Observation of anomalous optomagnetic resonances in birefringence and dichroism on the neon $3s_2$–$2p_4$ transition

É. G. Saprykin, S. N. Seleznev, and V. A Sorokin
Institute of Automation and Electrometry, Siberian Branch, Academy of Sciences of the USSR; Leninist Communist Youth League Novosibirsk State University

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Optomagnetic resonances with widths substantially smaller than the lifetime of levels at resonance with the light have been observed. The resonances behave in an anomalous way as the frequency of the probing light is tuned.

In a previous study[1] of the effect of a magnetic field on the absorption of a weak laser wave ($\lambda = 0.63$ μm) in a discharge in neon, some narrow optomagnetic resonances were observed. Their shape was essentially independent of the polarization of the wave. These resonances stem from a change in the integral population of the $2p_4$ level due to a disruption by the magnetic field of the alignment of atoms in the $1s_4$ level, whose characteristics correspond to these resonances[1)] (Ref. 2). By measuring the difference between the absorption of waves of orthogonal polarizations as a function of the magnetic field, directed along the electric vector of one of the waves, Nikolaev *et al.*[5] eliminated population effects and observed optomagnetic resonances due to a reradiation of light and anisotropic collisions directly on the $3s_2$–$2p_4$ transition. Their widths were determined by the constants of the $2p_4$ level.

In the present letter we are reporting the observation of some radically different optomagnetic resonances on this transition. The experimental procedure was similar to that described in Ref. 5, but in addition to the optomagnetic resonances in the absorption we also detected optomagnetic resonances in the difference between the refractive indices of the medium for the linearly polarized, orthogonal components of the light. In this case the transverse magnetic field made an angle of 45° with the polarization vectors of the components.

Figure 1 shows some characteristic optomagnetic resonances in (a) the birefringence and (b) the dichroism. Curves 1a–5a and 4b were found in neon-20. Curves 1b–3b correspond to the red wing of the absorption line, since they were detected in neon-22, whose 0.63-μm line is shifted 800 MHz from that of neon-20. The shape of the resonances is described well by the derivative of the sum of two Lorentzian functions with widths differing by a factor of five or six. The broad component is similar to that found in Ref. 5. The half-width of the narrow component in the birefringence[2)] is described as a function of the gas pressure by (at a discharge current of 50 mA)

$$H = (0.48 \pm 0.04)\text{Oe} + (0.25 \pm 0.03) \times P(\text{Torr})\text{Oe}. \quad (1)$$

The half-width of the resonances which are coupled with the $1s_4$ level is[2]

$$H(1s_4) = (4.6 \pm 0.2)\text{Oe} + (0.6 \pm 0.1) \times P(\text{Torr})\text{Oe}, \quad (2)$$

and the half-width along the magnetic-field scale corresponding to the relaxation rate

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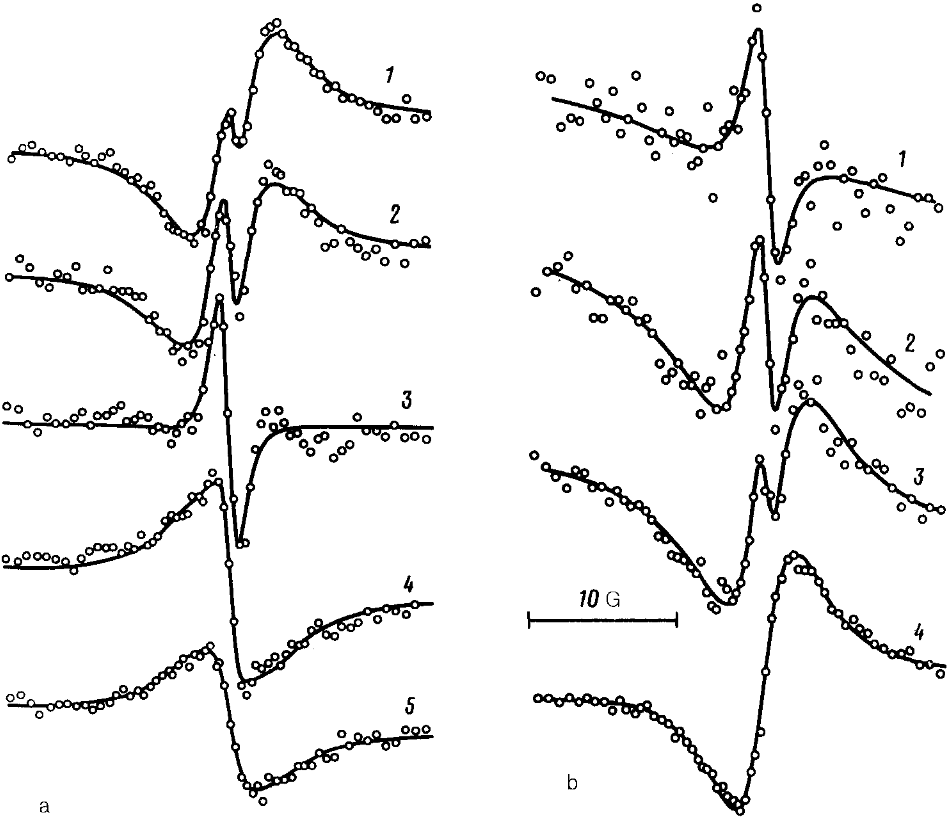

