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Modeling polarized atomic beam source (PABS)

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Introduction. The PolFusion experiment [1] aims to study the nuclear fusion of polarized deuterium and deuterons at beam energies in the laboratory frame up to 100 keV. There are two reaction channels considered for this process:

$$d + d = \begin{cases} t + p \\ ^3\text{He} + n \end{cases}$$

Studying these channels will expand our understanding of primary nucleosynthesis and the early stages of stellar evolution.
To conduct the experiment, it was necessary to create a polarized gas target. In the literature, three main types of such sources can be found: Lamb-shift sources (LSS)[2], optically pumped sources (OPPIS) [3], and sources based on Stern-Gerlach apparatus and hyperfine transition cells (PABS) [4].
The most suitable option, chosen by the authors of this work, was a polarized atomic beam source (PABS). It allows to obtain a target with maximum polarization and intensity. To select its optimal design, the authors performed simulations of the polarizer operation.
Principle of Operation of PABS. Molecular gas is fed into a radiofrequency dissociator, where gas molecules are split into atoms. Due to the pressure difference between the dissociator and the vacuum chamber, the atomic gas passes through a cooled nozzle. The atoms energy in the beam become equal to the thermal energy corresponding to the nozzle temperature. The atomic beam then passes through a skimmer and collimator forming the beam profile. The beam subsequently enters a polarizer consisting of a system of separating magnets and hyperfine transition cells. According to the Stern-Gerlach effect, atoms with an electron spin of +1/2 are focused when passing through the system of multipole magnets, while atoms with a spin of -1/2 are defocused and removed from the tract. To polarize the beam, hyperfine transitions between the energy levels of the 1S state of deuterium atoms are used. It occurs in RF cells.
Verification of the Polarizer Simulation Program. To assess the accuracy of the program, it was necessary to simulate the operation of existing ABS sources and compare the simulation results with experimental data. The following sources were chosen for testing:
1.ANKE ABS [5]
2. HERMES ABS [6].
Based on the testing results, the following conclusions were drawn [7]:
1. The intensity calculated during the simulation closely agrees with the intensity measured at experimental facilities.
2. The degree of polarization calculated during the simulation with considering the corresponding uncertainties lies within the range of experimental data.
Thus, the developed software meets all requirements. Its use for optimizing the PABS design is justified.
Selection of the Optimal PABS Design. The optimal design of the Stern-Gerlach system was chosen based on the optimal polarization degree (vector and tensor) and output beam intensity. The authors proposed three possible polarizer designs.
In Design No. 1, all lenses are sextupoles. In Design No. 2, some of the lenses are replaced with quadrupole lenses. In Design No. 3, all lenses are replaced with octupole lenses. Calculations are performed under identical initial conditions: nozzle temperature of 88 K and number of particles of 105 [7].
From the values obtained through the simulation, it was concluded that the source with Design No. 1 is optimal since the polarization values for this design are closest to the maximum theoretical values. It is also worth noting that the difference in intensity [7] between sources with Design No. 1 and No. 3 is insignificant.
Optimization of PABS by Nozzle Temperature. The atom speed after exiting the dissociator has a Maxwellian distribution with the most probable speed given by:
$v=\sqrt{2kT/m}$
where k is the Boltzmann constant, m is the particle mass, and T is the nozzle temperature. The speed determines the likelihood of an atom in the beam passing through the spin-separating magnet system. The written program thus allows for the assessment of the optimal nozzle temperature value. The simulation resulted in an optimal nozzle temperature of (81.3 ± 1.6) K, which agrees within the uncertainty with the experimental

value of (82.9 ± 1.4) K [8].
Conclusion. The authors developed a program allowing for an accurate calculation of the polarization degree and beam intensity. During this work, the optimal polarizer design was chosen and PABS was optimized by the nozzle temperature.

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