UNIVERSITÉ LIBRE DE BRUXELLES, UNIVERSITÉ D'EUROPE   **ULB**

ÉCOLE POLYTECHNIQUE DE BRUXELLES
FACULTÉ DES SCIENCES
Nuclear Physics and Quantum Physics research unit
http://pnpq.ulb.ac.be
Jean-Marc Sparenberg jmspar@ulb.ac.be
Pierre Descouvemont pdesc@ulb.ac.be

Master-thesis proposals for the year 2016-2017

The subjects proposed by the Nuclear Physics and Quantum Physics research unit (joint unit of the Sciences Faculty and of the École polytechnique de Bruxelles) are theoretical in nature and usually involve mathematical and numerical modeling. The formalism used is that of quantum physics and most applications include nuclear physics.

Our research unit is part of an Interuniversity Attraction Poles (IAP) program, BriX (The Belgian Research Initiative on eXotic nuclei for atomic, nuclear and astrophysics studies), in which we collaborate with other nuclear-physics groups, both theoretical and experimental, in Belgium and abroad. Through this collaboration, there is a possibility for very motivated ULB students to realize their thesis on experimental subjects at the KULeuven or at the ULiège, under the joint direction of KUL/ULiège and ULB supervisors. For further information, please contact Jean-Marc Sparenberg.

THEORETICAL NUCLEAR PHYSICS AND NUCLEAR ASTROPHYSICS

1. **Parametrization of low-energy elastic-scattering and capture-reaction cross sections with a simplified effective-range function**
   J.-M. Sparenberg,

   A simplified effective-range function allowing to parametrize elastic-scattering phase shifts for charged particles in a given partial wave has been recently proposed [1]. A first aim of this work is to apply this method to several systems relevant to nuclear astrophysics for the description of big-bang or stellar nucleosynthesis, and well studied by other methods (alpha+alpha, ^{16}O+p, alpha+d, p+p…). To do so, existing codes (Python programs with possible Fortran interface) will be adapted and generalized. Other aims, mostly requiring analytical developments, are (i) to study the analyticity properties of the simplified effective-range function in the complex wave-number plane and to compare it with more usual functions, (ii) to generalize it to radiative-capture reactions and to apply it to the above systems.

   [1] O. L. Ramírez Suárez and J.-M. Sparenberg, arXiv preprint:1602.04082

2. **Continuum-discretized-coupled-channel approach to three-body scattering states with the reaction-matrix method**
   J.-M. Sparenberg

   For two-body systems, the reaction-matrix (R-matrix) method is an efficient way of numerically treating continuum energies [1], by imposing a fixed boundary condition at

finite a distance (the so-called channel radius), which leads to mathematical discrete two-body states which are used as a basis. In particular, precise two-body scattering phase shifts can be obtained in this way, provided *all* discrete states are taken into account. For three-body systems, the R-matrix method can also be used to calculate three-body phase shifts, provided hyperspherical coordinates are used, but this requires a very large channel radius because of the slow decrease of the interaction potential [1].

An alternative approach, called CDCC [2], is to discretize one of the two-body continuum and to treat the discrete states as coupled channels, i.e. as a basis on which the three-body states are expanded. The CDCC method is usually used to model two-body collisions (projectile on target), taking into account the two-body structure of the projectile, and shows good convergence with a limited number of coupled channels. However, the method is not a priori designed to calculate three-body phase shifts. The aim of this project is to attempt such a calculation by combining the two-body R-matrix, taking into account *all* discrete states, with the CDCC method. Various test cases could be considered, ranging from nuclear physics (^{6}He halo nucleus) to atomic physics (^{6}Li-atom trimer). A Python code will be written from scratch by the student.

[1] P. Descouvemont and D. Baye, Rep. Prog. Phys. 73 (2010) 036301
[2] T. Druet *et al.,* Nucl. Phys. A 845 (2010) 88

MATHEMATICAL PHYSICS

1. **Construction of phase-equivalent potentials with supersymmetric quantum mechanics**
   J.-M. Sparenberg,

   Supersymmetric quantum mechanics is a very efficient tool to solve the scattering inverse problem, i.e. the construction of interaction potentials from scattering data [1]. In particular, SUSYQM with confluent transformations allows to deal with the unicity problem, i.e. the construction of all phase-equivalent potentials sharing scattering phase shifts but with different bound spectra. A new approach to confluent transformations was proposed recently [2]. The aim of this work is to explore its interest for the problem of phase-equivalent potentials, in particular for coupled channels. For that, analytic, symbolic and numerical calculations will be used (programming language: Python).

   [1] D. Baye and J.-M. Sparenberg, J. Phys. A 37 (2004) 10223
   [2] D. Bermudez *et al.*, Phys. Lett. A 376 (2011) 692

FOUNDATIONS OF QUANTUM PHYSICS

1. **Test of a quantum emergent-time theory on simple systems**
   J.-M. Sparenberg

   Physical theories in which time is not a fundamental concept, but rather a quantity emerging from a deeper level, are generally considered as quite exotic. Nevertheless, they received regular attention over the years, both in classical physics/general relativity [1, 2] as in quantum physics. There, in 1983, Page and Wootters proposed a theory where time emerges from the coexistence of subentities in physical systems [3]. These ideas were recently implemented experimentally in photonic systems [4]. The aim of this work is to understand this theory in depth, in particular through the related concepts of time, entropy and partial trace, and to apply it to simple test systems like a pair of spin ½ particles in a magnetic field, two particles in a 1D box, or a massive particle evolving in a free scalar or electromagnetic field.

   [1] J. Barbour, *The End of Time* (Oxford University Press, 1999)
   [2] E. P. Verlinde, JHEP 4 (2011) 29
   [3] D. N. Page and W. K. Wootters, Phys. Rev. D 27 (1983) 2885
   [4] E. Moreva, G. Brida, M. Gramegna, V. Giovannetti, L. Maccone, M. Genovese, Phys. Rev. A 89 (2014) 052122

2. **Microscopic modeling of a ionization-chamber-type quantum measurement apparatus on the basis of quantum scattering theory**
   J.-M. Sparenberg

   A possible explanation for the seemingly random nature of the result of a measurement in quantum mechanics is that this result is in fact determined by the microscopic state of the measuring device [1]. The purpose of this work is to test this hypothesis in the case of the detection of a spherical wave (alpha-radioactivity type) in an ionization tracking chamber (cloud chamber, wire chamber...), in order to explain the observation of straight paths that seem inconsistent with a spherical-wave emission. To do this, simplified models based on quantum scattering theory will be studied, either in one [2] or in three [3] dimensions, both analytically and numerically (programming language: Python, with possible Fortran interfacing).

   [1] J.-M. Sparenberg, R. Nour and A. Manço, EPJ web of conferences 58 (2013) 01016
   [2] R. Carlone, R. Figari, C. Negulescu, Commun. Comput. Phys. 18 (2014) 247
   [3] C. Cacciapuoti, R. Carlone, R. Figari, J. Phys. A 40 (2007) 249