High-Accuracy Measurement of the Spin-Dependent nd Scattering Length ◇

B. van den Brandt [a], H. Glättli [b], H.W. Grießhammer, P. Hautle [a], J. Kohlbrecher [a], J.A. Konter [a], A. Michels [a], F. Piegsa, H.-F. Wirth, and O. Zimmer
[a] Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[b] Commissariat à l'Energie Atomique, CE Saclay/SPEC LLB, F-91191 Gif-sur-Yvette, France

The aim of the present experiment is a direct and accurate determination of the spin-dependent neutron scattering length of the deuteron. Its theoretical implications as an essential input to novel effective field theories of interactions in few-nucleon systems were already described in the last annual report. Here we briefly present the method with which we hope to achieve an accuracy of 10^{-3}.

The spin-dependent neutron scattering length $b_{\rm i}$ can be determined directly with a polarised neutron beam passing through a polarised target, via detection of pseudomagnetic neutron precession around the axis of nuclear polarisation, which was first demonstrated in [1]. The precession angle is given by

$$\varphi^* = 2\lambda d \sum_k \sqrt{\frac{I_k}{I_k+1}} P_k N_k b_{{\rm i},k}. \qquad (1)$$

N_k is the number density, I_k the nuclear spin and P_k the nuclear polarisation, with the sum index k extending over the nuclear species with spin. λ is the de-Broglie wavelength of the neutrons, and d is the thickness of the sample. φ^* can be measured with an accuracy of at least one degree, using the method described in [2] based on Ramsey's well-known resonance technique with two separated oscillatory fields.

The measurement will be performed relative to $b_{\rm i,p}$ of the proton, which is known with the high accuracy of 2.4×10^{-4}. Using a single target which contains both deuterons and protons at hydrogen sites, absolute polarisation measurements can be avoided. Our method combines several measurements. First, both isotopes are polarised simultaneously via dynamic nuclear polarisation. After freezing the nuclear polarisation one determines the pseudomagnetic precession angle. According to eq.(1), and including an instrumental phase φ_0, it is given by

$$\phi_1 = \varphi^*_{\rm d} + \varphi^*_{\rm p} + \varphi_0 \qquad (2)$$

with

$$\varphi^*_{\rm d} = \sqrt{2}\lambda d P_{\rm d} N_{\rm d} b_{\rm i,d}, \quad \varphi^*_{\rm p} = \frac{2}{\sqrt{3}} \lambda d P_{\rm p} N_{\rm p} b_{\rm i,p}. \qquad (3)$$

Using hf-saturation, one can selectively depolarise either the protons or the deuterons, without significantly affecting the polarisation of the other spin species. The subsequent cross relaxation between the two spin systems can be held sufficiently slow by keeping the temperature sufficiently low. Saturating, e.g. first the protons, one can measure the angle $\phi_2 = \varphi^*_{\rm d} + \varphi_0$, and after a subsequent depolarisation of the deuterons one measures $\phi_3 = \varphi_0$. The method is completed with measurements of deuteron and proton NMR signals $\mathcal{I}_k$, taken as integral of the corresponding rf-absorption line before and after each measurement of a pseudomagnetic precession angle:

$$\mathcal{I}_k = C_k P_k N_k. \qquad (4)$$

Apart from natural constants, C_k is given as the product of g_k^2/I_k (with g_k denoting the g-factor) and a factor accounting for the sensitivity of the resonance circuit. If we take only ratios of pseudomagnetic precession angles, only the ratio of $P_k N_k$ for the two spin species occurs. Replacing it by the ratio of NMR signals via eq.(4), the common instrumental factor cancels out. This requires using the same, linear resonance circuit at the same frequency in the measurements of $\mathcal{I}_{\rm d}$ and $\mathcal{I}_{\rm p}$, which therefore have to be performed at different main magnetic fields to account for the different gyromagnetic ratios. Combining the various measurements into ratios and using eq.(3), we thus finally obtain

$$b_{\rm i,d} = \frac{1}{\sqrt{6}} \frac{g_{\rm d}^2}{g_{\rm p}^2} \frac{\phi_2 - \phi_3}{\phi_1 - \phi_2} \frac{\mathcal{I}_{\rm p}}{\mathcal{I}_{\rm d}} b_{\rm i,p}. \qquad (5)$$

It is the gist of this method that we donot suppose any exact knowledge of neither $N_{\rm d}$, $N_{\rm p}$, $P_{\rm d}$, $P_{\rm p}$, d or λ, nor of any absolute calibration factors.

The experiment is presently being set up at PSI in Villigen, Switzerland. A first run will take place in June 2004.

References

[1] A. Abragam, G.L. Bacchella, H. Glättli, P. Meriel, M. Pinot, J. Piesvaux, Phys. Rev. Lett. **31** (1973) 776

[2] H. Glättli and M. Goldman, Meth.Exp.Phys. **23C, chpt. 21** (Academic Press, New York, 1987) 241

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