**Internship (REF. NPP_1) Measurement of neutron wave functions in gravitational quantum states and analysis of experimental results**

Neutrons not only fall in a conventional manner in the gravitational field of the Earth, just like potatoes and other everyday objects do; under certain conditions, they reveal quantum behaviour or even form well-defined gravitational quantum states, as observed in experiments at the ILL. Due to the relative simplicity of quantum mechanical rules for solving this problem, we have been able to predict analytically the motion of neutrons in the gravitational field in the vicinity of a reflecting surface. The extremely small energy values of such states are in fact very sensitive probes for the presence of even tiny extra interactions, in particular those between the neutron and the mirror. Quantum bouncing particles, in more general terms, could play a role in quantum tests of the equivalence principle, in explorations of the gravitational properties of antimatter, in searching for new fundamental short-range and other interactions beyond the Standard Model of particle physics, in surface and thin-layer physics, and so on. A key factor in many of the applications mentioned is the precision of the measurement of parameters of the gravitational quantum states. A deviation from predicted values would suggest a departure from the simple model and might indicate new physics. A comparison of parameters for different quantum states as well as neutron polarization analysis would help to reveal the nature of this phenomenon. The GRANIT collaboration is pursuing this avenue of exploration using the recently constructed GRANIT facility.

**Activities of the trainee:**
The trainee’s main activity will be to participate in precision measurements of neutron wave functions in gravitational quantum states using several complementary methods, as well as to analyse the results obtained. The whole setup for this measurement has already been built and the first experiments of this type are in progress. The task of the trainee student will involve understanding the physics and techniques involved (in particular, through reading [V.V. Nesvizhevsky and A.Yu. Voronin, Surprising Quantum Bounces, Imperial College Press, London, UK, 2015]), actively participating in measurements, analysing eventual systematic effects, and further developing experimental methods with the aim of improving as far as possible the precision of this experiment in the flow-through mode.

**Key words:** Ultracold neutrons, gravitational quantum states, extra
fundamental forces

Level required: 5th year university studies in Physics
Notes: This post is an internship with a maximum duration of 5 months
Please send your application directly to the supervisor: Valery Nesvizhvskski, e-mail: nesvizh(at)ill.eu

Internship (Ref. NPP_3) Optimisation of the cold neutron beam facility ANNI

Precision experiments with cold neutrons search for physics beyond the Standard Model of particle physics. These experiments require a fine control of systematic effects. Pulsed neutron beams are very valuable in this respect, as they facilitate the control of background, neutron beam polarization, spectrometer response, etc. The cold neutron beam line ANNI has therefore been proposed as an instrument for the future long-pulse European Spallation Source.

The trainee will optimise the design of the ANNI beam line, using analytical estimates as well as Monte-Carlo simulations with McStas. This includes the guide design and the chopper system. The trainee may also participate in experiments at the cold neutron beam facility PF1B, and in particular in the testing of a novel polarizer. Good programming skills and a certain feeling for geometry and geometrical optics are required.

Activities of the trainee:
Main activity: Analytical estimations and Monte Carlo simulations, analysis of the results
Potentially experimental work: Installation of an experiment, data collection and analysis

Level required: 4th year university studies in physics
Notes: This post is an internship with a maximum duration of 5 months
Please send your application directly to the supervisor: Torsten Soldner, e-mail: soldner(at)ill.eu

Internship (Ref. NPP_4) qBounce: Ramsey Spectroscopy to test Newton’s Law at micron distances

In the last years, gravity experiments have been experiencing a renaissance for several reasons: Modern astronomical observations clearly point to the existence of dark energy and dark matter. Their true nature and content remain a mystery however. Furthermore, prominent candidates to formulate a consistent quantum theory of gravitation
require extra spatial dimensions. The neutron is an ideal tool to answer such questions. More precisely, bound quantum states of ultra-cold neutrons in the Earth’s gravity field connect gravity experiments at short distances with powerful resonance spectroscopy techniques.

