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Effective Giromagnetic Ratios in Artifical Nuclear Magnetization Pumping of the Noble Gases Mix

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Abstract. Dynamic of the nuclear magnetization of the two noble gases mix was studied in this research. Nuclear magnetization pumped along the induction of external magnetic field. Vector of nuclear magnetization is given a tilt by the week rotational magnetic field, which makes NMR for noble gases. Interaction between the nuclear magnetic moments of the different noble gases adducted to shifts at the frequency of nuclear moments precession in external magnetic field. Effective gyromagnetic ratios of the nuclear of noble gases is defined and it different from the tabulated value. There is theoretical calculation of effective gyromagnetic ratios in this research.

Keywords: NMR, gyromagnetic ratios, nuclear magnetization, shifts of the frequency.

Atoms with non-zero nuclear spin interact with an electromagnetic radio-field, being in a constant magnetic field. This phenomenon is called as a *nuclear magnetic resonance*. A lot of measuring tools and medical devices was created by using NMR. It was considered nonlinear dynamics of nuclear magnetization of noble gases under the influence of a radio-field and optical pumping in this research [1].

State of the nuclear spin decays by collisions with the other atoms or walls of a cell so slowly, because the nucleus at noble gases is protected by completely electronic shell. It allows using the gas cell as storage-device of information about nuclear spin. Mixes of two noble gases with different nuclear gyromagnetic ratios in a cell have chance for wide practical application. Article about the spin generator on mercury vapors ^{199}Hg and ^{201}Hg [2] is one of the first works in this research-area.

Nuclear spin makes precession movement in external magnetic field. Joint dynamics of nuclear spins of the different atoms in general magnetic field allows to exclude fluctuation of the external magnetic field. Therefore, gas cell may be to use as magnetometer. Larmor's precession frequency of nuclear spins with different gyromagnetic ratios is describes by easy formula:

$$\omega_n = \gamma_n B_0 + \Omega \qquad (1)$$

where ω_n – resonance frequency of radio-field or Larmor's precession frequency of nuclear spins, B_0 – induction of the external magnetic field in gas cell, γ_n – gyromagnetic ratio, Ω - frequency of mechanical rotation about vector of the external magnetic, n – sort of the noble gas. It is accepted, that gyromagnetic ratios γ_n for each sort of the atoms is known in equation (1). However, if the gas cell contains two or more sorts of the noble gases, magnetic-dipole interaction between atoms of different sorts appears. This phenomena creates the detuning from NMR of noble gases. Equation (1) should

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contain effective gyromagnetic ratios $\tilde{\gamma}_n$, instead of tabulated gyromagnetic ratios γ_n. Effective gyromagnetic ratios allow for the interaction between magnetic moments of nucleus.

Qualitative model of dynamic of nuclear magnetic moments is considered to explain appearance shifts in NMR. In the simplified model decay of the spin is compensated by laser pumping and radio-field, which creates NMR for all sorts of noble gases in cell. The established precession of nuclear magnetization vector $\vec{M}_n(t)$ round an external magnetic field $\vec{B}_0$ is described by the famous Bloch's equation [3]:

$$\frac{d\vec{M}_n(t)}{dt} = \gamma_n\left[\vec{M}_n(t)\cdot\vec{B}_0\right] \tag{2}$$

Interaction between magnetic moments of different sorts of noble gases requires modification of equation (2). Nuclear magnetization brings deviations in magnetic field in which nuclear magnetic moments makes precession. Thus, dynamics of nuclear magnetization of noble gases mix should be described by system from two equations:

$$\frac{d\vec{M}_1(t)}{dt} = \gamma_1\left[\vec{M}_1(t)\cdot\left(\vec{B}_0+\mu\vec{M}_2(t)\right)\right] \tag{3}$$

$$\frac{d\vec{M}_2(t)}{dt} = \gamma_2\left[\vec{M}_2(t)\cdot\left(\vec{B}_0+\mu\vec{M}_1(t)\right)\right] \tag{4}$$

where μ – proportionality factor between nuclear magnetization and the induction of magnetic field which it creates. Notice, only nuclear magnetization of other sort of noble gas brings deviations to induction of magnetic field in dynamics equations (3-4). This effect is explained that effective field of polarized active environment does not influence to dipoles, which creates polarization. Thus magnetic field is miscellaneous for different sorts of noble gases. It leads to limitations of using equation (1) at mathematical models of fidelity measurement devices based NMR.

Let's consider, that induction of the nuclear magnetization $\mu\vec{M}_1(t)$ much less, then induction of external magnetic field $\vec{B}_0$. Then system of equations (3-4) should be written in another form:

$$\frac{d\vec{M}_1(t)}{dt} = \gamma_1\left[\vec{M}_1(t)\cdot\vec{B}_0\right]+\gamma_1\vec{\wp}(t) \tag{5}$$

$$\frac{d\vec{M}_2(t)}{dt} = \gamma_2\left[\vec{M}_2(t)\cdot\vec{B}_0\right]-\gamma_2\vec{\wp}(t) \tag{6}$$

where vector $\vec{\wp}(t)$ described nonlinearity of the equations system (3-4). It should be defined as perturbation element:

$$\vec{\wp}(t) = \mu\left[\vec{M}_1^b(t)\cdot\vec{M}_2^b(t)\right] \tag{7}$$

Perturbation vector $\vec{\wp}(t)$ contains the solution of nonperturbated equation (2) for each sort of noble gas $\vec{M}_n^b(t)$ in first approximation. Initial conditions of this qualitative model are defined by parameters of pumping, spin decay and nuclear magnetic resonance for each sort of noble gas.

Let's use cylindrical coordinate system z_n, η_n, φ_n for defining the initial conditions $\vec{M}_n(0)=\vec{M}_n^0$:

$$\left(\vec{M}_n^0\right)_x = \eta_n\cos(\varphi_n),\quad \left(\vec{M}_n^0\right)_y = \eta_n\sin(\varphi_n),\quad \left(\vec{M}_n^0\right)_z = z_n \tag{8}$$

Now let's write solution of equation system (5-6) in which nonresonance low elements is suppressed:

$$\frac{d\vec{M}_n(t)}{dt} = \widetilde{\gamma}_n\left[\vec{M}_n(t)\times \vec{B}_0\right] \tag{9}$$

Dynamics equation (9) is different from Bloch's equation (2), because it contains effective gyromagnetic ratio $\widetilde{\gamma}_n$, which is defined by equation (10):

$$\widetilde{\gamma}_1 = \gamma_1\left(1+\mu\frac{z_2}{B_0}\right),\quad \widetilde{\gamma}_2 = \gamma_2\left(1+\mu\frac{z_1}{B_0}\right) \tag{10}$$

Results:

At research NMR of two noble gases mix it is necessary to consider detuning from resonance, which appears due to interaction between magnetic moments of different sorts of atoms.

References

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