ÉCOLE POLYTECHNIQUE DE BRUXELLES
FACULTÉ DES SCIENCES
Nuclear Physics and Quantum Physics
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UNIVERSITÉ LIBRE DE BRUXELLES

Master-thesis proposals for the year 2020-2021

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 mostly theoretical in nature and usually involve mathematical and numerical modeling. The formalism used is that of quantum physics and most applications include nuclear or atomic physics.

Our research unit is involved in several networks, in which we collaborate with other nuclear-physics groups, both theoretical and experimental, in Belgium and abroad. Through these networks, there is a possibility for motivated ULB students to realize their thesis on experimental subjects, for instance at the KULeuven or at the SCK-CEN Mol, under the joint direction of KUL/Mol and ULB supervisors. For further information, please contact Jean-Marc Sparenberg.

http://academy.sckcen.be/en/Your_thesis_internship/Bachelor_and_Master_thesis/Topics

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ATOMIC PHYSICS

1. Description of helium clusters from a decentered correlated Gaussian approach

Jérémy Dohet-Eraly

In spite of the fact that the helium atom is a noble gas, the existence of loosely-bound molecules composed by few helium atoms has been predicted by theory [1-3] and, in the case of the He-He molecule, experimentally established using diffraction experiments [4]. In this master thesis, we propose to develop a new computational approach for studying helium clusters combining a (decentered) correlated Gaussian approach [5] and the *R*-matrix method [6]. It is anticipated that this approach would be particularly well suited for describing both the ground and the excited states of the helium molecules. In addition, this method could be easily adapted, going beyond the bound-state study, to describe collision processes, in particular, the elastic scattering between a helium molecule and a helium atom.

[1] E. Hiyama and M. Kamimura, Few-Body Systems 54 (2013) 1551.
[2] M. Gattobigio, A. Kievsky, and M. Viviani, Physical Review A 84 (2011) 052503.
[3] A. Kievsky and M. Gattobigio, Physical Review A 87 (2013) 052719.
[4] R. E. Grisenti *et al.*, Phys. Rev. Lett. 85 (2000) 2284.
[5] Y. Suzuki, K. Varga, *Stochastic Variational Approach to Quantum-Mechanical Few-Body Problems*, vol. **54**, Lecture Notes in Physics, Springer, Berlin, 1998.
[6] P. Descouvemont and D. Baye, Rep. Prog. Phys. **73** (2010) 036301.

MATHEMATICAL PHYSICS

2. 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 a few years ago [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, interfaced with Fortran to use existing subroutines and complemented by Mathematica if needed). If successful, the method will be applied to the construction of exactly-solvable neutron-proton potentials.

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[2] D. Bermudez et al., Phys. Lett. A 376 (2011) 692

NUCLEAR PHYSICS

3. Study of coupled-channel effects on the ^{12}C+alpha system in nuclear astrophysics

J.-M. Sparenberg

The ^{12}C+alpha radiative capture leading to ^{16}O is of utmost importance in the nucleosynthesis helium-burning cycle of red giant stars [1]. Unfortunately, the corresponding reaction rate is too low to be directly measured experimentally at energies of astrophysical importance, hence the interest of theoretical estimates. However, such theoretical analyses are made complicated by the presence of ^{16}O bound states lying just below the ^{12}C+alpha threshold, which are known to have an impact on the reaction cross section similar to resonances. Recently [2], a new parametrization of the ^{12}C+alpha elastic-scattering phase shifts led to the surprising conclusion that one of these bound states might have an imaginary asymptotic normalization constant (ANC). The origin of this effect is still unknown. The aim of this work is to test on simple phenomenological coupled-channel potential models (coupled square wells, Woods-Saxon…) whether it could be due to a coupling with other channels than the ^{12}C+alpha one, and to evaluate its impact on the capture cross section. To do so, analytical and numerical calculations will be performed (Python program with Fortran interface).

[1] A. Coc, F. Hammache and J. Kiener, Eur. Phys. J. A (2015) 51
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4. Stopping power of ionizing particles in an active-target gas detector

J.-M. Sparenberg & D. Gaspard

Active-target gas detectors [1] have become an essential tool in experimental low-energy nuclear physics, in particular for the study of nuclear reactions taking place in astrophysical contexts (big bang and stellar nucleosynthesis). In these detectors, the gas mixture used creates an electric signal to record the tracks of the ionizing particles by a time-projection technique, but also slows down these particles down to energies of astrophysical interest. It is thus essential to know the stopping power of the gas for the studied ionizing particles and experimental campaigns are ongoing with this respect [2]. The purpose of this work is to explore a theoretical model of this stopping power based on a free-electron-gas medium [3]. This model seems efficient in condensed matter but has never been applied to gases up to now. It is proposed to test its validity in the context of active-target detectors and to compare it analytically with the Bethe formula and numerically (in Python) with softwares usually used. Possible connections with the decoherence pressure concept observed in matter-wave interferometry [4] might also be explored.

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[1] S. Beceiro-Novo *et al.*, Prog. Part. Nucl. Phys. 84 (2015) 124
[2] D. Torresi *et al.*, Nucl. Instrum. Meth.Phys. Res. B 389–390 (2016) 1
[3] C. Yang et al., J. Comp. Electron. 1 (2002) 24
[4] K. Hornberger et al., Phys. Rev. Lett. 90 (2003) 160401

FOUNDATIONS OF QUANTUM PHYSICS

5. Microscopic modeling of an ionization-chamber-type quantum measurement apparatus on the basis of quantum scattering theory

J.-M. Sparenberg & D. Gaspard

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 numerically (programming language: Python), either in one [2] or in three [3] dimensions. In particular, proximity resonances [4], and their possible link with the quantum measurement problem, will be studied in a time-dependent Schrödinger-equation approach.

[1] J.-M. Sparenberg, R. Nour and A. Manço, EPJ web of conferences 58 (2013) 01016
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[3] D. Gaspard and J.-M. Sparenberg, Int. J. Quantum Information 17 (2019) 1941004
[4] M. Rusek, J. Mostowski, and A. Orłowski, Phys. Rev. A 61 (2000) 022704