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# POLARIZED DEUTERON BEAM AT THE DUBNA SYNCHROPHASOTRON

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The Dubna 4.5 GeV/nucleon synchrophasotron is used for research in the field of relativistic nuclear physics. It accelerates a wide set of nuclear beams. In the last few years experimental possibilities of the synchrophasotron have been extended by using a polarized deuteron beam[1].

For this purpose some facilities are developed and used. They are the following: a cryogenic source of polarized deuterons POLARIS[1-4], a low-energy polarimeter behind the linac[5,6], a recoil particle spectrometer[7], and a magnetic spectrometer ALPHA[8,15]. A layout of these set-ups near the synchrophasotron is presented in fig.1.

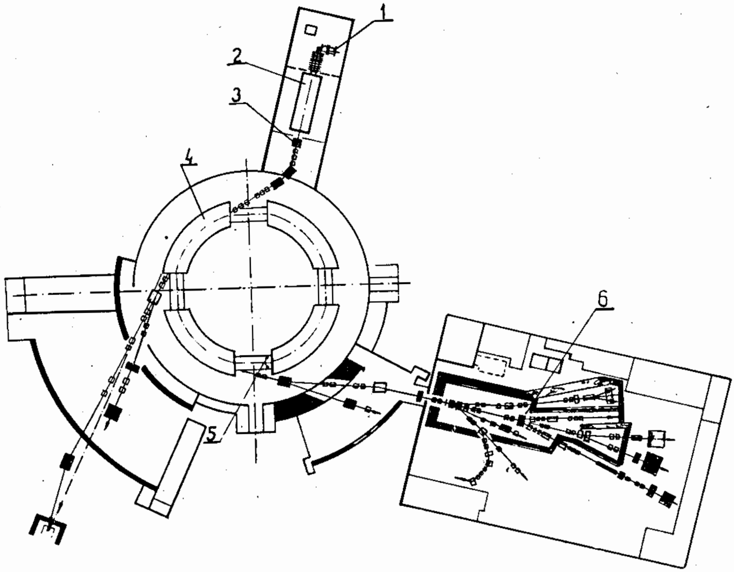


Fig.1. A layout of the systems for polarization research around the synchrophasotron. 1 - POLARIS, 2 - 5 MeV/nucleon linac, 3 - low-energy polarimeter, 4 - synchrophasotron, 5 - recoil particle spectrometer, 6 - two-arm spectrometer ALPHA.

## SOURCE OF POLARIZED DEUTERONS

The polarized deuteron source POLARIS operates using the atomic beam method. The major part of power supply in the sources operating by this method is needed for vacuum pumps

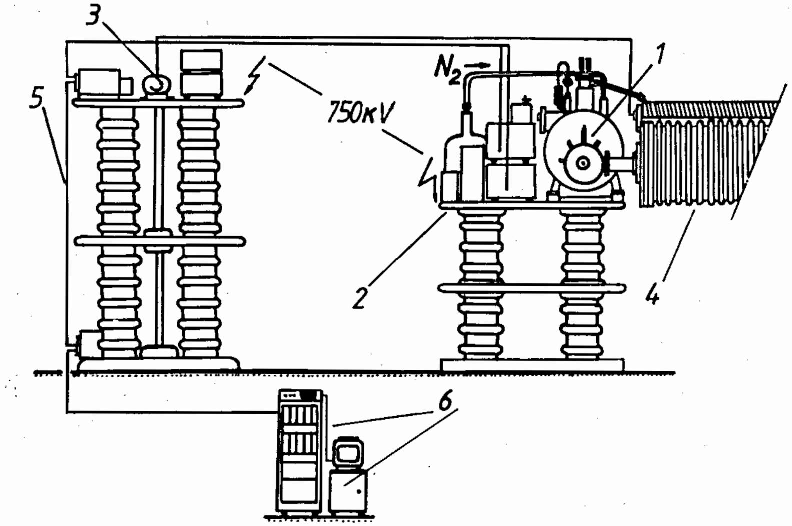


Fig.2. A layout of the cryogenic polarized deuteron source POLARIS on the high voltage terminal. 1 - POLARIS, 2 - high voltage terminal, 3 - autonomous power supply, 4 - preaccelerator tube, 5 - fiber glass lines, 6 - microcomputer for the test and control systems.

and magnets. Ion sources are usually installed on a high voltage terminal (fig.2). This restricts the dimensions of the source and the power of autonomous power supply.

