Warm Target Experiment

A. T. Holley

created: June 11, 2014
updated June 21, 2014

Overview

Presented are some initial results from a toy Monte Carlo simulation of our fifth force room temperature target. The current simulation only models the target, but other elements could be added fairly easily. The simulation, however, is slow since it is written in Python. (I used this as an exercise to help me learn more about Python for teaching purposes.) Also indicated are some examples of useful next steps to take in characterizing the experiment. Anyone who is interested is encouraged to make use of the model for these or other calculations.

Although this model is very far from vetted, the two tentative conclusions reached from these initial calculations are:

(A) The geometry considered here, in the semi-infinite plate approximation and in the absence of beam divergence, suggests a much more optimistic experimental reach than Murad's calculations. If this is the result of Murad's inclusion of bounces (and any other more realistic aspects of the experiment) then such effects could turn out to be rather important for this experiment.

(B) It should be sufficient to have the nucleon number densities in adjacent plates differ by at least 25%.

1 The Model

The Monte Carlo model is written in Python and is general enough that it can be straightforwardly extended to include input and output guides and fields, the "pi-coil" field, and the actual detector if desired. Currently it provides a realization of one channel of the target, which can be set in "horizontal" (plates left/right) or "vertical" (plates up/down) positions. Neutrons travel in straight lines unless they hit a plate or a wall and are currently assumed to be absorbed if they hit a wall and to scatter specularly if they hit a plate. The neutron spin is integrated classically according to

$$\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \gamma_{\mathrm{n}} \left(\vec{S} \times \vec{B}\right),$$

where between the plates $\vec{B}$ is currently composed only of the pseudo-magnetic field evaluated in the semi-infinite slab approximation, i.e.

$$\vec{B}_{AA}(\Delta x) = \frac{n}{\gamma_{\mathrm{n}}} \left(\frac{g_A^2}{4}\right) \left(\frac{\hbar}{mc}\right) \lambda \left(\vec{v} \times \hat{y}\right) \exp(-\Delta x/\lambda), \tag{1}$$

although additional real magnetic fields are easily added. It is also simple to determine the pseudo-magnetic field by numerically integrating the contribution from individual nuclei over a mass distribution (in order to explore, for example, edge effects), but this is much more computationally intensive.

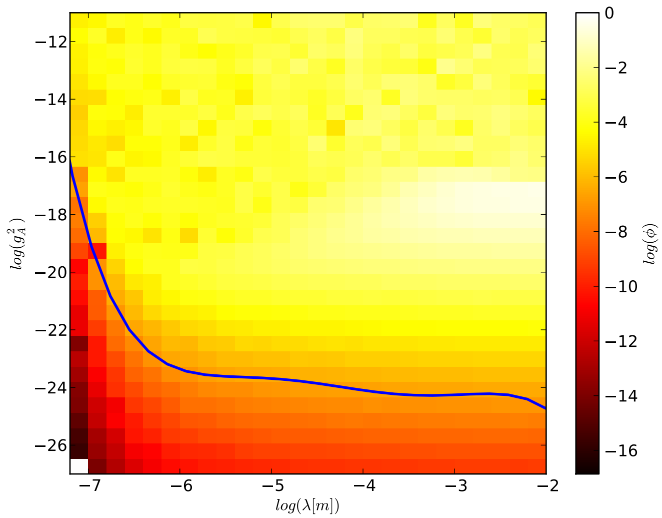
Since no detector, output coil, or "pi-coil" is currently implemented, the observed spin rotation angle is obtained by averaging the z-components (components in the beam direction) of the spin for all neutrons which reach the end of the target. The incoming neutrons are currently assumed to be perfectly polarized in the $+\hat{y}$ (upward) direction and to uniformly illuminate the entrance aperture of the target channel.

2 Semi-infinite plate approximation, no beam divergence

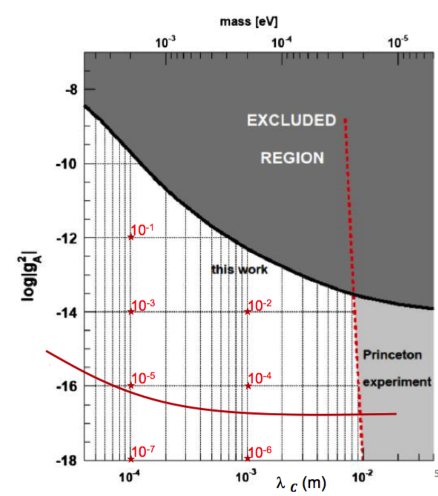
The simulation results shown here use the semi-infinite slab approximation and assume no beam divergence. As a result, they should be equivalent to a direct integration of the rotation angle due to Eq. 1.

