Nucleon Polarisabilities from Low-Energy Compton Scattering ◇

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Static nucleon polarisabilities gauge the stiffness of the nucleon against an external electro-magnetic field, parameterising the part of the real Compton amplitude at zero energy which is not explained by the Powell cross-section. *Dynamical* nucleon polarisabilities are the energy dependent generalisation to real Compton scattering [1].

To define them, one first subtracts the "nucleon-pole" effects from the real Compton amplitude. At fixed real photon energy, the structure-dependent part of the amplitude is then analysed by a multipole expansion, whose coefficients are the energy-dependent electric ($\alpha_{El}(\omega)$), magnetic ($\beta_{Ml}(\omega)$) and spin-dependent ($\gamma_{ElEl}(\omega)$, $\gamma_{MlMl}(\omega)$, $\gamma_{ElM(l+1)}(\omega)$, $\gamma_{MlE(l+1)}(\omega)$) polarisabilities. They describe the interaction of the nucleon with electric or magnetic ($X,Y = E,M$) photons of definite multipolarity, l,l', $Xl \to Yl'$ [1,2].

Dynamical polarisabilities test dispersive effects of the low-energy degrees of freedom inside the nucleon, induced by internal relaxation mechanisms, baryonic resonances and meson production thresholds. In Figs. 1/2, a dispersion analysis of the leading dynamical polarisabilities is compared to the Effective Field Theory of the nucleon. The latter is a model-independent and systematic approach to low-energy QCD, with spontaneously broken chiral symmetry implemented rigorously [1]. It incorporates the nucleon, the $\Delta(1232)$ and their respective pion clouds as explicit low-energy degrees of freedom. The results without explicit Δ (HBχPT) are also shown. Polarisabilities stem predominantly from charge displacements of the pion cloud around the nucleon and from the Δ resonance contribution. However, the counter-terms for $\alpha_{E1}(\omega)$ and $\beta_{M1}(\omega)$, which subsume all short-distance physics, turn out to be at least 4 times larger than naïve dimensional analysis predicts. With their size fixed to the static polarisabilities measured, their energy dependence is predicted in good agreement with a Dispersion Relation analysis, Fig. 1 [2]. No genuinely new degrees of freedom are missed at low energies. The spin-dependent polarisabilities, Fig. 2, are parameter-free predictions. γ_{M1M1} and β_{M1} show for the first time beyond doubt the importance of the magnetic $\gamma N\Delta$-interaction for the polarisabilities.

Most experiments to determine proton and neutron polarisabilities are performed by Compton scattering off protons and light nuclei at photon energies of $80 - 200$ MeV. At those energies, dynamical effects are large. Especially at large backward angle, unpolarised and polarised cross-sections are rather sensitive to the non-analytical structure of the amplitude around the Δ-resonance [2,3]. High-accuracy experiments on the proton and e.g. ^{3}He, as planned at MAMI and TUNL, will be able to extract the energy-dependence of the nucleon polarisabilities, both spin-independent [2] and spin-dependent [3]. In Compton scattering of a circularly polarised photon with momentum in the z-direction, the asymmetry Σ_x between the neutron-spin in positive or negative x-direction shows for example strong sensitivity on the spin-polarisbilities $\gamma_i(\omega)$, while higher polarisabilities are negligible; see Fig. 3 [3].

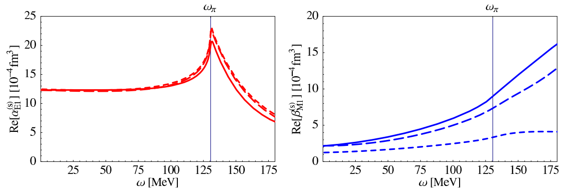

Fig. 1: The real parts of the iso-scalar, spin-independent dynamical electric and magnetic dipole polarizabilities [1,2]. Solid: Dispersion Relations; dotted: HBχPT; dashed: MSSE.

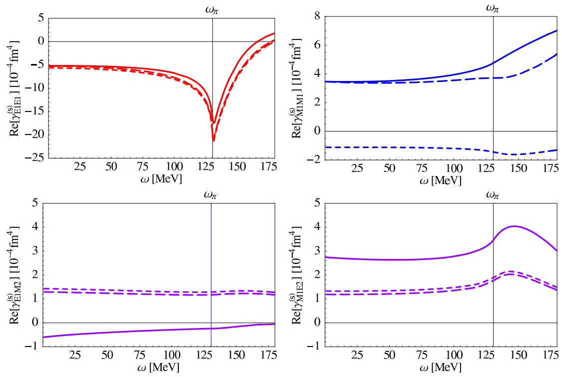

Fig. 2: The real parts of the iso-scalar, spin-dependent dynamical dipole polarizabilities [2]. Notation as in Fig. 1.

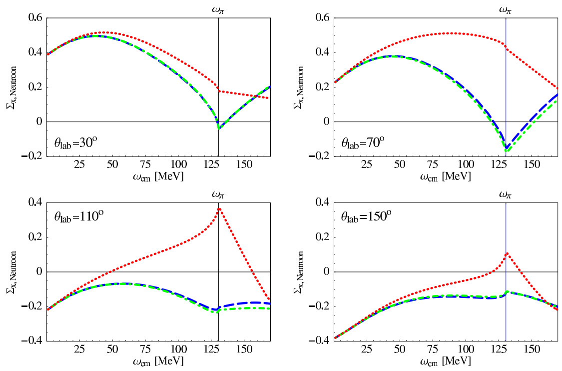

Fig. 3: Prediction for the asymmetry Σ_x on the neutron. Dashed: full result; dotted: no spin-polarisabilities; dot-dashed: no quadrupole polarisabilities.

Dynamical polarisabilities do not contain more or less information than the corresponding Compton scattering amplitudes, but as with any multipole decomposition, the facts are more readily accessible and easier to interpret. Stringent constraints for models and model-independet power countings of a low-energy Effective Field Theory of the nucleon follow from their analysis.

References

[1] H. W. Grießhammer and T. R. Hemmert, Phys. Rev. **C65** (2002) 045207

[2] R. Hildebrandt, H. W. Grießhammer, T. R. Hemmert and B. Pasquini, forthcoming.

[3] H. W. Grießhammer, T. R. Hemmert and R. Hildebrandt, forthcoming.

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