According to this problem the cryogenic type of a polarized deuteron source has been suggested and developed (see fig.3). Vacuum in the cryogenic source is supplied due to gas condensation on the cryosurfaces at the LHe-temperature. Magnetic fields are set up by the superconducting magnets operating in a persistent current state. The cryogenic source requires power only for the R.F. and control systems.

The cryogenic source POLARIS for a beam of polarized deuterons was installed at the accelerator in 1981, and the beam was first accelerated to high energies at the synchrophasotron[1].

The following processes have been realized in this source (see fig.4):

DISSOCIATION. Atomic deuterium is produced by a high frequency discharge of 80 MHz in a 7 $cm^3$ pyrex volume at a pressure of several torr. The discharge power is about 700 W. The dissociator tube is closely fitted into a teflon block having a thermal contact with a shield at $77^0$K.



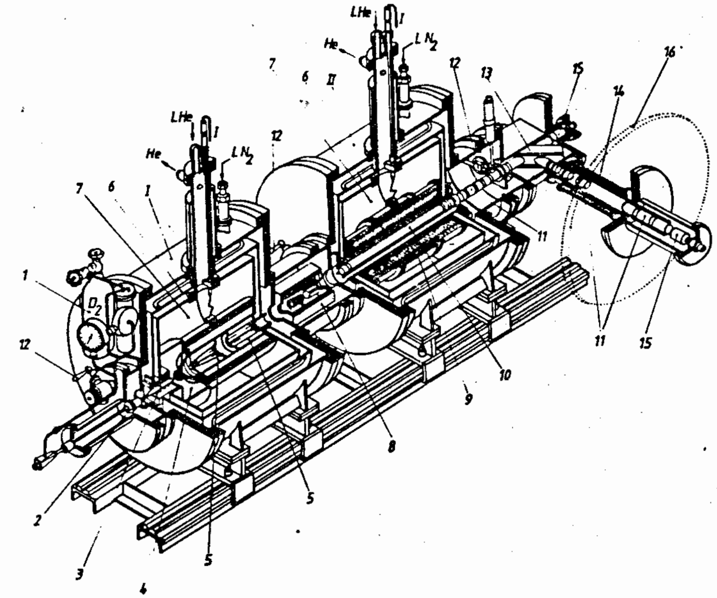

Fig.3. A general view of the polarized deuteron source POLARIS. I - polarized atom source, II - ionizer. 1 - $D_2$ volume, 2 - electromagnetic gas valve, 3 - dissociator, 4 - nozzle chamber, 5 - sextupole magnet, 6 - nitrogen shield, 7 - helium cryostat, 8 - R.F.cell, 9 - SC solenoid, 10 - electron optics, 11 - ion optics, 12 - vacuum gate, 13 - electrostatic mirror, 14 - solenoid of the spin-precessor, 15 - Faraday cup, 16 - position of the preaccelerator flange.

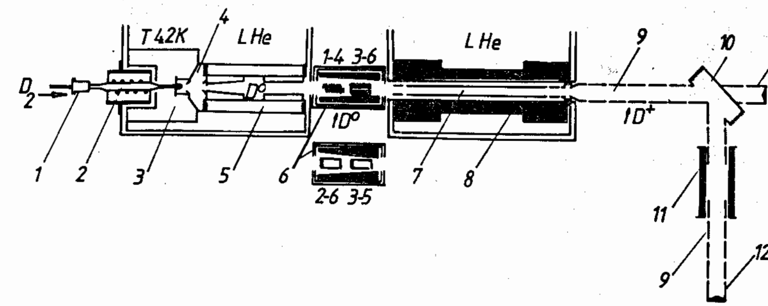


Fig.4. A principal diagram of the source POLARIS. 1 - electromagnetic gas valve, 2 - dissociator, 3 - nozzle chamber, 4 - skimmer chamber, 5 - sextupole magnet, 6 - R.F.cells, 7 - electron optics, 8 - SC solenoid, 9 - ion optics, 10 - electrostatic mirror, 11 - solenoid of the spin-precessor, 12 - Faraday cup.

