Electric field measurement device using Ramsey resonance method

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Introduction

To better implement experiment using polarized neutron techniques, the Ramsey resonance method with separated oscillating fields is employed.

A Ramsey apparatus is designed and constructed to characterize the electric field and pseudomagnetic field effects within the sample, as well as other related physical effects.

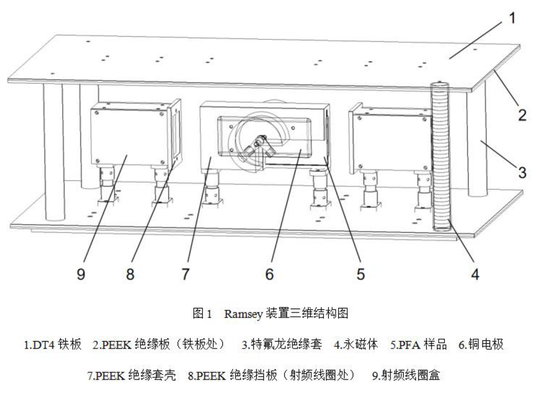
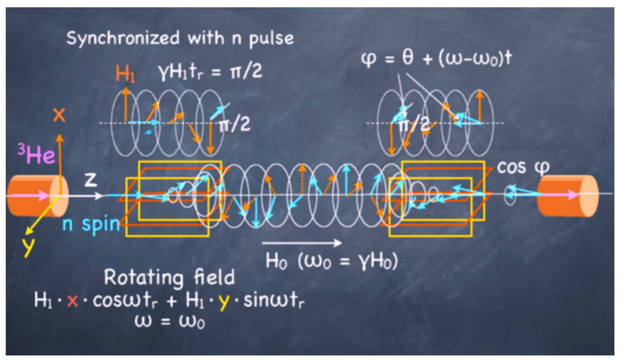


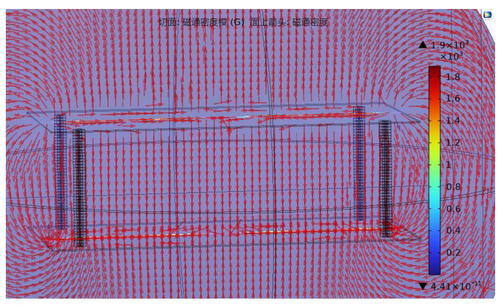
图 1 Ramsey 装置三维结构图

1.DT4 铁板 2.PEEK 绝缘板（铁板处） 3.特氟龙绝缘套 4.永磁体 5.PFA 样品 6.铜电极

7.PEEK 绝缘套壳 8.PEEK 绝缘挡板（射频线圈处） 9.射频线圈盒

Technical Route





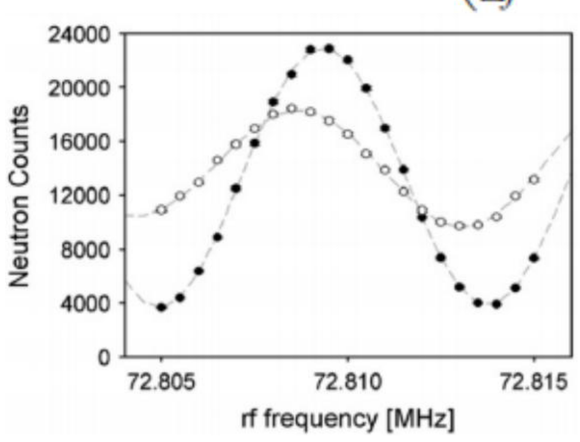
[1]

A polarized neutron beam propagates through a static magnetic field B_0, in which two phase-locked π/2 resonant spin flippers are arranged.Their radio-frequency field Brf oscillates perpendicularly to B_0 ($B_{rf} \ll B_0$), with an angular frequency ω close to the neutron Larmor frequency $\omega_0 = -\gamma_n B_0$.The amplitude of B_{rf} is tuned to rotate the neutron spin by 90° in each spin flipper, thus realizing a total 180° rotation of the polarized neutron spin vector.

Frequency scanning is applied to the second radio-frequency spin flipper both without and with the sample inserted, from which the complete Ramsey fringes (and their frequency shifts) are obtained.

Centered at the resonant frequency, the 21 data points obtained from experimental frequency scanning are fitted with a first-order corrected sine function.[2]

$$a(v) = a_0 + a_1 \cdot \sin\left(\frac{2\pi}{\Delta f} \cdot v - \varphi\right) \cdot (1 + a_2 \cdot v + \mathcal{O}(v^2))$$



Relationship between the phase shift and the frequency shift in Ramsey fringes

At the peak of the phase signal:

$$\frac{2\pi}{\Delta f} \cdot v_0 - \varphi_0 = \frac{\pi}{2}$$

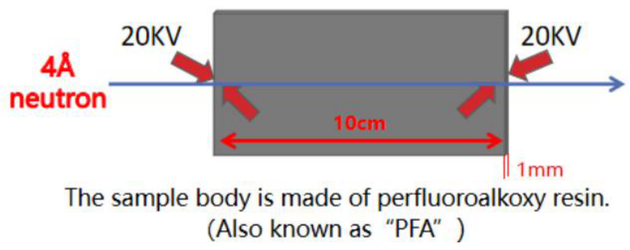
After shifting:

$$\frac{2\pi}{\Delta f} \cdot v_1 - (\varphi_0 + \Delta\varphi_{sample}) = \frac{\pi}{2}$$

$$\therefore \frac{2\pi}{\Delta f} \cdot \Delta v = \Delta\varphi_{sample}$$

Methodology

Owing to relativistic effects , electric and magnetic fields obey the Lorentz transformation in different reference frames. In this work, we employ neutrons to carry out measurements of the relevant electric fields.The effective magnetic-field vector B_{eff} sensed by a moving neutron is expressed as[2]:



