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 $^{10,11}\text{Be}$ SECONDARY BEAMS

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Elastic scattering, inelastic scattering and charge exchange reaction studies with ^6He , $^{10,11}\text{Be}$ secondary beams

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Motivations

Direct reaction studies play an important role in our understanding of the properties of nuclei. For example, elastic scattering measurements provide unique information on the total nuclear matter density distributions¹⁻²⁾, whereas charge exchange reactions connecting the target ground state with its isobaric analog state are sensitive to the difference between the neutron and proton density distributions³⁾. The availability of unstable nuclear beams has created a renewed interest in this type of studies since nuclei with unusually large proton to neutron ratio are predicted to present new type of structure. The neutron halo observed recently in very neutron rich light nuclei, i.e. ^{11}Li , is such a new phenomenon which has created much excitement. These investigations should help to better characterize the properties of these exotic nuclear species. They could also allow to test the validity of well established nuclear models which often have been adjusted to reproduce the properties of stable or nearly stable nuclei close to the stability valley.

We have commenced at GANIL an experimental programme for the study of elastic, inelastic and charge-exchange reactions induced by light unstable nuclei. These experiments benefit from the high resolution energy loss spectrometer SPEG and from the high quality secondary beams that are provided using the double superconducting solenoid SISSI⁴⁾. We report here on some of the results of the first experiment of this programme which was carried

out in March 1994, where we were interested in light neutron rich-nuclei, in particular, ${}^6\text{He}$ and ${}^{10,11}\text{Be}$.

Experimental methods

The secondary beams were produced by fragmentation of a 75 MeV/nucleon primary ${}^{13}\text{C}$ beam, delivered by the GANIL accelerator, on a 1155 mg/cm^2 carbon production target, located between the two superconducting solenoids of SISSI. The position of SISSI at the exit of the second cyclotron and at the entrance of the beam analysing α -spectrometer allows for an improved collection of secondary beams and transmission to the different experimental areas. This results in roughly one order of magnitude increase in beam intensity.

The experiment reported in this paper is the first one performed with SISSI. The magnetic rigidity of the beam transport system was set close to its maximum value. Table 1 gives the measured composition and the energy of the secondary beams incident on the target. The total intensity of the secondary beam was of the order of 10^7 particles/second for a primary intensity of 2×10^{12} particles/second. The intensity for ${}^6\text{He}$ and ${}^{11}\text{Be}$ was relatively low partly because the prototype production target holder used in this experiment could not accommodate a thick enough target to shift the optimum production rates for these neutron rich fragments to the magnetic rigidity of the beam lines. The momentum acceptance of the system SISSI+ α -spectrometer was of the order of 0.6% and the angular acceptance was around 100 mrad in the horizontal and vertical directions. We ran the experiment with this composite beam (instead of using an achromatic degrader to purify the secondary beam) in order to keep a good quality beam and to avoid any additional loss of intensity for the most neutron-rich fragments.

Table 1

Fragment	E/A	Percentage	Fragment	E/A	Percentage
${}^2\text{H}$	91.5	10	${}^8\text{Li}$	52.5	7
${}^3\text{H}$	42.0	19	${}^9\text{Li}$	42.0	1
${}^4\text{He}$	91.5	18	${}^9\text{Be}$	73.0	1
${}^6\text{He}$	42.0	2	${}^{10}\text{Be}$	60.0	21
${}^7\text{Li}$	68.0	15	${}^{11}\text{Be}$	49.5	4

The secondary reaction target was a foil of $100\mu\text{m}$ thick polyethylene, $(\text{CH}_2)_n$. The scattered particles were identified in the focal plane of SPEG by the energy-loss measured in an ionisation chamber and the residual energy measured in a plastic scintillator. All the fragments could thus be unambiguously identified. The momentum and scattering angle were obtained by

track reconstruction of the trajectory as determined by two drift chambers placed 70 cm apart and located near the focal plane of the spectrometer. The elastic and inelastic scattering of the secondary beam were measured on ^1H , ^{12}C , and ^{208}Pb targets in the range $\theta_{\text{lab}}=0.7^\circ$ - 6.0° , while the charge exchange reactions on ^1H and ^{12}C were obtained from $\theta_{\text{lab}}=0.0^\circ$ to 4.0° .

Figure 1 (left) shows a typical plot of the laboratory scattering angle versus the particle momentum for 60 MeV/nucleon ^{10}Be scattered on a $(\text{CH}_2)_n$ target. The projection on the momentum axis for a 0.1° wide slice at $\theta_{\text{lab}}=2.8^\circ$ is presented in figure 1 (right). The different peaks correspond, from right to left (decreasing momentum) to the elastic scattering of ^{10}Be on ^{12}C , to the inelastic scattering on the first excited state in ^{12}C at 4.4 MeV, and finally to the elastic scattering on the protons in the target. The broad structure underneath the ^{12}C inelastic peak corresponds to the excitation of the first excited state in ^{10}Be at 3.37 MeV which is broadened due to in-flight γ decay. The energy resolution (FWHM) deduced from the elastic scattering on ^{12}C is of the order $\Delta E/E=10^{-3}$, and the angular resolution, which is mainly determined by the angular width of the incident secondary beam is $\Delta\theta_{\text{lab}}=0.3^\circ$. These results are quite unique: for the first time a clear separation between elastic and inelastic scattering is obtained in experiments involving unstable projectiles produced by nuclear fragmentation.

Figure 1 left: θ_{lab} versus momentum for the elastic scattering of ^{10}Be on a $(\text{CH}_2)_n$ target at 60 MeV/nucleon; right: projection on the momentum axis of a 0.1° wide slice at $\theta_{\text{lab}}=2.8^\circ$.

A momentum spectrum obtained for the reaction $^6\text{He}(p,n)^6\text{Li}$ at $\theta_{\text{lab}}=1^\circ$, with $\Delta\theta=1^\circ$, is shown in figure 2. The narrow peak in the middle of the spectrum corresponds to the stripping in the target of the secondary beam $^6\text{Li}^{2+}$ to $^6\text{Li}^{3+}$. This peak provides a direct information on the angular width of the beam, which for the (p,n) measurements was of the order of 1° . The

other peaks correspond, from right to the left, to the (p,n) reaction populating the ground state and the 3.56 MeV state of ${}^6\text{Li}$. The latter is the isobaric analog state of the ${}^6\text{He}$ ground state and its study was one of the main motivations for the present experiment. We expect that the combined analysis of the elastic, ${}^6\text{He}(p,p){}^6\text{He}$, and the charge exchange reaction, ${}^6\text{He}(p,n){}^6\text{Li}$, which connects the target ground state with its isobaric analog state, will help to better determine the neutron density distribution of this neutron rich nucleus.

We have also tested the feasibility of measuring charge exchange reactions leading to unstable states by detection of the recoiling neutrons. This experiment which uses a number of elements from the neutron array EDEN ⁴⁾ is being analysed.

Figure 2. Momentum spectrum for the ${}^6\text{He}(p,n){}^6\text{Li}$ reaction measured at $\theta_{lab}=1^\circ$ with $\Delta\theta=1^\circ$.

In summary, we have shown that the combined use of SISSI and SPEG offers new opportunities for reaction studies which lead, in particular, to discrete states. These new opportunities will be further enhanced by using a system that reconstructs the angle of incidence and position of each beam particle at the target. This will further increase the experimental angular resolution and will be exploited in forthcoming experiments.

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