Abstract

At the superconducting 130 MeV Darmstadt electron linac S-DALINAC a new source of spin-polarized electrons using a GaAs cathode has been installed, opening the path for experiments with polarized electron and photon beams for nuclear structure studies at low momentum transfers, e.g., the search for forward-backward asymmetries originating from parity non-conservation (PNC) in the photon-induced fission process of $^{238}\text{U}$.

Detailed studies of different properties, e.g., the energy dependence of fission modes, the population of fission isomers, or the search for (PNC) effects in the photon-induced fission process of $^{238}\text{U}$, depends on high quality data, therefore needing high luminosities. An active gas target containing uranium may overcome the problem that large solid target thicknesses cause poor energy and angular resolution.

A single Frisch-grid ionization chamber has been built to test a mixture of standard counting gases (e.g., argon) with depleted uraniumhexafluoride ($^{238}\text{UF}_6$) using a triple alpha source, evaluating signal quality and drift velocity. For mass fractions up to 2 percent of $^{238}\text{U}$ in the counting gas. The drift velocity increases with rising UF$_6$ content, while a good signal quality and energy resolution is preserved.

Keywords:
photo fission, S-DALINAC, active target, UF$_6$, gaseous detector, ionization chamber, electrical properties

PACS: 25.85.Jg, 29.25.Bx, 29.27.Hj, 29.40.Cs, 51.50.+v

1. S-DALINAC

Around the superconducting Darmstadt electron linear accelerator S-DALINAC [1] a multi-facetted nuclear-physics program is realized. The S-DALINAC provides beam energies ranging from as low as 2.5 MeV up to typically 80-90 MeV, peaked at the design value of 130 MeV. At the S-DALINAC, research is done in the areas of nuclear structure, nuclear astrophysics, fundamental studies as well as the continuous upgrade of the accelerator, strongly supported by a center of excellence funded by the German Research Foundation (DFG). Nuclear resonance fluorescence experiments [2] as well as ($\gamma$,n)-photoactivation experiments [3, 4] are performed downstream of the

---

*Work supported in part by DFG through SFB 634, by the state of Hesse through the LOEWE center HIC for FAIR, and through the GSI-TU Darmstadt cooperation agreement.

*Corresponding Author

Email address: eckardt@ikp.tu-darmstadt.de (C. Eckardt)
injector at energies between 2.5 MeV and 10 MeV with average beam currents of up to 60 μA [5] at the 10 MeV bremsstrahlung facility. Recent fission studies [6] complete the experimental program at this site.

Passing the main linac increases the beam energy up to 50 MeV. The use of two recirculations yields a maximum energy of 130 MeV. A high-resolution energy-loss spectrometer [7] for form-factor measurements [8] and a large-acceptance QClam spectrometer for coincidence experiments [9] or single-arm scattering at 180° [10] are available. Photons are on hand at a high-resolution photon tagger [11] for astrophysically relevant photodisintegration and photon scattering studies between 5 MeV and 20 MeV and at a bremsstrahlung site for about 50 - 100 MeV electron beams [12], currently prepared for an experiment on proton polarizability.

The research programme is extended by the implementation of a polarized electron source, unraveling the potential for polarized electron and photon beams at low momentum transfer. First experiments to be performed are presented in an overview given in Ref. [13].

2. Polarized Injector SPIN

A laser-driven strained-layer superlattice GaAs electron source [14] along the lines of Ref. [15] is the core of the S-DALINAC polarized injector SPIN. First set up at an offline test stand site [16], where all components and necessary procedures had been investigated, the electron gun and its beam line have been implemented at the S-DALINAC between the unpolared thermionic source and the injector linac in 2010. A new chopper-prebuncher system has been set up and tested to match the 3 GHz time structure of the S-DALINAC, and a two-cell capture cavity [17, 18] has been re-installed at the S-DALINAC injector for compensating the difference between the lower (100 keV) injection energy of polarized electrons with respect to the unpolarized source (250 keV). Beam intensities of up to 50 μA, cathode lifetimes of about 100 hours, and small normalized emittances of about 0.15 mm mrad have been achieved. A pulsed operation mode was demonstrated as well as spin rotation by a Wien filter. Utilizing a 100 keV Mott polarimeter, a degree of polarization of about 86 (3) % was determined.

Two laser systems drive the source: a diode, optionally pulsed, for 3-GHz continuous-wave operation of the S-DALINAC and a Ti:Sapphire laser aimed at short laser pulses in the femtosecond regime with repetition frequencies of 75 MHz. The laser beam transport is done via optical fibre in case of the diode laser and a 40 m long evacuated transfer line for the intense Ti:Sapphire beam. Various components have been developed, e.g., a spectrometer for laser diagnostics, an autocorrelator for laser pulse length measurements, a Stokes polarimeter monitoring the degree of polarization, and an active stabilization of pointing and centering through the beam transport line.

