Nutation caused by a change in relaxation rate

E. B. Aleksandrov, M. V. Balabas, and V. A. Bonch-Bruevich

(Submitted 16 February 1987)
Pis'ma Zh. Eksp. Teor. Fiz. **45**, No. 6, 309–310 (25 March 1987)

Coherent oscillations in the populations of the levels of a quantum system (a nutation) are known to arise as a transient process when an interaction with a nearly resonant alternating field is turned on abruptly [see, for example, J. Macomber, Dynamics of Spectroscopic Transitions (Russ. transl. Mir, Moscow, 1979)]. In this letter we report an observation of nutation in an alternating field of fixed amplitude and frequency. The nutation arises when the relaxation time in the system is suddenly increased.

This effect has been observed in studies of the magnetic resonance of ^{87}Rb atoms. Rubidium vapor in a paraffin-coated flask was oriented by circularly polarized light from a ^{87}Rb lamp, directed along the magnetic field H_0. In weak fields the hyperfine structure of the ground state of rubidium forms two systems of equidistant magnetic sublevels, which resonance at nearly equal frequencies. In our case, in a field $H_0 \cong 1.5 \times 10^{-7}$ T, these frequencies differ by about 40 Hz, so that with a spin relaxation time of about 0.1 s it is possible to selectively excite the resonance in the $F=2$ state (exclusively). The alternating component of the magnetization that arises here is detected by an auxiliary light beam from a ^{85}Rb lamp. We use the D_2 line (7800 Å), which suffers essentially no absorption in ^{87}Rb vapor but which undergoes a pronounced Faraday rotation of its polarization plane. This effect provides a nonperturbing method for diagnostics of the transverse magnetization: The polarization plane of a transverse beam is rocked at the frequency of the alternating field (H_1) which induced the resonance.[2] The relaxation time of the magnetization of atoms is determined primarily by their interaction with the pump light, as can be seen by comparing parts a and b of Fig. 1. Figure 1a is an oscilloscope trace of the damping of the transverse magnetization when the alternating field is turned off. This trace reproduces the envelope of a high-frequency oscillation ($\cong 10$ kHz) which is not resolvable at the sweep rate used, 0.2 s per large division. Turning the pump light off causes a dramatic prolongation of the relaxation, as can be seen from Fig. 1b, which shows the damping of the transverse magnetization when the light and alternating field H_1 are turned off simultaneously.

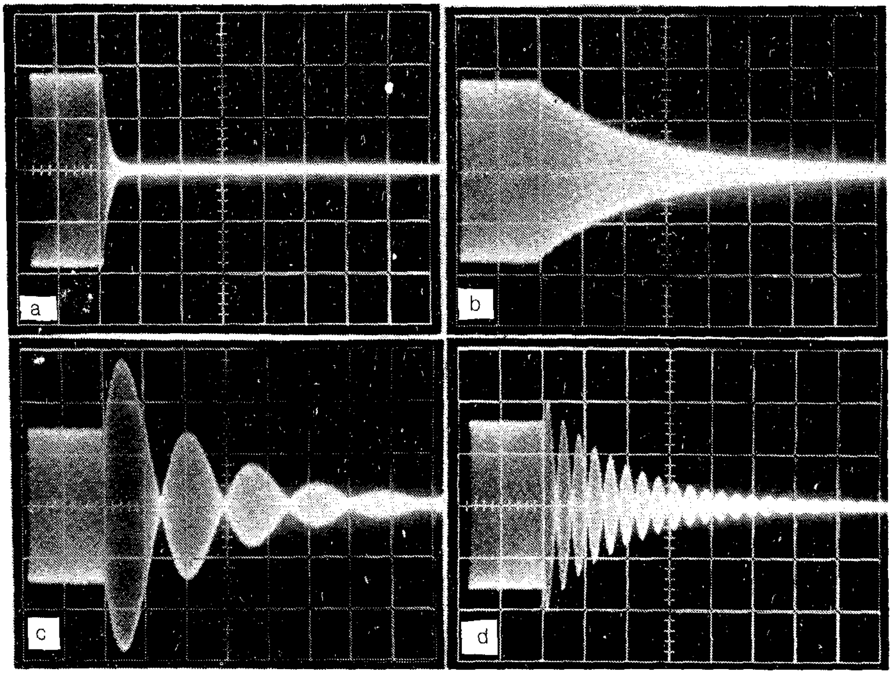

FIG. 1. Oscilloscope traces of the motion of the transverse magnetization of rubidium vapor upon the following events: a—The alternating field is turned off abruptly; b—the alternating field and the pump light are simultaneously turned off abruptly; c,d—the pump light is turned off abruptly. The horizontal scale is 2 s per large division.

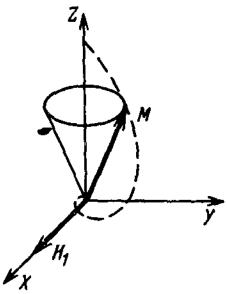

FIG. 2. Vector diagram of the magnetic resonance in the rotating coordinate system.

Finally, Figs. 1c and 1d demonstrate the appearance of a nutation when the pump light (alone) is turned off. The two traces here differ in the strength of the alternating field H_1.

It is an elementary matter to analyze the process by which the nutation is formed on the basis of the Bloch equations, and the process can be interpreted quite clearly. Figure 2 shows a vector diagram of the magnetic resonance in a rotating coordinate system. The relaxation process, which is provided by the pump light in this case, tends to align the magnetic moment of the atoms along the Z axis, while the field H_1, which is a static field in the rotating coordinate system and which is the field which induces the resonance, initiates a precession of the moment around the X axis. The equilibrium position of moment **M** is established as a result of a competition between these effect: The equilibrium value of the moment is "squeezed" between the field H_1 and the pump-relaxation. The dashed line in Fig. 2 is a hodograph of the elementary moment which arises in the Z direction and which is damped to the extent of the precession around X; in the laboratory coordinate system, the resultant moment traces out a cone of constant aperture. In this situation, turning the pump off liberates the moment **M**, which begins to precess freely around the X axis in the rotating coordinate system, being damped slowly. This is the nutation.

[1]J. Macomber, Dynamics of Spectroscopic Transitions (Russ. transl. Mir, Moscow, 1979).
[2]W. Happer, Rev. Mod. Phys. **44**, 169 (1972).

Translated by Dave Parsons