At ILL’s ultracold neutron source PF2, the qBounce collaboration aims at a first-time realization of Ramsey spectroscopy to test Newton’s Inverse Square Law of Gravity at micron distances. The proposed Ramsey-type setup consists of five regions. Neutrons are prepared in the lowest state and then transferred to a superposition between ground state and an excited state (\(\pi/2\)-flip). Then, this superposition may evolve, before another \(\pi/2\)-flip is applied and the resulting state is projected wrt. the ground state.

The experiments will start in November 2016 and last for one year. The results will be used to search for Non-Newtonian gravity, chameleon fields, large extra dimensions, and hypothetical spin-mass-couplings. Furthermore, a first test to search for a non-zero neutron electric charge will be realized.

Activities of the trainee:
In spring 2017, it is planned to extend the Ramsey-type set-up for spin-dependent measurements. For this purpose, the activities of the trainee cover the design, installation and commissioning of a guide field, and a system for spin-dependent neutron detection. Furthermore, it covers systematic tests and the integration of subsystems for these measurements in our experiment control (Labview).

Key words: Ultracold neutrons, UCN, gravity experiments, qBounce, PF2, dark matter search, dark energy search, axions, UCN detector

Level required: 4th year university studies in Physics
Notes: This post is an internship with a maximum duration of 5 months
Please send your application directly to the supervisor: Tobias Jenke, e-mail: jenke(at)ill.eu

Internship (Ref. NPP_5) Development and testing of new neutron converter coatings for a novel ultracold neutron (UCN) source

We have recently commissioned our new ultracold neutron source SUN-2, which uses superfluid helium, below 1 K, as the medium for converting cold neutrons to ultracold neutrons (UCNs). Once produced and accumulated in the converter vessel, the UCNs are extracted for
experiments at room temperature. Due to the low energy of UCNs in the neV range, they are reflected by walls and can therefore be stored in bottles. This property is extremely useful for high-precision experiments, such as the search for the neutron electric dipole momentum and precision measurements of the neutron lifetime, and also makes UCNs a sensitive probe to search for a 5th force. Present work is focusing on improving source parameters, notably the UCN storage lifetime, which depends critically on the material that the UCNs are in contact with during their accumulation in the converter vessel.

Activities of the trainee:
The trainee will be involved in the preparation and testing of new coatings based on deuterated materials with a high neutron optical potential and low neutron absorption. First, a coating facility will be assembled in a laboratory with which the samples are to be prepared. After checking that the coatings are stable at liquid nitrogen temperature, a tube will be coated internally and UCN storage measurements will be performed at low temperature. Depending on the exact starting date, the activity of the trainee will therefore involve the construction of a setup, performing measurements and data analysis. The topic is well suited for a Master’s thesis.

Key words: Ultracold neutrons, experimental low-energy particle physics

Level required: 4th year university studies in physics
Notes: This post is an internship with a maximum duration of 5 months
Please send your application directly to one of the supervisors: Skyler Degenkolb, e-mail: degenkolb(at)ill.eu or Oliver Zimmer, e-mail: zimmer(at)ill.eu

Internship (Ref. SPECT_2) INVESTIGATION OF CARBON NANOPARTICLES CONTAINING RESPONSIVE GEL NANOCOMPOSITES

Responsive hydrogels are three-dimensional polymer networks with a high water content. They exhibit a reversible volume phase transition (VPT) under certain conditions. This response can be induced by changing the environment, such as the nature of the swelling medium (composition, pH), temperature, electromagnetic field, etc. Among temperature-sensitive responsive hydrogels, those based on poly-(N-isopropylacrylamide) (PNIPA) are distinguished by their peculiar volume phase transition temperature (TVPT) around 34 ºC, close to the temperature of the human body. In the VPT of PNIPA, the swelling
medium of the polymer, along with its dissolved ions and molecules, is released into the surroundings. This property opens the route to various applications that require the targeted delivery of drugs. The gels are relatively deformable and – owing to their high water content and the physiochemical similarity of the network to the native extracellular matrix – potentially biocompatible.