3. Photofission experiments

A detailed microscopic theoretical understanding of the fission process has not been achieved yet [19]. In order to gain insight, e.g., fissioning shape isomers or mass and total kinetic energy (TKE) distributions as well as fragment angular distributions may be investigated. Detailed data may help elucidate the structure of intermediate states as well as the shape of the fission barrier, guiding theoretical studies for a better microscopic description of fission dynamics. Recently results on the mass and TKE distributions, parameterized in the fission-mode concept by Brosa et al. [20], from photo-fission of \(^{234,238}\text{U}\) have been obtained [6]. These experiments were done using a twin Frisch-grid ionization chamber [21] with a solid uranium target located at the common cathode. An important step for a correct analysis is the determination of the fragment emission angle with respect to the target, which can be extracted from the electron drift times to the anode [22]. Higher luminosities are desirable for a significant data improvement.

A different focus is the search for parity non-conservation (PNC) in the \(^{238}\text{U}(\gamma,f)\) reaction. Given the ratio of the weak and strong coupling constants, a PNC strength of \(10^{-7}\) is expected. Previous experiments with neutron-induced fission have shown an enhancement to \(10^{-4}\) [23, 24, 25]. Like in investigations on the helicity-dependent transmission of polarized neutrons from various targets (see, e.g., ref. [26] for an overview), the high level density and the selective excitation of states by low angular momentum transfer [27] is used to explain the enhancement. Even in the case of a broad excitation spectrum detectable effects should exist, as argued by Flambaum and Gribakin [28] as well as Wettig and Weidenmüller [29]. As the enhancement mechanism is not well understood, a high demand for new data using a different probe is given. The recently installed polarized electron injector SPIN will match this need, producing circularly polarized bremsstrahlung with a high degree of polarization close to the end-point energy, enabling the search for forward-backward asymmetries of the light and heavy fission fragments.
As a feasibility study first test experiments with unpolarized beam using a twin Frisch grid ionization chamber were carried out [30]. The test experiments demonstrated the usefulness of an ion chamber at the 10 MeV bremsstrahlung facility of the S-DALINAC, yet the required count rates were not achieved as indicated by the fission yields. As the accelerator is limited to 60 \( \mu \text{A} \), increasing the target thickness is mandatory, even with an upgrade to 150 \( \mu \text{A} \) [31] available in the future. Reaching higher luminosities thus requires a denser solid target, however, the mass and angular resolutions deteriorate with increasing target thickness. Therefore, an active gas-target including uranium atoms inside the counting gas is investigated. As UF\(_6\) is available as a gas at temperatures above 56°C, different admixtures with common counting gases, e.g., argon, are studied.

4. Active UF\(_6\) gas-target

For this investigation, a test chamber for UF\(_6\) - argon gas-mixtures has been built. The chamber was designed as a single Frisch-grid ionization chamber with a distance \( D = 4.2 \text{ cm} \) between cathode and grid, and a distance of 1 cm between grid and anode.

As UF\(_6\) is highly hygroscopic and easily forms hydrofluoric acid with even the slightest amount of water vapor, all installed elements of the chamber have been baked to 200°C for at least 12 hours to reduce water content. A high resistance against corrosion is mandatory, too. Hence, for safety reasons, all conducting parts inside the chamber are stainless steel (AISI 316L), and all insulators are polytetrafluoroethylene (PTFE). A leak test has been carried out showing an integral helium leak rate of 9.1 \( \text{mbar} \cdot \text{l} / \text{s} \), keeping water vapor at a minimum after emptying the chamber while ensuring no contamination in the experimental area. After assuring the leak tightness, the chamber was flushed with argon for more than half an hour at a moderate flow rate to remove any residual gas impurities. Thereafter the chamber was evacuated and then filled with argon of purity 6.0 equivalent to a volume of 950 mln (volume in ml under normal conditions).

A triple alpha source containing \(^{239}\text{Pu}\), \(^{241}\text{Am}\) and \(^{244}\text{Cu}\) is used for energy calibration purposes, emitting alpha particles at energies of 5155 keV, 5480 keV and 5795 keV, respectively. The alpha source is mounted on a stainless steel disk on the cathode plane inside the ionization chamber and fixed into position with a PTFE fitting. Electrons created by the energy loss of charged particles inside the active gas volume produce a signal at the anode proportional to the deposited energy. With the shielding inefficiency of the grid taken into account, an energy calibration of the chamber can be obtained. A typical charged particle inside the active volume has its charge center of gravity position denoted by \( \mathbf{X} \). The ratio \( \mathbf{X} / \mathbf{D} \) defines the signal suppression induced at the cathode relative to the anode signal and therefore the emission angle of the charged particle can be deducted.

