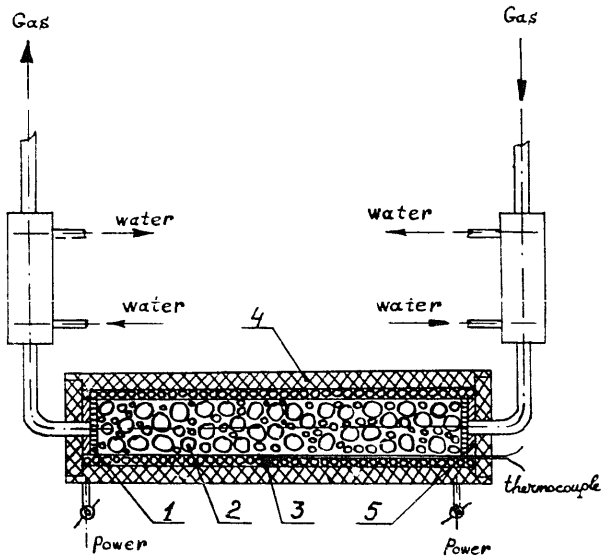

Fig. 2. Purification system. 1–filters; 2–Ti-sponge; 3–electrical heater; 4–heat insulation; 5–reactor.

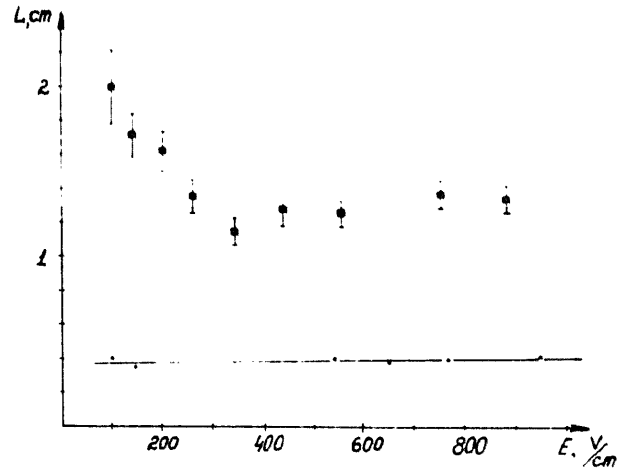

Fig. 3. Electric field dependences of the attenuation length L in liquid Kr. ●–commercial Kr; ■–Kr after purification.

Purification at 950°C and repeated many times procedure give the same result.

2.3. Purification of Xe

This purification system was also used for purification of Xe. We checked this possibility at a temperature of 800–950°C, but we did not see any effect after the purification procedure.

From our point of view the main impurity in Ar is O_2 (up to level 10^{-9} eqv. O_2), but Kr and especially Xe contain some another sort of impurities (like N_2O) in addition, which are not removed by Ti-getter.

3. Purity control detector

The two-phase purity control detector was made spacially for this experiment (the first version of this type of purity control detector was constructed in 1978 [5]). The scheme of the detector is shown in fig. 4. The detector is a flat pulse ionization chamber with a grid. The cathode (8) and anode (10) are stainless steel disks at 50 mm diameter; the screen grid (9) is wound with 90 μm diameter tungsten wire with a spacing of 1 mm. A ^{239}Pu alpha source ($E = 5.15$ MeV) is located on the cathode. The inter-electrode gaps are: $d_{GA} = 4.5$ mm and $d_{GC} = 18$ mm. The amplitude of the anode signals is measured by a charge-sensitive preamplifier and amplifier and a multichannel amplitude analyser (or oscilloscope). The liquefaction of the gas under investigation and its heat setting is performed using a bath (5), filled with the same condensed gas as the working gas, and a bath (6) filled with liquid nitrogen. When liquid nitrogen is injected to the bath (6), the "working type" gas is liquefied into the bath (5), resulting in cooling of the chamber down to the temperature of

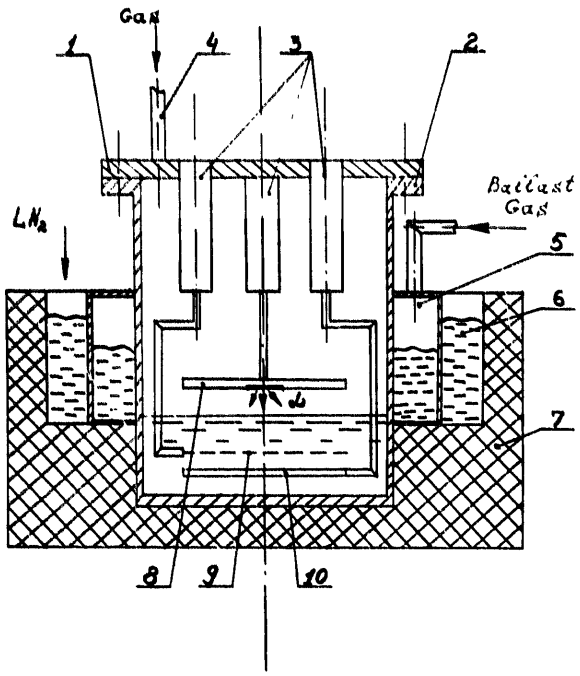

Fig. 4. Two-phase purity control detector. 1–lid; 2–housing; 3–electric inputs; 4–gas; 5–bath; 6–bath for liquid nitrogen; 7–heat insulation; 8–cathode; 9–grid; 10–anode.

condensation of the gas into the bath, with subsequent condensation of the working gas in the chamber.

The temperature of the cryogenic liquids in the bath (5) and in the detector are controlled by the pressure of the saturated vapours. The detector is filled with liquid so that the anode and grid are immersed in the liquid and the cathode is in the gas and the α-particle tracks are contained in the gas. The ionization electrons from the α-particle tracks are transported by the electric field to the node through a lager of the liquid under study ($d_{liq} = 1$–15 mm). The presence of electro-negative impurities is judged from the attenuation of the anode signal. In the gas, recombination on the α-particle tracks is considerably less than the liquid; therefore, it is possible to use low electric field strength (to 1 V/cm), for which attachment of electrons to impurities is maximal, as a rule. To determine the impurity concentration C the following formula can be used:

$$N(X) = N_0 \, e^{-KCX}, \qquad (1)$$

where K, in (ppm mm)$^{-1}$, is the attachment coefficient, C, in ppm, is the relative impurity concentration, X, in nm, is the electron drift path, and N_0 is the initial number of electrons. N_0 is determined in calibration measurements with the detector filled only with gas at the same pressure and temperature as in the main measurements. For precise measurements effect of the attachment in the anode-grid must be taken into account. The sensitivity of the two-phase purity control detector is 10^{-1}–10^{-12} eqv. O_2 (see ref. [4]).

4. Conclusion

The purification and purity control system for 2β-decay experiments with a liquid Ar ionization chamber were constructed and checked. The achieved level of purity for liquid Ar (1.9×10^{-9} eqv. O_2) is enough for our liquid Ar ionization chamber with 1.5 cm anode–cathode gaps. Using the constructed purity control detector it is possible to have a quick (≃ 15–20 min) purity control on all steps of work. As a result, the gas system for 2β-decay experiments is ready now.

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