Although the properties of responsive hydrogels make them excellent candidates for applications in drug delivery, sensors, actuators, micro-valves and pollution control, they have certain drawbacks. These challenges may conceivably be overcome by composite hydrogels. Carbon nanoparticles are widely used as polymer fillers, with a positive impact both on the physical and the chemical properties of composites. The aim of the present project is to develop and characterise novel composite materials for the controlled transport of environmentally and biomedically relevant molecules. The trainee will join the ongoing project in which soft polymer hydrogel–nanocarbon composites are being synthesised, fully characterised and tested for potential applications. The approach of the project is interdisciplinary, combining a range of disciplines from the physics and chemistry of carbon nanoparticles, through organic, colloid and polymer chemistry, to materials science. The morphological, chemical and mechanical characterisation of the synthesised nanocomposites involves both traditional and state-of-the-art methods of surface chemistry, analytical chemistry and materials science.

Activities of the trainee:
Depending on the trainee’s background, he/she will be involved in the data analysis of various scattering experiments (SAXS/WAXS, SANS, neutron spin-echo spectroscopy, X-ray photon correlation spectroscopy) and/or in laboratory work related to sample preparation and conventional characterisation.

Key words: SOFT MATTER, POLYMER GEL, NANOCOMPOSITES, X-RAY SCATTERING, NEUTRON SCATTERING

Level required: 3rd year university studies in physics or chemistry
Notes: This post is an internship with a maximum duration of 3 months
Please send your application directly to the supervisor: Orsolya CZAKKEL, email: czakkelo(at)ill.fr
Internship (Ref. SPECT_4) Effect of the synthesis methods on the properties of earth-alkaline hydroxide nanoparticles for innovative applications

This project is based on the study by neutron scattering of nanoparticles (NPs) of earth-alkaline hydroxides and their use in innovative applications (reinforcement of archaeological stones, deacidification of wood and paper, concrete reinforcement, etc.).

The objective of this work will be to study, mainly by neutron techniques, the effect of the synthesis method and the role of solvents on the nanoparticles in suspension (morphology, structure, assembly and agglomeration state). We also want to study by Quasi-Elastic Neutron Scattering (QENS) and Inelastic Neutron Scattering (INS), the effects occurring when NPs are applied to different materials as in the deacidification treatment of ancient paper or wood.

Due to the small size of the particles and their high reactivity, the application of NPs (produced using an innovative method) can reduce porosity and acidity and protect the medium (paper or wood). This changes the fragility (as defined by Angell) and causes a corresponding change in the dynamical response. We studied these changes in ancient and modern samples by means of elastic and quasi-elastic incoherent neutron scattering techniques, using different controlled hydration, and using the hydroxyl groups of the cellulose polymers combined with selective deuteration as a microscopic probe. This study was recently extended to wood samples from an ancient ship in collaboration with the CEA group in Grenoble ARC-NUCLEART. In wood, and in particular in waterlogged wood (shipwrecks), the presence iron (Fe) catalyses chemical degradation, which can be seen in increased acidity accompanied by cellulose degradation and reduced strength in the hull and other pieces of the ship structure. Very recently we began testing the deacidification and penetration depth of the treatment using NPs of Mg hydroxide on extraordinarily massive samples of wood from a Gallo-Roman shipwreck discovered close to Lyon by INRAP (French institute for archaeological research and conservation) in 2003.

