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Workshop of the ENST
« Espace de structure nucléaire théorique »
CEA-Saclay IRFU/SPhN
Orme des Merisiers, b 703, F-91191 Gif-sur-Yvette

STRUCTURE AND REACTIONS IN COUPLED REACTION CHANNELS

9-12th February 2009

Goals of the workshop.

The objectives of experiments using radioactive beams are to check the descriptions provided by current nuclear models, to test their validity and to obtain data to improve the predictive power of these models for the most extreme cases such as in regions with large N/Z ratio, large angular momentum and heavy masses. We put strong constraints on the models by studying extreme states of nuclear matter, and most of our experiments concern very unstable nuclei for which new phenomena appear, such as very diffuse nuclear surfaces, clustering, low-lying resonances or new magic numbers. These phenomena were not predicted by the models built or tested on the stable nuclei.
The structure and spectroscopy of radioactive nuclei are explored using direct nuclear reactions in inverse kinematics. Detailed information on the structure of light exotic nuclei and a complete picture of the spectroscopy can be deduced from direct reactions such as elastic and inelastic proton scattering (p,p') and transfer reactions:
• Excitation modes of the nucleus and couplings to low-lying states, to the continuum, and to other reaction channels, are probed by inelastic scattering, e.g. (p,p'), (d,d') or (α,α')...
• The single-particle shell structure and the overlap of the wave-functions are studied via nucleon transfer reactions like (p,d), (p,t), and (d,p). Shell structure and shell gaps can be explored via a joint program of Coulomb excitation and (p,p') reactions. Coulomb excitation provides the proton contribution to the excitation, expressed as the electromagnetic transition strength. The (p,p') reaction is sensitive to the neutron and proton contributions to the excitation. The combined information from the (p,p') and the Coulomb excitation measurements allows the proton and neutron contributions to be disentangled.

By a comparison of the nuclear observables (excitation energy spectra, angular distributions of cross section) and the predictions assuming various structure models we can deduce the relevant nuclear structure information, provided the reaction mechanism is understood and accurately modelled. The validity of the reaction models used to extract structure information is well established for nuclei in the valley of stability or close to this region. Although there are known sources of ambiguity even for stable nuclei, -the form factors and optical potentials – these are better understood for stable nuclei, however. The global features of the reactions, the order of magnitude of the cross sections and the shapes of the angular distributions are well reproduced by standard calculations.

When moving towards the drip-lines, the continued validity of the standard models may be questioned:
-- First we deal with very weakly-bound nuclei which may excite break-up easily or strongly couple to transfer channels during reactions. Thus, the reaction framework should be improved to take into account these effects as accurately as possible and to treat on the same footing the bound discrete states, the unbound states, the states embedded in the continuum and the scattering states.
-- The other source of uncertainty comes from the validity of the nuclear interaction potential which is used to describe the interaction between projectile and target. Elastic scattering measurements are needed to check the models used for the interaction potential.

The explicit role of the continuum coupling in calculating the scattering observables has been addressed in several few-body approaches, either by implicitly including the coupling to all orders or explicitly coupling to a discretized continuum. Knowledge of the continuum properties is necessary for understanding the properties of these nuclei. When these continuum couplings are poorly known, a first understanding of the scattering observables may be achieved with mean field optical potential analyses, where the coupling to the continuum is introduced effectively through phenomenological potentials which simulate the effects of the coupling on the interaction potential. Comparisons between the different frameworks help in understanding qualitatively the features of the continuum couplings.

The goal of the workshop is to define the best theoretical tools we need to use for the interpretation of the data on direct reactions which are collected at RIB facilities.
The present workshop will include the following talks and discussions about:
- The improvement of the coupled-reaction channels analysis, by making use of the most sophisticated developments in the theoretical framework [ex: use and test of the eXtended Continuum Discretized Coupled Channel (XCDCC) method]
- The contributions from core excitation, break-up effects, and transfer channels to bound states, transfer to continuum states;
- The influence of the choice of optical potentials, form factors, spectroscopic factors (relative signs, as well as amplitudes) on the cross sections
- The spectroscopic factors for light nuclei; Spectroscopic amplitudes from various models will be used to analyze the data for our reference cases.
- The extraction of the interaction potential by model-independent methods, e.g. S-matrix inversion.
- The form factors for the reaction calculations.

