MAGNETIC RESONANCE LINE SHIFT DUE TO INTERACTION OF SPIN SYSTEM WITH NONRESONANT RADIO-FREQUENCY FIELD

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It was shown in [1] for the first time that a linearly-polarized RF-field component rotating around a constant magnetic field H_0 in a direction opposite that of the precession of the spin of the atom shifts the magnetic-resonance line of the spin system towards smaller values of H_0. This shift, called the Bloch-Siegert effect, was observed experimentally in a number of studies (e.g., [2, 3]). Seiden [4] considered theoretically a more general case of the resonant-frequency shift of a spin interacting with a rotating RF field $H_1(t)$ having an arbitrary frequency different from the resonant one. However, the smallness of this effect, which is proportional to the ratio $H_1^2/4H_0^2$, made it practically unobservable in ordinary experiments on nuclear or electron magnetic resonance ($H_1^2/4H_0^2 \sim 10^{-12}$).

We report here experimental observation of such shifts in a system of optically oriented Cs^{133} atoms. The possibility of registering resonance in very weak fields H_0 at appreciable amplitudes of the field $H_1(t)$ makes it possible under these conditions to make the shift much larger than the width of the magnetic-resonance line.

The experimental procedure coincides essentially with the usual procedure for observing the longitudinal component of the average angular momentum of an optically oriented spin system [5]. A circularly polarized beam of resonant light propagates along a magnetic field $H_0 \approx 0.077$ Oe and orients the Cs^{133} atoms in a cell having paraffin-coated walls. Two linearly polarized RF fields $h_1(t) = h_1 \cos \omega t$ and $H_1(t) = H_1 \cos \Omega t$, parallel to each other and perpendicular to the field $\vec{H}_0$, are applied to the system of atoms. The field $h_1(t)$ serves to excite the magnetic resonance of the Cs^{133} atoms. Its frequency is close to $\omega_0 = -\gamma H_0$ and its amplitude is chosen to be very small and constant. The field $H_1(t)$ is used to "shake up" the spin system, and it is precisely its effect on the resonance of the Cs^{133} atoms which is investigated in the experiment. The amplitude and frequency of the field $H_1(t)$ can vary in a wide range. The magnetic resonance of Cs^{133} is registered by the usual procedure of slow passage of the line in the presence of weak low-frequency modulation of the field H_0. To eliminate the influence of the magnetic noise on the measurement results in the weak field H_0, the entire system is placed in a four-layer magnetic screen, in which the residual field is compensated for in three

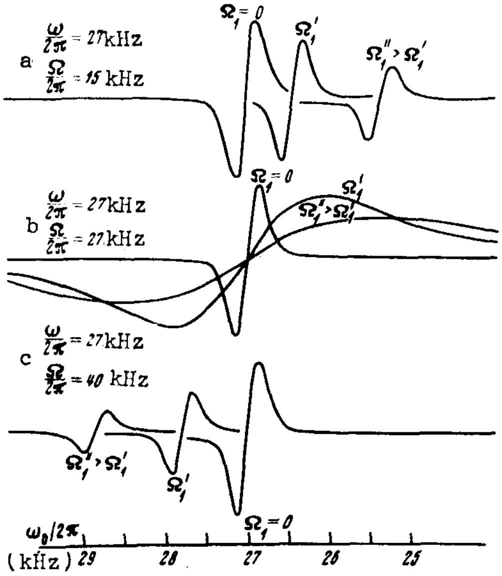

Fig. 1. Magnetic resonance signal of Cs^{133} in the presence of a nonresonant RF field $H_1(t)$: a) $\Omega < \omega$, b) $\Omega = \omega$, c) $\Omega > \omega$.

directions, accurate to $\sim 10^{-5}$ Oe, by a system of Helmholtz coils.

It follows from a theoretical calculation for the linearly polarized field $H_1(t)$ that the shift $\Delta\omega' = \omega_0' - \omega_0$, where ω_0' is measured in the presence of the field $H_1(t)$ and ω_0 in the absence of this field, is equal to

$$\Delta\omega' = -\frac{\omega\Omega_1^2}{4}\frac{\Gamma^2 + \omega^2 - \Omega^2}{(\omega^2 + \Omega^2 + \Gamma^2)^2 - 4\omega^2\Omega^2}, \quad (1)$$

where $\Omega_1 = -\gamma H_1$ and Γ is the width of the magnetic-resonance line. If $\omega - \Omega >> \Gamma$, then

$$\Delta\omega' = -\frac{\omega\,\Omega_1^2}{4}\frac{1}{(\omega - \Omega)(\omega + \Omega)}. \quad (2)$$

It is seen from (2) that the sign of the shift is determined by the sign of the frequency difference $\omega - \Omega$, and its magnitude is proportional in first approximation to the square of the amplitude of the "shaking" field.

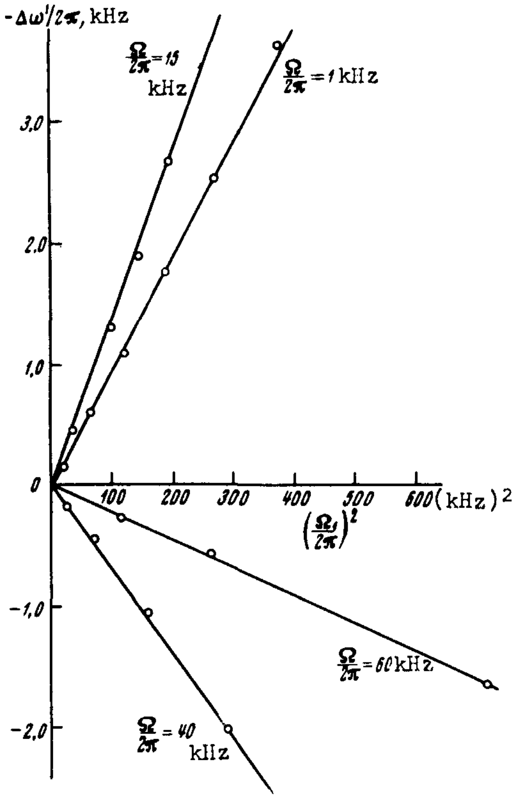

Fig. 2. Shift of Cs^{133} resonance line vs. square of the amplitude of the nonresonant field $H_1(t)$.

Figure 1 shows a plot of the magnetic-resonance signal of Cs^{133} atoms for the case when the frequency of the "shaking" field satisfies the conditions $\Omega < \omega$ (a), $\Omega = \omega$ (b), and $\Omega > \omega$ (c). In each case, the signal was plotted with an automatic x-y potentiometer for different values of the amplitude H_1 of this field.

The experimental results have confirmed with good accuracy the conclusions of the theory. Indeed, for $\Omega < \omega$ we have $\Delta\omega' < 0$ and the resonance line shifts towards smaller values of the field H_0, whereas at $\Omega > \omega$ the direction of the shift is reversed. As to the dependence of the shift on the amplitude of the field $H_1(t)$, it is seen from Fig. 2 that it is quadratic in the entire range of investigated values of Ω_1.

[1] F. Bloch and A. Siegert, Phys. Rev. 57, 522 (1940).
[2] J. Brossel and F. Bitter, Phys. Rev. 86, 308 (1952).
[3] J. Brossel, J. Margerie, and J. Winter, Compt. rend. 241, 556 (1955).
[4] J. Seiden, Compt. rend. 240, 2228 (1955).
[5] B. Cagnac, These, l' Universite de Paris, 1960.