A series of characterisation measurements was also performed, directly on the suspensions of MgOH2 and CaOH2, before and after application to the wood, using the PSCM equipment at the ILL and the AFM facility at the ESRF. On the same sample, a test using small angle neutron scattering was conducted. These kinds of measurements are important in order to define the role of the solvent in the penetration of the NPs into the fibres and the efficiency of the treatment by NPs.
Activities of the trainee:
The trainee will be involved in the analysis of QENS data from samples of ancient paper treated by MgOH2 NPs and in the analysis of the density of states (DOS) from INS measurements on ancient paper. Furthermore the trainee will analyse the data from ancillary measurements, e.g. Dynamic Light scattering, measurements of Z-potential and AFM measurements, as well as SANS measurements carried out on the suspension of MgOH2 NPs before and after treatment of the wood.

Key words: earth-alcaline hydroxide nanoparticles, neutron techniques, deacidification of wood and paper

Level required: 4th year university studies in physics
Notes: This post is an internship with a maximum duration of 4 months
Please send your application directly to the supervisor: Claudia MONDELLI, email: mondelli(at)ill.eu

Internship (Ref. SPECT_7) Understanding localised A+ vibrations in layered thermoelectric ACrSe2 compounds via lattice dynamics calculations

With applications in renewable energy and sustainable development, thermoelectrics are a very significant field of nowadays research, and different approaches have been devised by solid state chemists to achieve their required low thermal conductivity and high electron conduction. In the recently discovered thermoelectric AgCrSe2 [1], a remarkably low thermal conductivity has been observed at room temperature. Thanks to molecular dynamics calculations, it has been linked to an efficient phonon scattering mechanism, mediated by localised in-plane vibrations of Ag+ in this naturally layered compound.

The aim of the project is to carry on dynamics calculations on AgCrSe2, to go further in the understanding and characterisation of the Ag+ motion, to study in particular (i) how the localised vibration mode evolves with temperature up to 300 K, (ii) the formation of tunnel-like paths bridging two adjacent Ag+ sites and its temperature evolution, and (iii) whether the vibration mode couples or not with the antiferromagnetic ordering of the Cr spins at 55 K. The calculations will then be extended to other monovalent cations, like Cu+ and Au+, to apprehend how this impacts the characteristics of the in-plane vibration mode. These results will be used to determine the best A+ ion in terms of phonon scattering optimisation.

Activités of the trainee
This student will perform ab-initio molecular dynamics simulations, using the VASP DFT code and the numerical tools available at the ILL. He/She will derive the neutron scattering observables from the trajectories of the atoms, and will compare them to the experimental data. Depending on neutron beamtime availability, inelastic scattering experiments on a powder sample of AgCrSe2 will also be considered.

Key words: Density Functionnal Theory, Molecular Dynamics, Inelastic Neutron Scattering, Thermoelectrics

Level required: 5th year university studies in physics
Notes: This post is an internship with a maximum duration of 4 months
Please send your application directly to the supervisor: Stefan ROLS, e-mail: rols(at)ill.eu

Internship (Ref. DIF_2) Weighting factors in correlation functions for neutron diffraction
The aim of this internship is to complete and improve an already existing web application for calculating the weighting factors for the total scattering technique. This technique allows the determination of the pair correlation function, which is the Fourier transform of the structure factor. In the case of monoatomic systems, the relationship between these two magnitudes is simple, but for multiatomic systems different weighting factors, multiplying the different partial structure factors, must be taken into account. These factors are cross products of the concentrations and cross sections of the atomic species present in the system.
A Neutron Calculator has already been developed in Javascript language and has already been incorporated in an interactive web page. This calculator uses a table of neutron data (scattering lengths and cross sections, among others) to calculate the above-mentioned factors, both in the Faber-Ziman and Bathia-Thornton formalisms.
The web page for the Neutron Calculator is still under development and the neutron data table is still incomplete. Thus, the main objectives of this project are: (1) to validate the code already written in Javascript, and (2) to complete the input data table. As second priority, a third objective
involves (3) translating the Javascript client code into PHP, in order to secure it in a server-based application. Applicants must be undergraduate students of physics or engineering with skills in programming web pages (HTML, CSS, Javascript, PHP). Applications from computer science students with good skills in mathematics may also be considered.