FORMATION OF THE COLD ATOMIC BEAM. After the dissociator a gas flow is supplied to a teflon pipe (l = 95 mm, $\phi$ 3 mm) the end of which has a temperature of $40^0$K. The deuterium expense equals 0.005 $cm^3$ (STP)/pulse. The atomic beam under molecular flow conditions is formed by a skimmer. The skimmer diameter is 4.5 mm. The distance between the end of the teflon pipe and the skimmer is 11 mm. The most probable velocity of beam atoms is equal to 1000 m/sec, the temperature of the beam is $30^0$K[12] (see fig.5).

SPATIAL SPIN SEPARATION OF THE ATOMIC BEAM. This process takes place in the gradient field of two superconducting sextupole magnets. The sextupole magnet configuration was determined by computing simulation[13]. The aperture of the first magnet increases from 10 mm to 18 mm along a length of 100 mm and that of the second magnet is constant with a diameter of 28 mm along a length of 145 mm. The distance between the magnets is 45 m m. The field on the tips equals 1.0 T. The distance between the skimmer and the entrance of the sextupole magnet is 33 mm (see fig.6).

NUCLEAR POLARIZATION. The nuclear polarization of the atomic deuterium beam is performed by the radio-frequency method due to transitions between the hyperfine structure states of

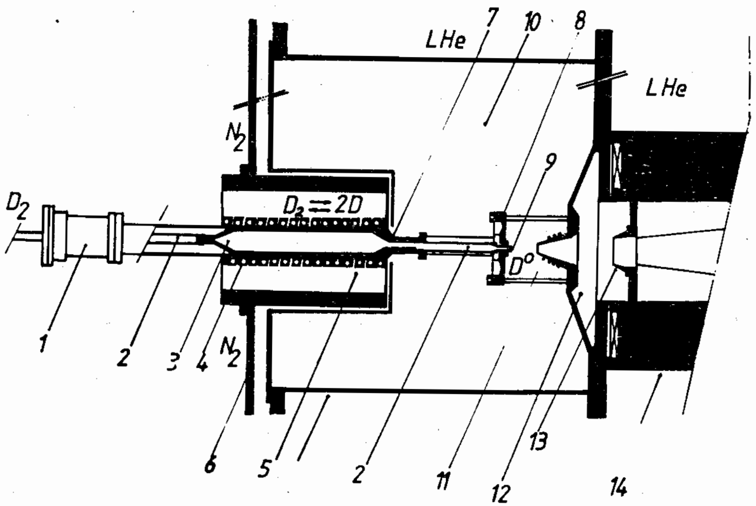


Fig.5. Details of the atomic source. 1 - electromagnetic gas valve, 2 - teflon pipe, 3 - dissociator tube, 4 - spiral resonator, 5 - teflon block, 6 - nitrogen shield, 7 - teflon sleeve, 8 - accomodator, 9 - nozzle, 10 - nozzle chamber, 11 - skimmer, 12 - skimmer chamber, 13 - collimator, 14 - sextupole magnet.



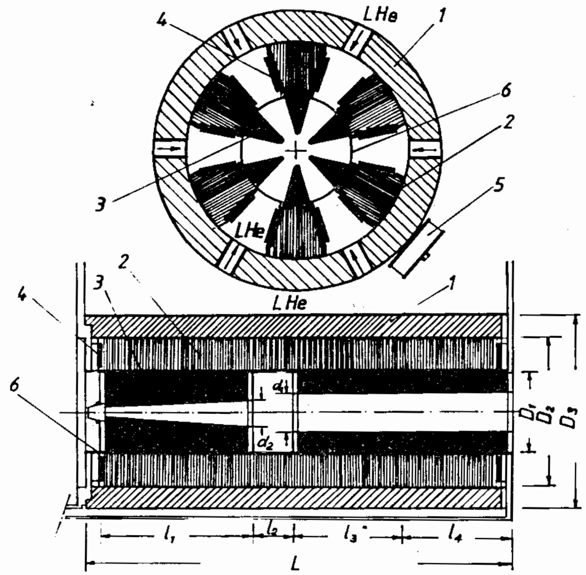


Fig.6. SC sextupole magnet. 1 - yoke, 2 - pole, 3 - pole tip, 4 - SC coil, 5 - switch, 6 - cryostat pipe.

