The modern experimental data concerning structure of atomic nuclei are insufficient for solving fundamental problems of physics. Lack of information is especially sensitive in the field of low-energy nuclear interactions, where a lot of uncertainties related to the processes of interaction between very low energy charged particles and nuclei, exist.

Last time nuclear astrophysics has strongly developed, and astrophysicists need new reliable data on the cross-sections of the reactions involving low-energy light nuclei. The problems of controlled thermonuclear synthesis and medical practice suffer from lack of information of this sort too. One can obtain these data, provided the precision experiments, in particular, on measurement of the cross-sections of the reactions \((p, \gamma)\) and \((p, a)\) on light nuclei, which accompany processes of star burning [1].

In this work the beam of protons accelerated to 1.2 MeV is used.

The experimental facility (figure 1) consists of the target vacuum operational chamber having dimensions 600x300 mm, disposed at the end of the ion guide of the accelerated charged particle beam. In the center of the chamber a target is installed in the beam axis. The target holder represents a goniometer head [2] that possesses six extents of freedom. The charged particle beam is formed by means of two diaphragms disposed in front of the operational chamber, positioned two meters apart from each other.

The products of nuclear reactions are analyzed by means of three detectors:

1. The Germanium gamma detector that records gamma quanta of the energies up to 10 MeV. The cryostat with the detector is introduced to the target chamber from below at an angle of 90° with respect to an incident particle beam. The vacuum space of the chamber is separated from the cryostat with the detector by an aluminum cap having an open entrance on the bottom and a thin window on a target side. A distance of the cap surface on the target side can be varied up to the beam axis.

2. The hard gamma quanta are recorded with high efficiency by means of two scintillation large-volume detectors. One of them is disposed on a car allowing to study the angular distribution of gamma quanta through hermetic windows of the vacuum chamber. The second scintillation detector is disposed at the resonance chamber in the particle beam exit. The resonance chamber is provided by a system allowing to measure the
Fig. 1. Appearance of the installation
energies of incident accelerated particles within ±20 keV, as well as to study profiles of the implanted ion distribution by the technique of nuclear reactions.

In view of application of the back scattering technique in the fields of radiation physics and physics of atomic nucleus, two surface-barrier detectors are installed. One of them is fixed rigidly on a holder at and angle 135° with respect to an incident particle beam and the other is fixed to a mechanism capable to rotate around the target by 360° with a step of 6°.

With the preserved dispositions of the recording and analyzing systems, the products of nuclear reactions of interactions between nuclei of aluminum and beryllium have been studied.

By means of the installation described above, the calibration measurements of the gamma spectra for the \((p, \gamma)\) reactions on the targets from aluminum, aluminum oxide \((Al_2O_3)\) and beryllium have been carried out. The aluminum oxide film \(\sim20\) mkg/cm\(^2\) thick has been obtained by etching the aluminum foil; as a result, the oxide has been remained as a non-etched self-confining film. The thin beryllium target has been manufactured by means of beryllium vacuum deposition on the stainless steel substrate \(4\) mm thick.

Measurements have been carried out in the proton energy range from 340 to 1050 keV with the beam current up to 2 \(\mu\)A. The targets are used without additional cooling, and the current higher than 1-2 \(\mu\)A haven’t been supported. A distance between the germanium detector surface and the incident proton beam axis comprises 3.5 cm. One measurement lasts from 20 minutes to three hours.

In figure 2 the \(\gamma\) spectrum obtained in the \(^{27}Al(p, \gamma)^{28}Si\) reaction is shown, and in figure 3 the reduced cross-section of this nuclear reaction occurred at a thin target from aluminum oxide and the yield of the reaction for the first excited state in \(^{28}Si\), accompanying the gamma emission, versus the proton energy are depicted.

![Fig. 2. \(\gamma\)-ray spectrum obtained with the 996 keV protons. The 40 cm\(^3\) detector was at an angle 90° with respect to the beam direction and 3.5 cm from the beam spot on the target. The thin Al\(_2\)O\(_3\) target was employed for this.](image-url)
As in a thick target the incident protons loose its energies within the entire energy range, the yield graph has a step-like shape within the resonance energy interval, and the yield values increase when the proton energy is getting larger.

For a thin target from aluminum oxide the peaks within the range of the \( (p, \gamma) \) nuclear reaction are clearly observed, in accordance with the data [3].

At the same time, the proton back scattering spectrum has been measured by the charged-particle silicon-lithium surface-barrier detector. The detector energy resolution comprises 15 keV; so the spectral lines of aluminum and oxygen can be observed, and later the carbon line has appeared.

![Graph](image)

**Fig 3.** Experimental 1779 keV \( \gamma \)-ray yield as a function of proton energy of the reaction \( ^{27}\text{Al}(p, \gamma)^{28}\text{Si} \) is shown for the thick target (top curve) and the peaks (under top curve) this is the counts of the known resonances obtained for the thin aluminium target.

As the number of oxygen nuclei in the aluminum oxide film is even larger than the number of aluminum nuclei, we hoped to observe products of the \( ^{16}\text{O}(p, \gamma)^{17}\text{F} \) nuclear reaction. Actually, the appropriate \( \gamma \) emission, usually occurred as a result of discharge of the \( ^{17}\text{F} \) excited states, hasn’t been revealed. May be, the reason is a large magnitude of the \( ^{27}\text{Al}(p, \gamma)^{28}\text{Si} \) cross-section, compared to that of the reaction on oxygen, leading to suppression by enhanced background from the reaction on aluminum.

In measurements of the \( ^{7}\text{Be}(p, \gamma)^{10}\text{B} \) cross-section of the nuclear reaction (see figure 4) the curves of the \( \gamma \) excitation functions can be divided into two groups (see figure 5). The low-energy transitions (413.8, 718.3 and 1021.9 keV, emitting from the lower \( ^{10}\text{B} \) levels, refer to the first group. The appearance of curves for these \( \gamma \) transition functions (figure 15) is in good agreement with the data [4].
As for a lesser difference in the reaction cross-section versus the proton energy, it can be explained in our case by the fact that in our measurements a thicker target has been used, allowing to suppress stronger the low-energy protons than the high-energy ones; so within the proton low-energy range the reaction products from a larger proton energy range are recorded for a single measurement.

![Pulse height spectrum of the reaction $^9$Be(p,γ)$^{10}$B obtained with 1 MeV protons. The detector was at an angle of 90° with respect to the beam direction. All energies are quoted in keV](image)

Another group covers the $\gamma$ transitions within the spectrum hard energy range: 6469, 6976 and 7484 keV. Appearance of the excitation functions for these transitions is somewhat different from that for the first group, as the produced resonances aren’t the same.

**REFERENCES**