ELectron-Ion Scattering in a storage ring (eA collider) – ELISe *

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The ELISe project pages can be found on:
http://www.gsi.de/fair/experiments/elise/

Abstract

The ELISe experiment will be part of the installations envisaged at the NESR for FAIR. It offers worldwide unique opportunities to scatter electrons off exotic nuclei.

Physics opportunities

For all stable nuclei, it has been shown [1] that the central densities are about the same ($\approx$ 0.17 nucleons/fm^3) and that the matter density radius is roughly proportional to the atomic number to the power of minus one-third ($R \sim A^{-1/3}$). The surface thickness (or diffuseness, $a \approx 1$ fm, see Fig. 1) is approximately independent of the mass number A. The spatial proton and neutron distributions have approximately the same form and only differ in magnitude. This is no longer the case for nuclei far from stability where skins ($R_p \neq R_n$ with $a_p \approx a_n$) and halos ($R_p \neq R_n$ with $a_p > a_n$, or $a_n > a_p$) were found. Heavy bubble-like nuclei (strong depression of central density) are also theoretically predicted. A pure electromagnetic probe like the electron allows to measure, with excellent precision, the proton distribution using elastic scattering. Together with elastic hadron scattering (e.g. p,p at medium energies) where only the matter density distribution can be measured, also the neutron density distributions can be extracted.

The determination of charge radii and extraction of nuclear matter radii are crucial for studying the evolution of neutron and proton skins along isotopic chains. For theory, the precise knowledge of the skin thickness is decisive (e.g. [2]) to understand isovector interactions and the symmetry energy. The quantity R_n - R_p is not only related to the symmetry energy but also to the slope of the equation of state (EOS) for neutrons which is proportional to the pressure. Several modern Skyrme Hartree-Fock models using different parameters [3] predict a clear linear and strong dependence between the neutron skin thickness $S = R_n - R_p$ for lead and the slope of the neutron EOS. In ref. [4] the relation of S to several quantities like the nuclear binding energy, the compressibility etc. is studied for a large amount of mean field theories.

The diffuseness parameter reflects the behaviour of the nuclear potential (e.g. spin-orbit) and eigenfunctions at the nuclear surface. It is an important ingredient for computing the asymptotic behaviour of the wave function. This is relevant to understand e.g. hadron-nucleus reactions which are sensitive only to the outer region of the nucleus due to strong absorption. See for example the large differences between the spectroscopic factors measured via *(e,e'p)* and (d,^{3}He) [5].

Since ELISe can measure *elastic form factors* that are not accessible by other means, the diffuseness of charge density distributions will be uniquely determined. The isotopic dependence of higher moments of the charge distributions will also be determined. These are again related to the isovector interaction since the proton density follows the neutron density due to static polarization.

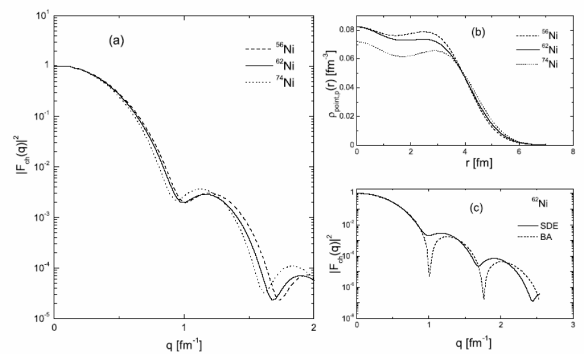

Figure 1: Elastic charge form factor for different Ni isotopes (a), the corresponding point proton distributions (b) and the effect of the Coulomb distortion of the electrons(SDE curve includes it, BA doesn’t) on the form factor (c). Taken from ref. [6].