deuterium atoms in the magnetic field. Weak field and strong field transitions are realized. Two types of R.F. cells have been developed: a vector polarization cell ($P_z = \pm\frac{2}{3}$) for the transitions $1 \rightarrow 4$ and $3 \rightarrow 6$ and a tensor polarization cell ($P_{zz} = \pm 1$) for the transitions $2 \rightarrow 6$ and $3 \rightarrow 5$.

Each R.F.cell includes two resonators and a dipole magnet with a positive magnetic field gradient along the beam (see fig.7). To avoid the influence of the magnetic field of the ionizer solenoid an R.F.cell is surrounded with three magnetic shields. The operating parameters of the R.F. cells are presented in table 1.

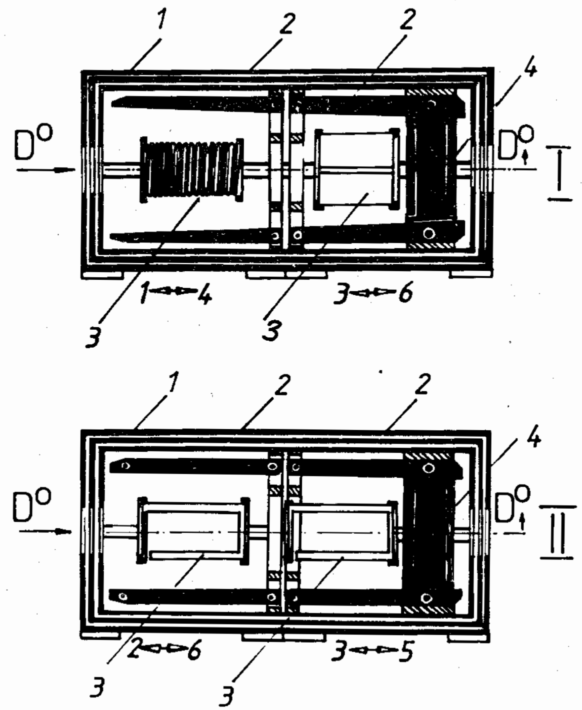


Fig.7. R.F.cell. 1 - magnetic shield, 2 - dipole magnet, 3 - resonator, 4 - magnet coil.

Table 1

| Transition | Ho, G | $\frac{d}{dz}$ Hz, G/cm | Hi, G | f, MHz | l, cm | d, cm | β, |
|---|---|---|---|---|---|---|---|
| 1 → 4 | 7.0 | 1.0 | ~1 | 9.4 | 4.5 | 2.5 | ~32 |
| 3 → 6 | 43 | 1.4 | ~1 | 346.4 | 4.5 | 2.5 | ~23 |
| 3 → 5 | 68 | 1.9 | ~1 | 320.1 | 4.2 | 1.6 | ~17 |
| 2 → 6 | 38 | 1.4 | ~1 | 384.9 | 4.2 | 1.6 | ~23 |

Ho - static field strength in the center of the R.F.-cavity, $\frac{d}{dz}$ Hz - static field strength gradient, Hi - amplitude of the RF field, f - frequency, l - length of the R.F.-cavity, d - diameter of the R.F.-cavity, β - adiabatic factor.

