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Charissa at the Vivitron

The Charissa Collaboration

September 1995

Abstract

In this document, the Charissa collaboration delivers a status report on its Strasbourg beamline and describes the research work it is likely to undertake at the Vivitron in the course of the next 5 years. Several specific experiments are proposed.

1 Introduction

Charissa is a large collaboration, consisting of the Universities of Birmingham, Manchester, Oxford, Surrey and York, studying heavy ion interactions at low–medium energies. The principal interest of the collaboration is the study of clusters in nuclei (based at the Australian National University), although other interests of the collaboration are the study of light heavy ion interactions (based at Strasbourg) and studies with radioactive beams (based at GANIL). Charissa's Vivitron programme is governed by agreements which form Annexes 1 and 2 to the Memorandum of Understanding between EPSRC and IN2P3 dated 29th May 1992.

2 Status of the Charissa Beamline at Strasbourg

The Charissa beamline from Daresbury was installed at Strasbourg in November 1994. After a period of refurbishment in February 1995, the beamline was commissioned with beam in July 1995. A further commissioning run is planned for October 1995, after which Charissa's first physics experiment at the Vivitron will be performed.

3 Charissa's Physics Programme at the Vivitron

As explained in Section 1, Charissa's interests fall into several categories and it is convenient to consider the collaboration's Vivitron programme under those same headings.

3.1 Light Heavy Ion Interactions

3.1.1 Lithium Breakup Near Threshold

A recent analysis of the elastic scattering of ^{6}Li and ^{7}Li by ^{208}Pb concluded that, at energies just above the Coulomb barrier, the polarization contribution to the real potential is of opposite sign for the two isotopes. The results are consistent with the existence of a threshold anomaly for ^{7}Li but not for ^{6}Li. The strengths and energy variation of the imaginary potentials are also considerably different. This is in contrast to the results at higher energy, where the double-folded potential (generated from the M3Y nucleon-nucleon interaction) of either projectile must be scaled by a factor of about 0.6 in order to describe the elastic scattering. Although there are differences in the structure and breakup thresholds of ^{6}Li and ^{7}Li they were not expected to be sufficiently great to give rise to such marked differences in the scattering of the two projectiles.

Certain consequences for some of the unobserved reaction processes are implied by these findings. The existence of a threshold anomaly for ^{7}Li suggests, for example, that the relative importance of breakup for the two projectiles, which is similar at high energies, changes dramatically when the bombarding energy is reduced to near the Coulomb barrier. Indeed, it has been suggested that the quasi-elastic scattering cross-section σ_{qe} may be two to three times greater for ^{6}Li at Coulomb barrier energies than for ^{7}Li and, if it is the case that breakup dominates σ_{qe} for ^{6}Li, as expected, the ratio of the breakup cross-sections would be even greater.

In November 1994, the Vivitron Programme Advisory Committee granted Charissa 6 days of beamtime to measure the α-particle yield from ^{6}Li and ^{7}Li breakup following scattering by a ^{208}Pb target over a range of bombarding energies from 25 to 60 MeV. If our present models of ^{6}Li and ^{7}Li are correct the observed cross-sections for ^{6}Li and ^{7}Li breakup will differ dramatically at bombarding energies near the Coulomb barrier and be similar at higher energies. The data obtained in the proposed experiment should be sufficient to confirm or refute the picture described earlier. The collaboration hopes to perform this experiment towards the end of 1995. In the longer term, the collaboration aims to perform a kinematically complete comparison of ^{6}Li and ^{7}Li breakup near the Coulomb barrier, from which it would be possible to ascertain via which channels the breakup proceeds.

3.1.2 Studies with ^{9}Be

The existence of a threshold anomaly in ^{7}Li scattering and the absence of such a phenomenon in ^{6}Li scattering has been explained in terms of a difference in projectile breakup. The ^{9}Be nucleus is very weakly bound and this may significantly modify the effect. To provide further insight into this, the collaboration proposes to measure angular distributions for the elastic scattering of ^{9}Be by ^{208}Pb for a range of energies from the Coulomb barrier (approximately 45 MeV for this system) to approximately 100 MeV. Also, it is to be hoped that once it is established whether ^{9}Be exhibits a threshold anomaly it will be possible to suggest reasons for the difference in behaviour of the two lithium isotopes by a comparison of the known structures of these three nuclei. Thus far, there has been little data on the elastic scattering of ^{9}Be published, and no systematic study of ^{9}Be elastic scattering angular distributions with high quality data has been reported.

