Training in Advanced Low Energy Nuclear Theory

First week

Expectations: the student will be exposed to and will develop the formal aspects of scattering theory, and so appreciate the basic ingredients that support more advanced computations.

- Background - from many-body collisions to model descriptions with a few degrees of freedom, reaction classifications and timescales, effective interactions and Hamiltonians, the optical potential and mean-field. Review and hands-on studies of solutions of bound, resonant and continuum quantum two-body problems. (Monday, Week 1) – Lecturer Tostevin

- Scattering theory I: boundary conditions, differential and integral equation forms for single-channel, two-body systems. The R-matrix reaction approach. Study of the role of complex and Coulomb interactions on elastic scattering, examples and exercises. (Tuesday, Week 1) – Lecturer Nunes

- Scattering theory II: The Born series, the two-potential forms, exact and development of perturbative schemes. Comparison of differential and integral equation techniques. (Wednesday, Week 1)– Lecturer Nunes

- Scattering theory III: generalisation of differential and integral forms for many-channel problems, Born approximation and coupled channels, Feshbach P's and Q's, bare and effective channel interactions, illustrative examples and exercises. (Thursday, Week 1)– Lecturers Nunes, Moro

- Coupling interactions: Collective and cluster-like Coulomb and strong interaction couplings, nucleon and cluster-folding models, multipole expansions, B(Eλ) transition strengths and transition densities. Examples: e.g. inelastic reaction for a collective (rotational) nucleus, Coulomb excitation. (Friday, Week 1)– Lecturer Moro

Second week

Expectations: The student will be introduced to a number of methods for practical applications for the analysis of experiments, and gain confidence in selection of the inputs involved and the validity of the approximations used.

- Channel Coupling: Continuum: the bin representation and continuum-continuum couplings. The interfaces between nuclear structure and reactions, nucleon and cluster models, overlap functions of one and two particles, spectroscopic strengths and associated form-factors. (Monday, week 2) – Lecturer Tostevin

- Semiclassical concepts: time dependent approaches, Coulomb excitation, first-order perturbation theory and higher-order corrections, post-acceleration, virtual photon description. Example: Coulomb dissociation of halo nuclei. (Tuesday, week 2) – Lecturer Moro

- Eikonal methods: derived eikonal equations for point particles, the eikonal solutions for phase shifts and the S-matrix. Eikonal and optical limit techniques for composite projectiles. Elastic, reaction and other cross sections and the content of momentum distributions. Example: analysis of knockout reactions including momentum distributions. (Wednesday, week 2) – Lecturer Tostevin

- Transfer reactions: Approximations. From exact and perturbative amplitudes, Q-value, momentum and L-transfer matching, periphery analysis. The adiabatic approximation for breakup and transfer, Johnson and Soper-like methods for transfer, zero-range and finite range effects. Example: analysis of (d,p) reactions including extraction and sensitivity to spectroscopic factors and the ANC. (Thursday, week 2) – Lecturers Nunes, Tostevin

- WKB approximation. Capture reactions: direct and resonant, S-factor, low-energy behaviour. Fusion reactions and barrier penetration methods. Channel-coupling and fusion enhancement. Examples: determine the capture reaction cross sections for an E1 process assuming simplified states, Coupled-channels barrier-passing fusion calculations. (Friday, week 2) – Lecturers Descouvemont, Tostevin

Third week

Expectations: The student workload will include both formal and research project preparation effort. Students will begin consideration and literature study for their more-extended research project (requiring them to select their area of project work). They will prepare a short research plan. The final project report will be in the format of a scientific paper with relevant referencing.

- R-matrix method, computational and phenomenological aspects. Resolution of the Schrodinger equation with the computational R-matrix. Example: determining scattering cross sections from optical potentials. Analysis of experimental cross sections with the phenomenological R-matrix. Example: extracting energies and widths of resonances from actual data. Extensions to multichannel problems and to radiative capture. (Monday and Tuesday, week 3) – Lecturers Descouvemont, Simpson

- Microscopic descriptions of reactions based on cluster models: explicit antisymmetrization and the resonating group method (RGM). Equivalence between the RGM and the Generator Coordinate Method (GCM). Applications to simple systems: alpha+nucleon and alpha+alpha. Generalizations to multi-cluster system descriptions, and to ab-initio calculations. (Wednesday/part Thursday, week 3) – Lecturer Descouvoment

- Q&A session. Discussion of final project timescales, expectations and selection. (part Thursday pm, week 3)

- Review. Collective and/or individual discussions of final research project (Friday, week 3)