5. Experimental Results

First the functionality of the chamber at different temperatures between 30°C and 70°C has been tested. Signal quality as well as electron drift velocities were evaluated and an energy calibration was needed. Due to the dimensions of the chamber, only low-energy alpha particles are completely stopped inside the active volume. The produced electrons drift along the field lines towards the anode, inducing a signal on the cathode. Special attention was given to the signal quality, which is visible in Fig. 1 (a). Clearly separated signals can be seen in the two-dimensional plot, indicating a high resolution due to a pure argon atmosphere with no air impurities. The events in Fig. 1 (a) can be used to create an energy spectrum, allowing for an energy calibration, confer Fig. 2 (a). Another important quantity is the drift velocity of the electrons in the active volume. This value was measured at a temperature of 70°C and a gas volume of 950 mln. Normalized to the pressure, results for different electric field strengths are shown in Fig. 3 (a). The behavior of the drift velocity is typical for argon, with a peak value at a small reduced electric field strength of around 100 V/(cm \cdot atm) and saturation at higher field strengths, as can be seen in Fig. 3 (a).

The next step was to test different mixtures of argon gas and small amounts of UF\(_6\). First one mass per cent of uranium, added as UF\(_6\) to an argon volume of 1055 mln, was investigated, later the uranium content was increased to two mass percent, in order to study the behavior of the gas mixture with respect to signal quality and electron drift velocity. Figure 1 (b) gives an indication of the signal quality with an amount of two mass per cent uranium in the system. Obviously, adding UF\(_6\) to the argon gas distorts the signals. As can be seen the mean free range of the alpha particles from the calibration source now exceeds the dimensions of the chamber. Therefore, the alpha particles are
not completely stopped, consequently the signals are washed out. At lower energies, two lines of lower intensity with respect to the calibration source can be seen. Apparently, they originate from the alpha decays of $^{238}$U and $^{234}$U, respectively, taking place close to or on the surface of the electrodes. Overall, many events may be identified, as UF$_6$ is distributed over the entire active volume, thus creating background in the energy spectrum. Events with low cathode pulse height are probably due to UF$_6$ molecules frozen out on the electrodes.

Figure 2 (b) shows the energy spectrum of the calibration source obtained with an argon / UF$_6$ mixture (two mass per cent uranium). Due to the higher alpha radioactivity in the counting gas the background noise level increases. Corresponding to the additional lines in Fig. 1 (b) visible energy peaks for $^{238}$U and $^{234}$U, respectively, show up at energies below the calibration source. With a specific activity of 12.2 kBq/g and an estimated mass of 60 mg, the alpha activity of the $^{238}$U content in the chamber should be about 730 Bq. Although the calculated activity of the $^{238}$U is in the same order of magnitude as the activity of the calibration nuclides, which is around 1 kBq each, the visible energy peak for $^{238}$U is about two orders of magnitude lower than the calibration peaks. Apparently only a small amount of UF$_6$ is located on the electrodes, assuming only uranium near the center of the cathode contributing to this
peak, therefore the idea of a good uniform distribution of uranium within the counting gas holds true. Air impurities might have entered the chamber during the gas filling process, probably due to a contamination of the UF₆ sample. This could be a possible explanation of the observed anti-correlation between anode and cathode pulse height as seen by the slight inclination to the left (cf. Fig. 1 (b)). Nevertheless, this is still under investigation in a second measurement campaign with a renewed gas mixture.

Two different sets of measurements for varying UF₆ concentrations of one and two mass per cent of uranium inside the active volume were taken. The results from the electron drift-velocity measurement are shown in Fig. 3 (b) as a function of reduced field strength. As a reference corresponding values of pure argon data are included. All three data sets show a comparable behavior at small field strengths. In the case of the argon / UF₆ mixture the drift velocity at higher field strengths increases with growing uranium concentration, eventually leading to saturation effects.

6. Outlook

The operation of an ionization chamber with a gas mixture of argon with up to two mass per cent uranium in the form of UF₆ has been demonstrated. Signals from a triple alpha source in the energy range of 5-6 Mev are well resolved after adding some UF₆ content to the gas mixture. During the UF₆ filling procedure, a signal distortion could be seen, an effect, which seemed to recover after some time. This might result from a slight contamination of the uranium sample and could possibly be solved by a second argon flushing. In the future, the counting-gas properties of Ar + UF₆ at higher uranium concentrations of up to 60 mass per cent uranium will be investigated, where the target thickness of the active target would be equivalent to a solid target with a thickness of around 1 mg/cm², as required for high-quality photo-fission data, therefore necessary for the search for PNC effects. Other issues to be investigated are the performance of the active target over a long time period, the reproducibility of the gas behavior as well as test experiments taking photofission data in a bremsstrahlung beam. Some efforts may be taken to improve data collection, e.g., sampling the signals with fast ADCs and improving the signal granularity. Therefore segmented electrode designs are currently under investigation, and a readout system for a larger number of channels is under construction.

References

[30] A. Göök et al., these proceedings.