In recent years, experimental and theoretical investigations have been refocused on the nuclear electric dipole (E1) response. The investigations have been stimulated by results of nuclear resonance fluorescence and Coulomb dissociation experiments which yielded a significant concentration of E1 strength below the particle threshold in stable and non-stable nuclei (for a recent overview we refer to [7] and references therein). Besides the implica-

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tions for the r-process nucleosynthesis, where the low-lying strength could significantly increase the neutron capture cross-section [8], there are clear indications that the strength is correlated to the neutron-excess [9] and especially prominent in exotic neutron-rich nuclei. Up to now, however, the isospin character and the structure of the dipole excitations are far from being settled (see e.g. [10]) and the correlation between the differences in the radial neutron-proton density distribution (neutron skin) and the low-lying E1 strength distribution are still speculative. In addition, there are recent theoretical investigations in the framework of the Relativistic Random-Phase Approximation [11], which predict the existence of low-lying E1 transitions also as a fundamental feature of proton-rich exotic nuclei. As an example, results of recent calculations of the electron scattering on the ^{6}He nucleus [12] demonstrates the enhancement of low-energy dipole modes in electron scattering at small momentum transfers. For the nucleus ^{6}He, which is a benchmark nucleus for all theoretical models of two-neutron halo nuclei, the scattering experiments can be realized at the ELISe *eA*-collider. *Transition formfactor measurements* will offer the unique opportunity to study the momentum-transfer dependency of E1 transitions below and above the particle threshold and contribute to pin down their structure by means of their q-dependence.

In addition, *break-up reactions* induced by electron scattering on halo nuclei can reach the order of ten millibarns for 10 MeV electrons and increase logarithmically at higher energies [13]. This means, that information about the continuum structure of weakly-bound nuclei (e.g. scattering lengths and effective ranges) are easily accessible in the electron-ion collider mode.

Nuclear fission is best suited to study the dynamic properties of cold and moderately excited nuclear matter. At low excitation energies, the onset of dissipation in a super-fluid Fermionic system and the influence of nuclear structure on nuclear level densities can be studied. Nuclear fission is also a unique tool to explore shell effects at extreme deformation. The measurement of the $\sigma_{ee'f}$ cross section with well defined momentum and energy transfer provides additional information on the nuclear fission process, e.g., on the multipolarity of the nuclear excitation [14] prior to the decay as well as it allows to study the fission barriers, neutron separation energies, branching ratios of neutron to fission decays and the level density parameter. One can study by this way the dependence of nuclear fissility on the dynamics of nuclear motion (dipole, monopole, quadrupole etc). The advantage of ELISe for fission studies with unstable nuclei, namely the possibility to determine precisely and in a model independent way multipole excitation functions, even when the resonant strength is spread over an excitation range of some MeV, has been already demonstrated for stable uranium isotopes by Th. Weber et al. [15]. Although in e-scattering the isoscalar and isovector resonances are equally excited, the interaction of the electron with the nucleus is well understood. The coincidence between the scattered electron and the fission fragments eliminates the radiative tail of elastic scattering, which in heavy nuclei can overshoot the resonant strength by some orders of magnitude.

The ELISe project offers also the unique possibility to study nucleon-nucleon (N-N) correlations as a function of the proton to neutron ratio in *quasi-free electron scattering* experiments. In symmetric nuclear matter the single particle states are depleted by ≈ 15%. This amount can be found at high missing energy and momentum. In asymmetric matter with neutron excess a larger depletion occurs for protons while for neutrons the occupation probability increases. With ELISe one could measure occupation probabilities for neutron-rich as well as proton-rich nuclei up to an asymmetry of 0.4. The distortion due to final state interaction on medium-light nuclei can be kept under control in parallel kinematics [16]. The identification of the residual system will also allow to perform (e,e'p) experiments from deep shells (as 1s ones) under exclusive conditions and thus a comparison of the spectral response of all the shells of light and medium nuclei in exclusive conditions will be obtained for the first time.

Spectrometer Design

Simulation of the ELISe (electron-ion collider) electron spectrometer [17] consisting of a predeflector system in the NESR in combination with a second vertical dipole stage has been performed for real experimental conditions. The achievable momentum resolution was studied with variable parameters, i.e.:

- initial electron energy (125 - 500 MeV),
- angle of turn of the electrons by the first magnet **a** (70^0 - 90^0),
- mean value H (1.8 - 2.5T) and coefficient of focusing of magnetic field in the second magnet **b**,
- vertical aperture of the first magnet (±1.5 mrad - ±150 mrad),
- length of interaction region for electrons and ions (0.1 - 10 cm),
- coordinate component of the vertical emittance **Δy** of the electron beam (0 - 0.2 mm).