The sample body is made of perfluoroalkoxy resin.
(Also known as "PFA")

$$\mathbf{B}_{\text{eff}} = \mathbf{B}_{\text{lab}} - \frac{\mathbf{v} \times \mathbf{E}}{c^2}, \quad \text{for } |\mathbf{v}| \ll c.$$

Due to electric field–induced precession, the angular vector of the neutron spin experiences a net change[2]; the relevant formula is obtained from the path length L of the neutron passing through the electric field.

$$\boldsymbol{\theta} = \int_l \frac{d\langle \mathbf{I} \rangle}{|\langle \mathbf{I} \rangle|} = \int_l \gamma_n \left[\mathbf{e}_I \times \frac{\mathbf{B}_{\text{lab}}}{|\mathbf{v}|} - \mathbf{e}_I \times \frac{(\mathbf{e}_v \times \mathbf{E})}{c^2} \right] dl$$

Simulation

The device was debugged for polarization flipping with no electric field applied to the sample, as shown in Figure 1.

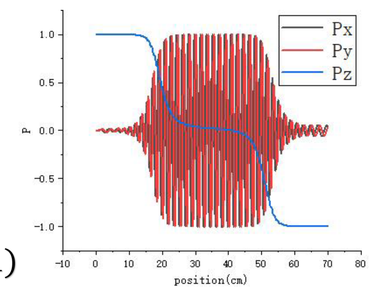


Fig.1. Polarization Simulation

$$y = a_0 + a_1 \cdot cos\left(\frac{2\pi}{\Delta f} \cdot \omega + rad\right) \cdot (1 + a_2 \cdot \omega), \quad (1)$$

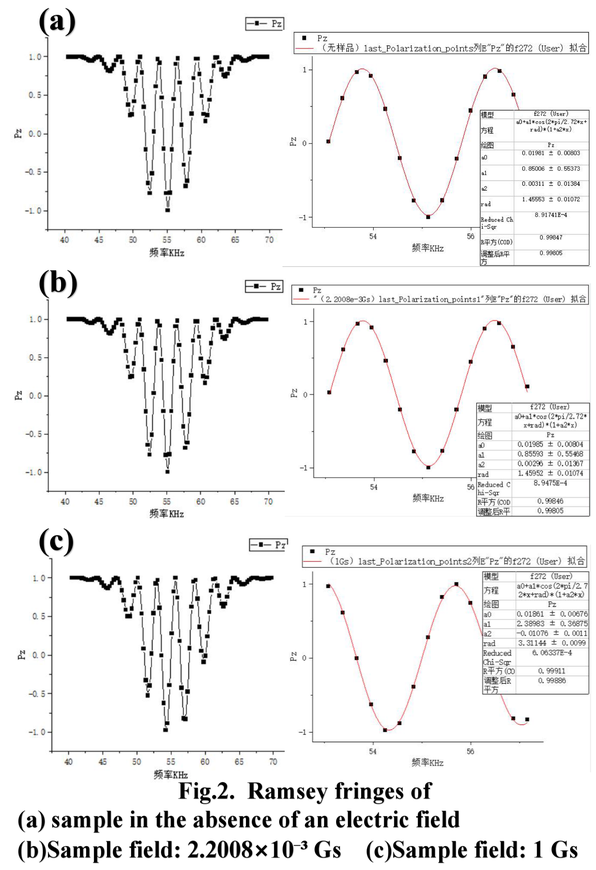


Fig.2. Ramsey fringes of
(a) sample in the absence of an electric field
(b)Sample field: 2.2008×10^{-3} Gs (c)Sample field: 1 Gs

The simulated Ramsey fringes presented in the left column of Figure 2 were acquired through frequency sweeping. A total of 25 data points were selected symmetrically from the center of the fringes to both sides for functional fitting (right column,Equation (1)), from which the corresponding phase information was obtained.

(a): rad=1.45553 rad
(b): rad=1.45952 rad
} 0.00409rad≈0.229°

(c): rad=3.31144 rad
} 1.85326rad≈106.3°

Verify Data Accuracy:
From simulated data (10 cm, 1 Gs sample field),
Calculate Additional Precession:

$$\boldsymbol{\theta} = \boldsymbol{\omega} \cdot \boldsymbol{t} = \boldsymbol{\gamma_n} \cdot \mathbf{1Gs} \cdot \frac{\mathbf{10cm}}{\mathbf{989m/s}} \approx \mathbf{1.852853\,rad}$$

(Expected experimental results)

Conclusions

Electric field measurement device based on Ramsey resonance method enables the detection of weak electric fields inside samples or the measurement of the Larmor precession angle of polarized neutrons, which reflects the effect of phase accumulation caused by the internal electric field of the sample. This Ramsey apparatus is designed to further explore the application potential of this innovative experimental method.

Key References

[1] Piegsa, F.M. et al., Nucl. Instr. and Meth. A 589, 318, 2008.

[2] Hussey, DS , PHYSICAL REVIEW LETTERS,2020.

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