2.1 What is the estimated experimental reach?

Taking plates made of W and Al separated by 1/8" and flat on the level of a μm (so that neutrons are assumed not to approach a plate more closely than 1×10^{-6} m), the integrated spin rotation angle as a function of g_{A} and λ that the model produces is:



The blue line is a smoothed representation of a line drawn through points which correspond to a total spin rotation angle (through the 0.5 m target) at the level of 5×10^{-7}. Note that these results are considerably more optimistic than Murad's (see plot below taken from Chris' 2014 APS talk). This may be a result of Murad's considering bounces, which were neglected here. Murad's geometry was also somewhat different form the one used here, and it is not known whether he incorporated edge effects which are not included here. Depending on how different Murad's geometry was from the one considered here, it may be, then, that some of these "second-order" details will be rather important in the experiment.



Next steps:

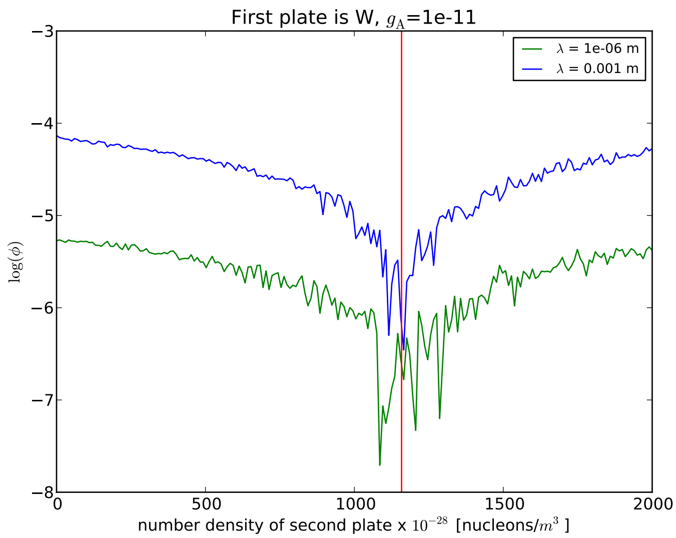
(1) Compare the above results to a direct integration.

(2) Repeat the simulations with bounces.

(3) Repeat the simulation with finite-sized plates.

2.2 How different do the nucleon number densities in adjoining plates need to be?

Here one plate is set as W and the nucleon number density of the other plate is varied. The vertical red line indicates the W nucleon density. As expected, the integrated rotation angle has a minimum when the two plates are identical.



Roughly, it appears that we'd like to have number densities which differ by at least 25% or so. For reference, here is our current table of number densities:

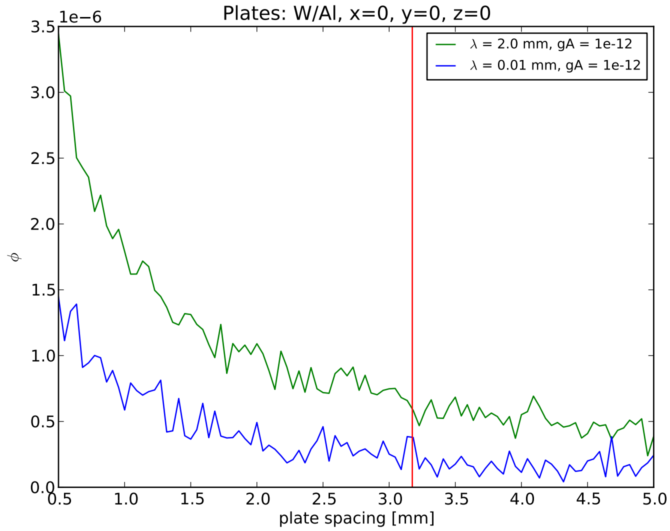
Material	[nuclei/cc] $\times 10^{22}$	[nucleons/cc] $\times 10^{22}$
Al	6.02	$6.02 \times 27 = \underline{162.54}$
Ti	5.67	$5.67 \times (46 * 0.082 + 47 * 0.074 + 48 * .738 + 49 * 0.054 + 50 * 0.052) = \underline{271.706}$
Cu	8.48	$8.48 \times (63 * 0.69170 + 65 * 0.30830) = \underline{539.469}$
Pb	3.31	$3.31 \times (204 * 0.014 + 206 * 0.241 + 207 * 0.221 + 208 * 0.524) = \underline{685.968}$
W	6.3	$6.30 \times (180 * 0.001 + 182 * 0.263 + 183 * 0.143 + 184 * 0.307 + 186 * 0.286) = \underline{1158.56}$

Note that 0.3175 cm $\times$ $(4 + 3) = 2.2$ cm so that with 1/8" spacings and 1/8" plates, five materials will span only half of one 5 cm $\times$ 5 cm quadrant.

Next Steps:

(1) Generate (g_A, λ) maps for pairs Al/Ti, Ti/Cu, Cu/Pb, Pb/W.

3 How does the integrated signal vary with plate separation?



Unsurprisingly, in the no beam divergence, semi-infinite plate limit the integrated rotation angle begins to rise quickly as the plate separation approaches λ. The vertical red line here indicates the 1/8" plate separation currently envisioned.

Next Steps:

(1) Repeat with bounces.

(2) Repeat with finite-sized plates.