Technique of production of argon-37 at proton cyclotron and detector for measurements

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Abstract

The technology of production of the isotope Ar-37 at proton cyclotron is developed. It is based on irradiation of the Cl-37 target with the protons of energy of a few a MeV. The example of production of tiny amount of Ar-37 is described and discussed. The detectors to measure the intensity of the sample is discussed.

1 Introduction

The $^{37}$Ar isotope is very important in different fields of physics. It decays by 100% electron capture (EC) $3/2^+ \rightarrow 3/2^+$ transition to the ground state of the stable nuclide $^{37}$Cl. The decay scheme is complete as there no excited levels of $^{37}$Cl below the EC decay energy $Q^+=813.87$ keV [1]. Due to the monoenergetic neutrino lines (811 and 813 keV) and the absence of the nuclear $\gamma$-radiation it is suitable to test neutrino detectors. In 1988 Haxton proposed to employ the $^{37}$Ar source to calibrate radiochemical detectors of solar neutrinos [2], especially gallium based one ([3], [4]). Approximately 1 MCi source was produced [5] according to that proposal and the SAGE detector was successfully calibrated [6]. Another perspective possible usage of the isotope is a calibration of low energy electron detectors by means of the low energy Auger electron and X-ray emission. It can be used in the experiments aiming to search for a possible sterile neutrino admixture in the $\beta$-spectra of different isotopes. In particular, the experiments with tritium [7] are possible employers of the $^{37}$Ar source.
2 Technology of production by neutron irradiation

The 1 MCi $^{37}$Ar used for the gallium detector calibration neutrino source was manufactured by irradiating a piece of pressed calcium oxide in the fast breeder reactor BN-600 in Russia [5]. The technology was based on the $^{40}$Ca(n,α)$^{37}$Ar reaction. The fast neutron flux was measured by an organic scintillator [8]. A special facility was built [9] in order to extract the gaseous $^{37}$Ar sample from the CaO target. An obvious disadvantage of the method is that after neutron irradiation there is a lot of $^{39}$Ar - in [5] they report the contamination to be of 0.34% of the gas volume fraction.

3 Technology of production by proton irradiation

The reaction $^{37}$Cl(p,n)$^{37}$Ar looks to be able to produce much more pure samples of $^{37}$Ar. One of the first usage of the method was published in [10]. We have developed a technique of preparation of the target based on a KCl film. The target is a Nb foil $20\times10\times1$ mm with a spot of thin KCl film deposited at the foil in vacuum. The spot is roughly circular with the area of $1.5$ cm$^2$. The thickness of the film is $100\ \mu$m, the mass of the KCl is about 30 mg. The target was firstly irradiated at the Moscow State University proton cyclotron of the Institute of Nuclear Physics; the energy of protons was $E_p=7$ MeV and the current was $I_p=2\ \mu$A.

The calculation of an expected activity of $^{37}$Ar was done without taking into account of ionization energy loss. The maximal expected value of the intensity may be estimated as

$$N = N_p\sigma n = \frac{I_p\Delta t}{e}\sigma\rho d\frac{N_A}{A}$$

Here $N$ is the number of $^{37}$Ar atoms produced in the reaction; $e$ is the electron charge, $1.6\cdot10^{19}\ \text{Q}$; $N_p$ is the number of protons bombarded the target during irradiation for the time period $\Delta t$ and the current $I_p$; $\sigma$ is the cross-section of the reaction; $\rho$, $d$ is the density and thickness of the target; $A$ is the atomic number of the target; $N_A$ is the Avogadro constant, $6.02\cdot10^{23}\ \text{mol}^{-1}$.

An isotope $^{37}$Ar is produced in the reaction $^{37}$Cl(p,n)$^{37}$Ar that has a cross-section of $\approx 0.5$ barn at the proton energy $E_p=7$ MeV. The target KCl has the molar mass of $74.5\ \text{g/mol}$ and the density of $1.98\ \text{g/cm}^3$. Taking into account the 24.2% abundance of $^{37}$Cl in the natural target we may expect for 2 hours
irradiation $N = 3.5 \cdot 10^{11}$ atoms of $^{37}\text{Ar}$. Because half-life of $^{37}\text{Ar}$ is 35 days it corresponds to $5.7 \cdot 10^4$ Bq of the intensity immediately after end of bombardment. The real sample was obtained after 2-hours irradiation and filling a proportional counter at special system [11]. The proportional counter was made according to the technology described in [12]. The result of the intensity measurement was about $5.3 \pm 0.6$ Bq that is in good agreement with the calculation.

4 Conclusion

The technology of production of pure $^{37}\text{Ar}$ based on irradiation the KCl target with protons with an energy of a few MeV is developed and tested for small amount of source. The proportional counter is most suitable detector to measure a tiny amount of $^{37}\text{Ar}$.

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