Our reference/benchmark cases will be: ^{10,11}Be(p,p) (p,d) ; ^{8}He(p,p) (p,d).
For future workshop sessions we plan to work on the following systems:
^{6,8}He+^{12}C, ^{6,8}He+ ^{208}Pb (direct reactions and break-up).
In the long-term range, with all the members of community working in the field of exotic nuclei and direct reactions, we would like to establish the standard procedures to extract accurate information on the nuclear structure of radioactive nuclei and to develop an appropriate framework to handle the analysis of the reactions induced by weakly-bound nuclei.

Organizers and Contacts:

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PROGRAM OF TALKS AND DISCUSSIONS

Invited speakers:

Eric Bauge, CEA Bruyères-le-Châtel DAM ,
"Form factors used in the calculations of direct reactions"
Daniel Baye, Université Libre de Bruxelles,
"R-matrix calculations for direct reactions at low scattering energy"
Guillaume Blanchon, CEA Bruyères-le-Châtel DAM,
"*Unbound exotic nuclei studied by transfer to the continuum reactions"*
Angela Bonaccorso, INFN, Sez. di Pisa,
"*Overview of direct reaction calculations for projectiles far from stability"*
Huu-Tai Pierre Chau, CEA Bruyères-le-Châtel DAM,
"*Deuteron form factors in CDCC calculations"*
Ray S. Mackintosh, The Open University, Milton Keynes, UK,
"*The nuclear potential from the reaction studies and via S-matrix inversion*"
Nicolas Michel, CEA-Saclay IRFU/SPhN,
"*Unbound states and spectroscopic factors in the Gamow Shell model"*
Antonio Moro, Facultad de Fisica Univ. de Sevilla,
"*Interplay between break-up and transfer to the continuum in the scattering of deuterons by nuclei"*

Talks introducing the workshop topics:
Nicholas Keeley, "*Transfer and elastic reactions studied in Coupled reaction channel framework"*
Valérie Lapoux, "*Introduction: Nuclear structure of exotic nuclei probed via direct reactions"*

Presentations
All talks are given 45 minutes in total, 35 minutes of presentation and 10 minutes for questions and discussions. If you agree, the presentations will be put on the web after the workshop. Please give a copy of your presentation to the organizer.

Participants
All participants wishing to present their views and contribute to the discussions during the various sessions of the workshop are kindly asked to bring a few slides if they want to explain their topics of interest and raise questions about the reaction frameworks. Please inform the organizers about your intended contribution, and indicate for which session you want to take part in the discussions.

Meeting rooms
Seminars and discussion sessions are in room 135 or 125 in building 703 at l'Orme des Merisiers.

Web pages of the ESNT ***L'Espace de Structure Nucléaire Théorique***
http://irfu.cea.fr/Sphn/Espace_Theorie/index.php
Practical information can be found on the Web pages of the ESNT workshop
http://irfu.cea.fr/Sphn/Espace_Theorie/general/notice.htm
Transportation: http://irfu.cea.fr/Sphn/Espace_Theorie/general/Transportation.pdf
Hotels: http://irfu.cea.fr/Sphn/Espace_Theorie/general/hotel.pdf

WORKSHOP PROGRAM

Monday 9th	Tuesday 10th	Wednesday 11th	Thrusday 12th
Room 135 9h15 *Welcome and practical information* 9h45 *Introduction (V.Lapoux)* 10h15 N. Keeley 11h00 Break 11h15 R. Mackintosh 12h15 Lunch	*Room 135* 9h30 A. Bonnacorso 10h15 A. Moro 11h00 Break 11h15 ***Contributions from transfer and core excitation, break-up effects, continuum coupling in the analysis of direct reactions Ex ^{10,11}Be+p*** 12h00 Lunch	*Room 125* 9h30 *Discussions/calculations* ***- Form factors for direct reactions*** ***- Entrance channel potentials for elastic and transfer reactions in CRC calculations, comparison with other frameworks*** 12h00 Lunch	*Room 125* 9h30 D. Baye 10h15 Break 10h30 Introductive talks for the Discussions on: ***Direct Reactions framework for SPIRAL2/EURISOL*** *Chair:* *A.Bonnacorso* 12h00 Lunch
Room 135 14h00 N.Michel 14h45 G. Blanchon 15h30 ***Discussions on the treatment of the transfer form factors to the continuum*** 16h15 Break 16h30 ***Discussions on spectroscopic factors and resonances***	*Room 135* 13h30 E. Bauge 14h15 P. Chau 15h30 Break 16h-18h ***Forum session: Questions of the participants to the speakers***	*Room 125* 13h30 -18h *Discussions/examples on* ***CDCC frameworks Status (Approaches with core excitation, 4-body treatment) Limitations, improvements*** *Chairmen:* *N.Keeley and A.Moro*	