The initial parameters were taken from Report [18]. The studies were calculated for ^{132}Sn ions. The electron tracking inside the magnets was realized using a stepwise integration of the trajectories according to the value of the magnetic field with a minimal step size of 1 mm. The magnetic field inside the first magnet was parameterized using: $H = H_0 \cdot (r/r_0)^{\mathbf{b}}$, were r_0 is the radius of the central electron trajectory in the second magnet, and **b** is the coefficient of focusing while $H_0 = 2.2$ T.

The electron tracking inside the electron spectrometer takes into account the multiple scattering which limits the thickness of the first coordinate detector. The coordinate resolution of these position detectors should be 0.2 mm in order to provide the necessary momentum resolution. Here, the distance between the beam line and entrance of the second magnet was chosen to be 1 m, and the distance from the beam plane to the output from the second magnet equals to 92 cm.

The coordinate detectors in front of the second magnet are assumed to be equipped with 100 micron mylar windows. They can be filled with a argon gas mixture (10mm thickness) with about 1/3 of atmospheric pressure. Their spatial resolution should be about 0.2 mm. Under these conditions the angular uncertainty due to multiple scattering is negligible (much less than 1 mrad), the single plane efficiency is about 70%.

The second coordinate detector at the quasi focus of the second dipole stage, should be operated under atmospheric pressure. The efficiency then is about 98%/plane, keeping the spatial resolution at 0.2 mm.

Simulations show, that using only the position information at the second magnet's quasi focal plane, results to a momentum resolution of only 0.4%, which is not yet enough to distinguish elastic and inelastic scattering. Therefore full tracking through the spectrometer is required in order to achieve the necessary resolutions of 0.01% and 1 mrad in momentum and scattering angle, respectively. As an example, one may take into account the value for the vertical angles β at the entrance of the second magnet. If one builds a calibration table of average values **u**(p_i) where **u** is the coordinate along the second position detector (stepsize for p_i, electron's momentum, 100 keV/c) for each value of β_j (stepsize of 0.2 mrad), one ends up with 3.75 million elements that are used to interpolate tracks in order to achieve maximum resolution. The final resolution for different momentum ranges is shown in Figure 2. Here the length of the interaction zone of electrons and ions is taken to be 10 cm, the coordinate component of the vertical emittance is 0.087 mm. It can be shown, that the best result corresponds to the case **a** = 90°, **b** = 0.5.

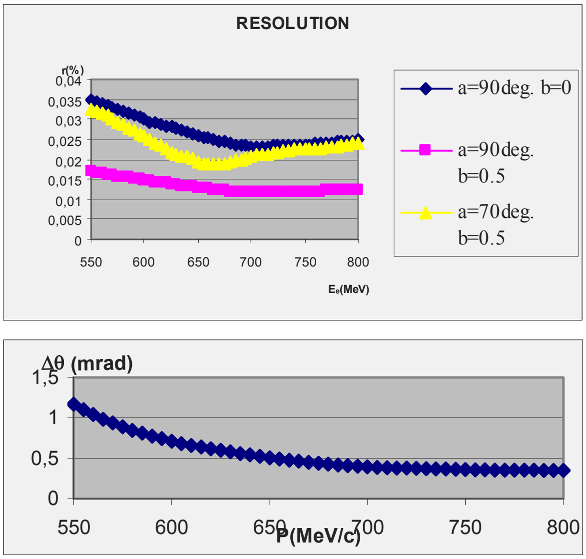

Figure 2: Dependence of the achievable resolution in angle and momentum. For details, see text.

Straw tube prototypes (see Fig. 3) have been build and put into operation at the GSI detector laboratory. They will soon be tested in a test experiment at TU-Darmstadt. They seem to be especially favourable for the first coordinate detector system due to their mechanical properties.

In a separate study, the sources of errors in the luminosity measurements using bremsstrahlung quanta have been investigated. It can be shown, that the luminosity can be reliably determined within a few percent, taking into account realistic offsets of beam and collimation axis, the influence of different ion velocities, and the variations in the absolute position of the interaction zone

Figure 3: Straw tube prototypes: straw thickness 126µm; capton on Al (0.2 µm) covered by C-layer (5 µm). Length = 60 cm; Inner diameter = 7.5 mm. Ar/CO_2 (80/20) atmospheric pressure at 1850 V.

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