It would also be of interest to investigate the breakup of ^{9}Be, as this nucleus breaks up into three fragments ($\alpha + \alpha + n$), as does ^{11}Li and many other radioactive species. Thus, from a purely technical point of view, ^{9}Be is a useful nucleus to investigate as the same techniques will be needed for the measurement of the breakup of many radioactive beams. From the theoretical point of view, work is continuing on the development of models of three-body breakup in an effort to understand this complex process. At the moment these models are best suited to high energies, due to the simplifying assumptions that have to be made in order to make the problem tractable. However, the highest beam energies likely to be available at the Vivitron would overlap with the extreme limit of applicability of current four-body codes, thus any data that can be obtained at these energies would be welcome in order to probe just how far these approximations can be pushed. Much detailed planning will be needed to assess the feasibility of such a measurement, as a kinematically complete coincidence experiment is needed, necessitating the detection of the neutron or the recoiling target nucleus, either of which would be difficult.

3.1.3 Transfer Reactions Near the Coulomb Barrier

Another area of interest is the study of reaction processes near the Coulomb barrier. Recent coupled-reaction-channels calculations for the ^{16}O scattering by a range of Ni isotopes predict that the (^{16}O,^{12}C) partial reaction cross-section excitation function should exhibit a sharp rise to a peak just above the barrier followed by a slower drop at higher energies. This is believed to be due to a Q-value mismatch, although as the calculations do not include multi-step paths it would be interesting to measure the cross-section at selected energies to ascertain whether the actual behaviour is similar to the simple calculations. Any disagreement would indicate that multi-step processes become dominant at relatively low energies for this partition. The calculations also predict a markedly greater yield in the higher excited states of the residual Zn nuclei, thus it would be of value to measure the total cross-sections for individual final states. Such precision may require the use of the Q3D magnetic spectrometer.

3.1.4 Breakup at Energies above the Coulomb Barrier

For nearly fifteen years, it has been known that the scattering of heavy ions is affected by couplings between the ground and resonant excited states of the projectile. More recently, continuum-discretized coupled-channels (CDCC) calculations for polarized ^{6}Li scattering have revealed the profound effects of couplings to nonresonant excited states. However, before the CDCC method can be fully accepted, it is crucial that CDCC predictions for ^{6}Li breakup be compared with a high quality ^{6}Li breakup data set.

To test the validity of the CDCC technique, the collaboration proposes a kinematically complete measurement of $^{6}\mathrm{Li} \rightarrow \alpha + d$ breakup at a projectile energy of 70.5 MeV, where a high quality elastic scattering data set is already in existence. This measurement is experimentally challenging, requiring high efficiency and thick detectors to stop the lightly ionizing breakup products. However, the collaboration believes that silicon-scintillator telescope technology developed for MEGHA can perform this important measurement.

3.2 Studies of Nuclear Clustering

Charissa's clustering programme is based at the 14UD Pelletron accelerator in the Department of Nuclear Physics of the Australian National University. The 14UD is capable of reliable operation with terminal voltages up to ~ 15.5 MV, while higher energy beams can be obtained by use of a superconducting post-accelerator. Charissa's latest instrument, the Multi Element Gas Hybrid Array (MEGHA) which is a state-of-the-art charged particle detection system consisting of 44 gas-silicon-scintillator telescopes, is presently being installed on a dedicated beamline at the end of the ANU post-accelerator. The Charissa collaboration envisages using MEGHA at the ANU for the foreseeable future. However, MEGHA is a modular system and spare modules have been built to allow the collaboration to use MEGHA technology at laboratories other than the ANU (for instance, when an experiment requires a beam which the ANU facility cannot provide). Likely deployments would be at GANIL and at the Vivitron (using two MEGHA modules in the Charissa chamber).

4 Summary

In this document, the Charissa collaboration has set out its likely physics programme at the Vivitron for the next 3–4 years. Strasbourg forms the base for the collaboration's study of light heavy ion interactions. The collaboration also foresees Strasbourg as being a secondary facility for its nuclear clustering programme, which will remain based at the Australian National University for the foreseeable future. Over the next few years, the collaboration is likely to want to perform the following experiments using the Vivitron:

Experiment	Ion	Energy [MeV]	Voltage [MV]
Breakup near the Coulomb barrier	^{6,7}Li	25–60	8–15
Threshold anomaly in ^{9}Be scattering	^{9}Be	45–100	9–20
^{9}Be breakup	^{9}Be	> 100	> 20
(^{16}O,^{12}C) reaction	^{16}O	38–50	7–10
^{6}Li breakup above the Coulomb barrier	^{6}Li	70.5	17.62