BEAM IONIZATION. The polarized atomic beam is ionized by an electron impact in a Penning ionizer (see fig.8). The beam of electrons oscillates between the reflecting and extracting electrodes in the magnetic field of the superconducting solenoid (B = 2.6 T). The polarized deuterons extracted from the ionizer are focussed by ion optics. To visualize a pulsed

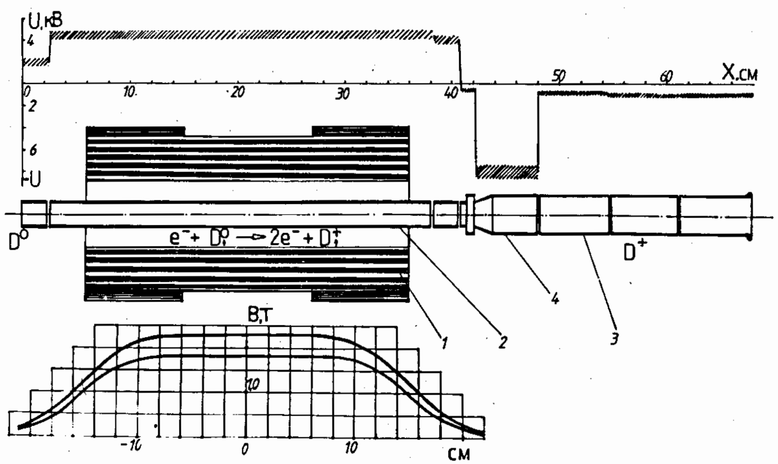


Fig.8. The magnetic field and electrode voltages of the ionizer. 1 - SC solenoid, 2 - electrodes of electron optics, 3 - electrodes of ion optics, 4 - extracting electrode.



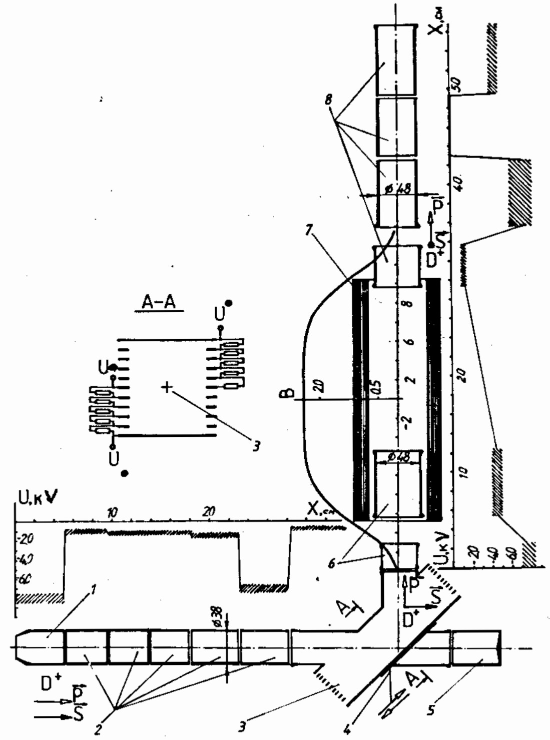


Fig.9. System for orientation of the deuteron spin. 1 - extracting electrode, 2,6 -electrodes of ion optics, 3 - electrostatic mirror, 4 - gate, 5 - Faraday cup, 7 - solenoid of the spin precessor, 8 - electrodes for adjustment with the preaccelerator tube.

operation of the ionizer, voltages and currents of the ionizer electrodes are measured and transmitted to the console monitor.

SPIN ORIENTATION OF DEUTERONS. To avoid depolarization effects during an acceleration cycle of the synchrophasotron, nuclear spin should be oriented along the magnetic field of the accelerator ring. This is achieved by bending the beam at 90° in an electrostatic mirror and by subsequent spin rotation in the magnetic field of the spin precessor solenoid (see fig.9). The energy of the deuteron beam is about 3 keV at the output of the source while the current is about 200 μA (see also table 3).

## CONTROL SYSTEM

The source dissociator, R.F.cells of nuclear polarization, ionizer electrodes and spin microprocessor and electronics installed on a high voltage terminal. Information exchange between the microprocessor and the microcomputer placed on the console is performed by a fiber glass optic system[16]. A flag signal is supplied to the experimental physics setups at a moment of R.F. cell switching.

