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Target Wall Multiple Scattering Effects In Neutron Polarization Experiments Using A Liquid ^{4}He Target

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Multiple scattering (MS) effects in connection with the material surrounding a liquid target have been treated to some extent in low energy neutron scattering, see e.g. ref. 1 and references therein. Above 14MeV neutron energy it becomes increasingly difficult to make a quantitative prediction because of the small amount of data available, especially on inelastic neutron scattering, which becomes more and more important. In this contribution we present the results of Monte Carlo calculations which in addition to MS in the target itself also treat MS effects due to the enclosing target vessel, cold shield and vacuum tank in the scattering of 51 MeV polarized neutrons off a liquid ^{4}He target. (For more detail see ref. 2). Our target geometry is representative for a liquid cryogenic target: liquid ^{4}He is contained in a 50 mm inside diameter sphere made of pyrex with 1.1 mm thick walls. A PM looks through the flat bottom of the sphere at the scintillations of recoil α's thus forming a detector with ~20% energy resolution. The target is surrounded by a cold shield in the shape of a 1 mm thick copper cylinder of 70 mm diameter. The whole assembly sits in a vacuum tank made of 1 mm thick aluminium and 100 mm diameter. Scattered neutrons are detected at back-angles in plastic scintillation counters (10 cm wide, 50 cm high, 8.4 cm thick) 1 m away from the target.

We shall now consider the MS process in more detail and make the following distinctions (it is sufficient to take into account double scattering only; nevertheless we will retain the notation "multiple scattering"):

1) MS in the liquid itself (MS1)
2) MS in connection with the enclosing walls (MS2), for which we consider 2 cases: a) The first scattering takes place in any of the walls, and the second in the liquid. b) The first scattering takes place in the liquid, and the second in any of the walls. (MS in the walls only can be excluded since a valid event must produce a signal in the ^{4}He target/detector).

MS corrections to the analyzing power A_y arise mainly through 2 sources: i) a rotation of the neutron spin in the 1st scattering. For the case MS1 we have found however that this contribution is negligible at our energies since the differential cross section for nα is very forward peaked and for small angles the spin rotation is small. Since for neutron scattering off heavier material this behaviour is even more pronounced we conclude that the spin rotation can be neglected in the scattering from the walls. The main MS contribution is then given through ii) a "dilution" of the nα analyzing power which arises through its strong angular dependence at back-angles (cf. ref. 2): a 1st scattering through only ~10-20^o shifts the angle in the 2nd scattering to a point where A_y is very small or has even opposite sign.

In principle MS calculations call for a detailed description of the cross sections including here also polarization observables over the whole range of energies. For MS1 sufficiently accurate nα phase shifts were obtained from pα phase shifts, where the Coulomb phases had been removed.

For wall scattering the angle range to be considered was restricted to < 90° since in the following (or preceding) ^{4}He scattering a sufficiently large signal must be produced in order to be accepted as a valid event. Elastic scattering was treated exactly (within the limits of the available data) whereas inelastic scattering was included in an approximative way up to excitation energies of ~10 MeV (MS2 a) and ~4 MeV (MS2 b). Higher excitation energies were not considered since such events would not meet the target-neutron detector TOF cut conditions (see below). Spin effects were neglected totally.

For a given angle the MS contributions depend critically on the cut applied to the target-neutron detector TOF: double scattered neutrons loose more energy than single scattered ones. They are hence slower and can be cut out to some extent by applying a stringent cut to the target-neutron detector TOF. In table I we have listed the MS corrections to A_y in % separately for MS1 and MS2 at 50 MeV incident neutron energy at Θ_{lab} = 135° for different cut widths (the cuts were placed symmetrically around the single scattering TOF peak).

As MS2 a) and MS2 b) behave similarly with respect to the cuts we have simply added them in table I. Usually effect MS2 b) contributes more than MS2 a) by a factor 2 to 3. In brackets we have listed also the ratio D/S of double scattered to single scattered neutrons. Statistical uncertainties obtained from the variance of a whole set of Monte-Carlo simulations are $\lesssim$ 10% for the corrections to A_y and < 1% for the D/S values. The systematic uncertainty due to phase shift and cross section normalizations, approximations etc. is estimated to < 10% for MS1 and < 20% for MS2, because of the less well known inelastic processes which contribute with ~ 30 % to MS2.

Table I. MS correction to A_y and to $\frac{d\sigma}{d\Omega}$ (in brackets) for different cut widths at E_n = 50 MeV at Θ_{lab} = 135°.

cut width	MS correction to A_y[%] (D/S[%])			
[ns]	MS1	MS2 (pyrex)	MS2 (copper)	MS2 (aluminium)
2	0.54 (1.65)	0.42 (1.48)	0.38 (2.10)	0.22 (1.01)
3	0.93 (2.26)	0.62 (1.73)	0.51 (2.38)	0.28 (1.16)
4	1.35 (2.80)	0.75 (1.89)	0.55 (2.48)	0.30 (1.25)
6	1.80 (3.50)	0.79 (1.97)	0.56 (2.54)	0.31 (1.30)
∞	2.40 (3.89)	0.79 (2.00)	0.54 (2.56)	0.31 (1.31)

Clearly the MS1 contribution is more sensitive to the cut width than MS2, which is due to the fact that the reaction kinematics are different for light and heavy targets. Therefore the wall effects become relatively more important for small cut widths and for our cut width of 4 ns (mainly given by the ~2.7 ns time resolution of the neutron beam) the overall MS2 correction (1.60%) is slightly larger than the MS1 correction (1.35%). It should also be noted that this behaviour is even more pronounced for the cross section correction D/S. (5.60% as compared to 2.80%).

In conclusion it is clear that MS effects in connection with the enclosing walls cannot be neglected in a precise measurement.

References

1) W. Tornow and G. Mertens, Nucl. Instr. Meth. 146 (1977) 545
2) C. Gysin et al., contribution to this conference