Activities of the trainee:
(1) Learning the basis of the mathematical and physical concepts behind the calculation of weighting factors in total scattering experiments
(2) Validating and improving the existing Javascript code for the Neutron Calculator
(3) Updating and completing the neutron scattering data table
(4) (Optional) Translating the Javascript code into PHP

Key words: Total neutron scattering, correlation functions, weighting factors, HTML programming, Javascript programming

Level required: 3rd year university studies in physics or engineering
Notes: This post is an internship with a maximum duration of 2.5 months
Please send your application directly to the supervisor: Gabriel Cuello, e-mail: cuello(at)ill.eu

Internship (Ref. LSS_1) Regulating fat digestion by engineering lipid emulsions

The intake of dietary fats (lipids) and its effects on health have become a major focus of our modern societies since, over the past few years, changes in both lifestyle and eating habits have resulted in an increase of obesity levels. Consequently, developing solutions that may have beneficial impacts on health is urgently needed. Controlling the digestion of fats is key to addressing this ongoing health crisis but also to controlling the absorption of drugs in oral lipid-based formulations. The overall aim of this broad project is to develop a formulation strategy which slows down and thus reduces lipid absorption.

Bile salts (BS) are biosurfactants produced in the liver and released into the small intestine (duodenum), which play key roles in lipid digestion and absorption. BS facilitate the adsorption of the lipase/co-lipase complex to fat droplet interfaces, thus promoting enzyme-catalysed lipolysis, and they also desorb from the interface and shuttle insoluble lipolysis products to the gut mucosa in mixed micelles, to facilitate their absorption. Therefore, given that BS is a key player in lipolysis, the strategy will consist in using
appropriate emulsifiers that compete with BS for adsorption at the water/fat droplet interface and thus slow down lipase adsorption. Our work focuses on two different classes of applicants, widely used in both the food and pharmaceutical industries: methylcellulose ethers (MC) and cyclodextrins (CD). Although both of them have demonstrated potential as dietary fibres (reducing fat absorption), there is still a staggering lack of mechanistic understanding of the competitive interfacial processes leading to lipase inhibition, slower lipid digestion and associated health benefits.

The specific proposed project will focus on formulating oil/water emulsions with these two candidates and studying their structure and evolution in the presence of BS and lipase/co-lipase. First, a phase diagram of each oil/water/emulsifier mixture at different mixing ratios will be characterised, using visual observation, turbidity, and dynamic light scattering (DLS). Thereafter, dynamic studies will be carried out with DLS to assess the impact of the addition of BS, and then lipase/co-lipase complex, on the oil-in-water (o/w) emulsions stabilised by a broad range of the inhibitory emulsifiers. These preliminary data will be of considerable interest since they will provide a basis to further neutron reflectivity (NR) and small-angle neutron scattering (SANS) experiments.

Key words: Emulsion, Phase diagram, Dynamic Light Scattering

Level required: 5th year university studies in physiochimie/formulation

Notes: This post is an internship with a maximum duration of 5 months
Please send your application directly to one of the supervisors: Olivia Pabois, e-mail: pabois(at)ill.eu or Isabelle Grillo, e-mail: grillo(at)ill.eu:

Internship (Ref. LSS_2) Using sugar to control the self-assembly of polysaccharide–surfactant complexes

The development of smart materials from renewable resources is a modern challenge which requires a multidisciplinary approach. A simple and versatile preparation route for complex materials is based on the self-assembly of small molecules into large functional supramolecular aggregates. One very promising system is based on self-assembled complexes of chitosan, a cationic polysaccharide, and oppositely charged fatty ethoxylated carboxylic acids. These systems were shown to assemble into hierarchal, complex structures with strongly responsive properties [1-2] which can be exploited, for example, for the separation and recovery of pollutants [3] (as schematically depicted in the figure below).

