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REFERENCES

[1] R.E. Jacob, S.W Morgan, and B. Saam, Phys. Rev. Lett. 87 (2001) 143004

Depolarisation of ^{3}He due to wall collisions

Hyperpolarised ^{3}He is used extensively in neutron facilities for neutron-spin filtering, and in a variety of other contexts from engineering to medicine. However its use is impeded by the fact it loses its polarisation with time. In good containers, ^{3}He remains polarised for hundreds of hours. In other containers made in the same manner, it may lose its polarisation after a few hours. Currently, good and bad containers are identified by trial and error. To improve the proportion of good containers, we need to identify the depolarisation process which leads to such huge variations.

We believe that they are due to variations in the density of unwanted magnetic impurities on the container walls. For a typical cell (a few centimetres across) of ^{3}He gas (at room temperature and pressure), the depolarisation takes tens or hundreds of hours, while the time to diffuse across the cell is about a second; so each atom undergoes a huge number of wall collisions before it is depolarised. Thus the depolarisation could originate from the fact that when a ^{3}He atom collides with the wall, its spin is very slightly rotated by the tiny short-range magnetic field generated by such an impurity (see **figure 1**).

We model the motion of each ^{3}He atom as a random-walk, so it is crucial to analyse the number of times the random walk hits the container walls in a time t (see **figure 2**).

This number will be different for different random walks, and so we must think in terms of the probability distribution of the number of boundary collisions. This distribution is characterised by two quantities; (i) the average number of wall collisions, $N(t)$, in the time t, and (ii) the variance in the number of wall collisions, var$[N(t)]$, in the time t.

For a one-dimensional random walk enclosed between two walls a distance X apart, we find that for times t much bigger than the time to diffuse across the container:

$$N(t) = vt/X \quad (1)$$
$$\mathrm{var}[N(t)] = t/(3\,\tau_{mfp}) \quad (2)$$

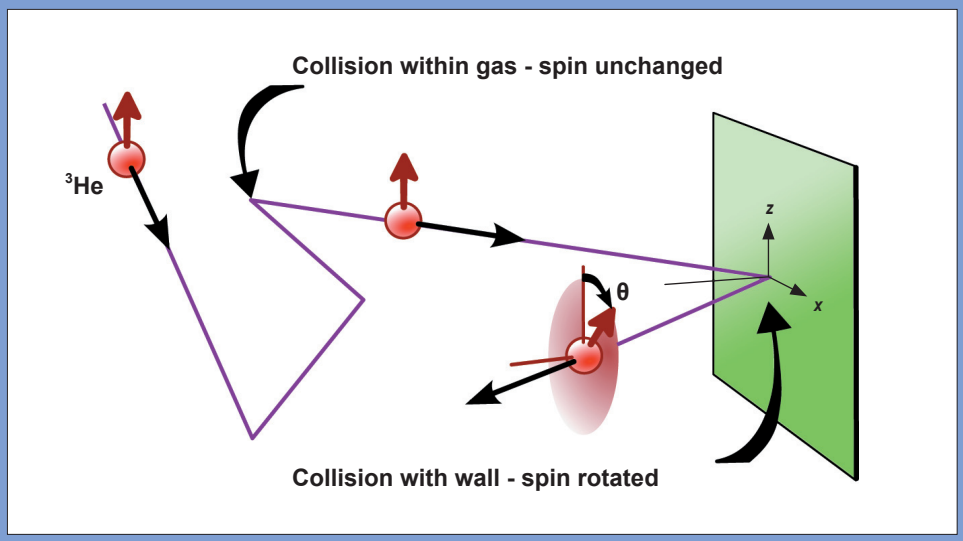

Figure 1:
At each wall collision, the spin of the ^{3}He atom is rotated by a very small random angle, θ. We neglect spin rotations at collisions within the gas, since wall collisions dominate the depolarisation in all but the very best containers.

Hyperpolarised ^{3}He gas is slowly depolarised by collisions between the ^{3}He atoms and the walls of the container it is in. This depolarisation is thereby related to the statistics of a random-walk's collisions with walls. We find that the statistical fluctuations in the number of wall collisions show *universality* in the long time limit, being *independent* of the distance between walls. Remarkably, this means that wall-scattering can induce depolarisation processes which are independent of the container size.

where v and τ_{mfp} are the velocity and mean-free-path of the walker (the ^{3}He atom). The result for the average is not unexpected, it goes like $1/X$. However the result for the variance is quite remarkable, despite being an effect of the walls it is completely *independent* of the inter-wall distance, X. We can then approximate an atom's motion in a cubic container by three independent random-walks in the *x,y,z*-directions.

Typically, $\tau_{mfp} \sim 10^{-10}$s and $X/v \sim 10^{-5}$s, thus the variance in Equation (2) is 10^5 times larger than the average in Equation (1). This vast difference is due to strong correlations between subsequent wall collisions, see **figure 2**. If correlation had been weak, one would have found the average and variance to have been of similar magnitude, so fluctuations about the average (square-root of variance) would have been of order the square-root of the average. This type of argument was used by Smoluchowski in his model of Brownian motion. For our problem, in contrast, neglecting correlations would under-estimate the variance by a factor of 10^5.

The fluctuations in the number of boundary collisions are so much larger than one would naively expect, we argue that they should not be neglected when calculating the depolarization rate of the gas.
In particular, we show that they are a strong source of depolarization in those cases where the spin-rotation at each wall collision has a preferred direction (e.g. a rotation by angle $+\theta$ is more probable than by angle $-\theta$). This will be the case whenever the magnetic impurities in the container walls have been partially aligned, for example by exposure to a magnetic field before the container was filled with ^{3}He. Similar effects were observed during an experiment in [1], which we are now trying to reproduce and study systematically.

Remarkably, the depolarisation rate associated with this process is *independent* of the container-size. This is despite the fact that it is induced by wall-collisions, and the typical number of such collisions decays with increasing container-size.

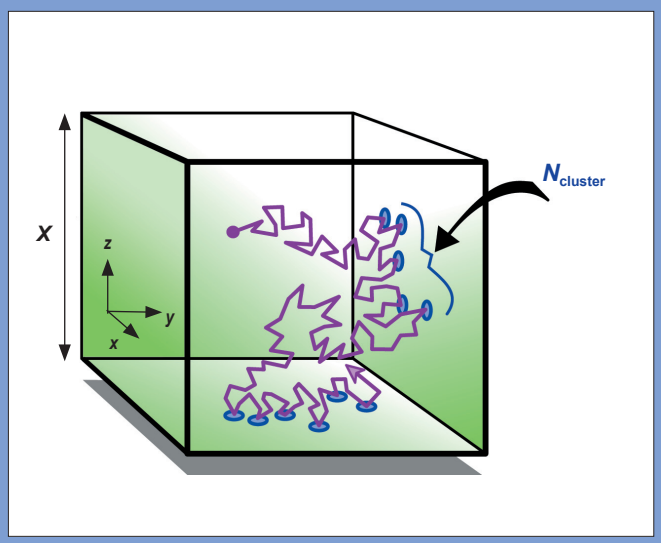

Figure 2:
The random-walk of a ^{3}He atom as it diffuses in the gas in a cubic container. Wall collisions (marked with blue circles) occur in clusters, which means that there are strong positive correlations between subsequent collisions. An atom far from the wall has no wall-collisions until it diffuses there, then it will typically undergo $N_{cluster}$ collisions before diffusing a way from the wall again. Approximating this motion by three independent random-walks in the x,y,z-directions, we find that $N_{cluster} \propto 1/X$, which leads to the X-independence of var[N(t)].