## LOW-ENERGY POLARIMETER

In order to measure the vector and tensor polarization of the beam behind the linac, a polarimeter with $^4He$-, $^3He$-targets bas been developed[5,6]. For vector polarization measurement the reaction $^4He(\bar{d},d)^4He$[9-11] is used. The deuterons elastically scattered backward ($\theta_{lab} = 126°$) have a large asymmetry. Not deuterons but recoil α-particles emitted at an angle of 15° are detected by the thin semiconducting detectors (60 μm). For tensor polarization measurement ($^3He(\bar{d},p)^4He$) fast protons emitted forward are detected. The results of the polarization measurements behind the linac are summarized in table 2.

Table 2

| Transition | Polarization | Linac output | Recoil particle spectrom. | Spectrometer ALPHA |
|---|---|---|---|---|
| 3 → 6 | Pz | 0.47±0.04 | 0.44±0.03 | 0.52±0.05 |
| | Pzz | - | - | 0.00±0.08 |
| 1 → 4 | Pz | -0.37±0.04 | -0.39±0.03 | -0.32±0.04 |
| | Pzz | - | - | 0.08±0.08 |
| 3 → 5 | Pz | - | - | 0.19±0.04 |
| | Pzz | -0.06±0.08 | - | -0.66±0.05 |
| 2 → 6 | Pz | - | - | 0.22±0.05 |
| | Pzz | 0.54±0.08 | - | 0.53±0.05 |

## INTERNAL BEAM POLARIMETER

To determine the degree of beam polarization during acceleration, an internal polarimeter was mounted inside the ring of the synchrophasotron[7]. The products of interaction betwen the polarized deuteron beam and the thin film $CH_2/CD_2$ target are detected by a two-arm spectrometer with semiconducting detectors. The vector polarization is determined by measuring the left-right asymmetry of recoil protons/deuterons. The results of this measurement are given in table 2.

## HIGH ENERGY POLARIZATION MEASUREMENT

To measure the deuteron polarization of a slow extracted deuteron beam, the two-arm magnetic spectrometer ALPHA is used[8,15]. The measurement is based on the left-right asymmetry of the deuteron forward scattering of hydrogen, where the well-known analyzing powers Ay and Ayy can be used to 3 GeV/c. The results of the polarization measurement are shown in table 2.



## USE OF THE POLARIZED BEAM

The acceleration of polarized deuterons is approximately 15% of the running time. The beam of polarized deuterons is extracted from the accelerator by the slow and fast extraction systems (fig.1). The results of the polarization measurement presented in table 2 prove the absence of depolarization during the acceleration. This corresponds to the calculations according to which a main resonance exists at energies of more then 10 GeV. The synchrophasotron is a weak focusing machine ($\nu_z^o = 0.87$).

The intensities of the polarized deuteron beam at different places are presented in table 3.

Table 3

| Position | Source Output | Linac Output | Recoil Particle Spectromet. | Spectrometer FALPHA |
|---|---|---|---|---|
| Beam energy | 3 keV | 10 MeV | | 9 GeV |
| Beam intensity, part. /pulse | $5 \cdot 10^{11}$ (200 μA) | $2.5 \cdot 10^{10}$ | $1.25 \cdot 10^9$ | $5 \cdot 10^8$ |

Some groups of physicists use the polarized deuteron beam for studying nucleon-nucleon scattering and deuteron structure.

It is planned in future to increase the intensity of the polarized deuteron beam up to 1 mA by using the charge exchange ionizer[14].

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Поляризованный пучок дейтронов на синхрофазотроне

Кратко описываются экспериментальное оборудование и установки для ускорения поляризованного пучка дейтронов на синхрофазотроне ОИЯИ. Приводятся основные характеристики криогенного источника поляризованных дейтронов ПОЛЯРИС. Представлены результаты измерений интенсивности ускоренного пучка, а также векторной и тензорной поляризации на выходе линейного ускорителя ЛУ-20 и выведенном пучке, векторной поляризации внутри кольца синхрофазотрона.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1990

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Polarized Deuteron Beam at the Dubna Synchrophasotron

The experimental equipment and setup used to accelerate a polarized deuteron beam at the Dubna synchrophasotron are briefly described. Basic characteristics of the cryogenic source of polarized deuterons POLARIS are presented. The results of measurements of the intensity of the accelerated beam, vector and tensor polarization at the output of the linac LU-20, inside the synchrophasotron ring and in the extracted beam are given.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1990