With the aim of improving control over the systems’ properties and
adding novel functionalities, \(\beta\)-cyclodextrin, a cyclic saccharide, will be added to the complexes. In particular, \(\beta\)-cyclodextrin selectively threads onto the hydrophilic part of the surfactant, thereby changing its self-assembling properties and the interactions with chitosan.

Activities of the trainee:
The trainee will prepare and characterise the supramolecular complexes formed by a cationic polysaccharide, chitosan, oppositely charged surfactants, and cyclodextrins. The project can be subdivided in three main parts: 1) the determination of the phase behaviour, 2) the quantitative determination of the binding constants, and 3) the structural characterisation of the complexes. In detail:

1) Optical inspection and turbidity measurements to determine the stability of the complexes. How many phases are present as a function of the pH and composition of the system.

2) Densitometric experiments to determine the equilibrium constant and the stoichiometry of the complexation reaction. This determination will be performed at various pH, i.e. degrees of ionisation of the surfactant, and in the presence of the polysaccharide. In combination with calorimetric measurements, this will make it possible to determine the thermodynamic origin of the binding processes.

3) The complexes of chitosan and alkyl ethylene oxide carboxylic acids exhibit a surprisingly rich structural behaviour [1-2]. Static and dynamic light scattering, electrophoretic mobility, and possibly small-angle neutron scattering will be used to investigate the structural behaviour of the chitosan-surfactant-cyclodextrin mixtures on various length scales. The information gained will be combined to produce a complete picture of these complex systems. The correlation between the thermodynamic driving forces for the self-assembly process and the resulting structure and functionality will allow us to understand these systems and to tailor them for specific purposes. In summary, the trainee will be confronted with the major characterisation techniques used for soft-matter systems. He/she will learn how to perform the experiments, analyse the data, and combine the information in order to produce a comprehensive picture.

References:
Internship (Ref. DIR_2) Characterisation and Dating of Iron Alloy Artefacts Using Neutron Techniques and Complementary Methods

Techniques available at the ILL, such as Neutron Activation Analysis and Neutron Residual Stress Mapping, are to be used to characterise a selection of iron alloy objects found at the Berezina battle site during archaeological digs, in order to identify the precise chemical fingerprint of the objects concerned and hence obtain a dating estimate through comparison with similar manufacturing methods from different ages found in the literature. Through this exercise a procedure will be established for analysing any simple metal compound using neutron measurements which can be applied to any present day industrial client of the ILL.

‘Bulk analysis’ and non-destructive results from the ILL (and possibly other neutron research centres for Prompt Gamma Activation Analysis) will be compared with those obtained using more conventional metallurgy micro-structural analyses, such as optical microscopy, TEM, BEM, etc.

Activities of the trainee:
The student will carry out the following activities during the internship:
1. Continue the literature research carried out in 2016 on iron alloy fabrication techniques from the 18th century to the present day, with particular emphasis on the chemical evolution of industrially fabricated alloys. It is hoped to contact directly identified experts in this field in order to create working collaborations.
2. Assist with in-house neutron experiments at the ILL under the supervision of the tutor and the relevant ILL instrument local contacts. The student will also participate in the analysis of the results obtained. It may be that certain measurements could be carried out at other neutron centres but this will depend on their availability.
3. Prepare samples, perform metallurgical tests on them and interpret the resulting data under the supervision of the academic tutor.
4. Under academic supervision, collate the results from activities 2 and 3 and compare them with the information available from the literature research (1), thus providing insight into each object’s fabrication history and ageing.
5. Propose at the end of the internship a methodological procedure applicable to the characterisation of components and/or samples from industrial clients. The student will also present a full report covering all the work carried out and the results obtained and will prepare an article on the work and conclusions of this study for future publication.

Key words: Material Characterisation, NAA, PGAA, Residual Stress Mapping, Archaeology

Level required: 2nd year university studies in materials
Notes: This post is an internship with a maximum duration of 6 months
Please send your application directly to the supervisor: Duncan ATKINS, e-mail: atkins(at)ill.eu