FIG. 1. Evolution of the shape of optomagnetic resonances in (1a–5a) the birefringence and (1b–4b) the dichroism in neon as the laser frequency is tuned from the blue region to the red region.

of the hexadecapole moment of the $2p_4$ level,[6]

$$H(2p_4) = (2.3 \pm 0.05)\text{Oe} + (0.83 \pm 0.22)P(\text{Torr})\text{Oe}, \tag{3}$$

is sharply different from (1). The observed width of the narrow resonance thus cannot be explained on the basis of the known relaxation processes in the $2p_4$ and $1s_4$ levels.

The plot of the amplitudes of the components of the resonances versus the frequency deviation of the laser light in Fig. 2 also demonstrates that the behavior of the narrow component is anomalous for a dipole transition.

This technique is insensitive to the integral transport of population from neighboring levels, so it can be suggested that we are dealing here with a transport of coherence as described for certain conditions in Ref. 7. In our case, expression (3.13) of Ref. 7 splits up into the sum of two Lorentzian functions. The wider one corresponds to the characteristics of the $2p_4$ level, while the parameters of the narrow one are associated with the original level. The difference in widths cannot be explained on the basis of a difference in the g-factors of the levels. The fact that the resonances are narrow should be attributed to the low relaxation rates of the polarization moments,

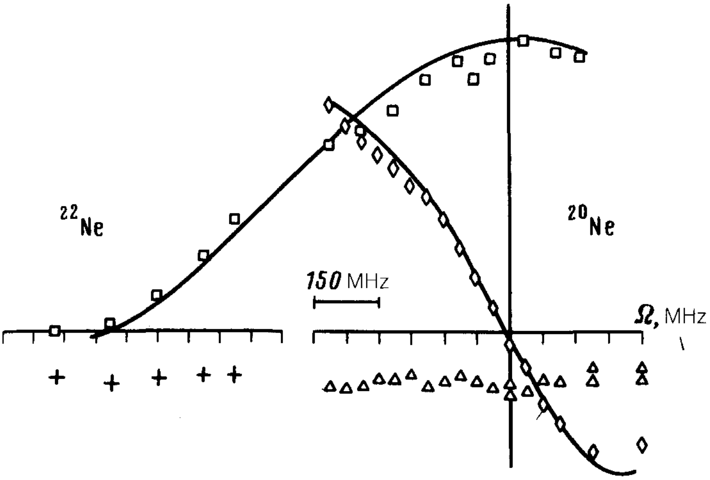

FIG. 2. Change in the amplitudes of the components of the optomagnetic resonances as the laser frequency is tuned. □—Broad component of dichroism; + —narrow component of dichroism; ◇—broad component of birefringence; △—narrow component of birefringence.

i.e., processes in long-lived levels. In the case at hand, these might be the $1s_5$ and $2s_5$ levels, whose decay to the ground state is forbidden and which are coupled with the $2p_4$ level by optical transitions.[3)]

The anomalous behavior of the narrow optomagnetic resonances as the laser frequency is tuned can be explained on the basis that a coherence is induced on a forbidden transition to the ground state during the reabsorption of UV light of a multipolarity higher than electric dipole, under conditions of anisotropic illumination (an extended volume), or in nonadiabatic collisions with electrons whose velocity distribution is also anisotropic. In this case there may be an excitation of polarization moments whose rank is higher than an alignment and for which the amplitudes of the resonances depend in a different way on the frequency deviation. In particular, we know[8] that Zeeman components with $\Delta M = \pm 2$, which are forbidden in dipole transitions, are observed in quadrupole lines in a transverse magnetic field. We also know that nonadiabatic collisions with electrons induce forbidden transitions (Ref. 9, for example).

A conversion of (1) to the frequency scale (for $\Delta M = 2$) with the help of the g-factors of the $1s_5$ and $2s_5$ levels (1.503) yields

$$\Gamma = (1.99 \pm 0.15)\text{MHz} + (1.05 \pm 0.13) \times P(\text{Torr})\text{MHz}. \qquad (4)$$

If (1) is a consequence of the disruption of the hexadecapole moment ($\Delta M = 4$), the number in (4) must be doubled. The $1s_5$ level is metastable, and its radiative width is much smaller than described by (4). Data on the $2s_5$ level (2.4–4.4 MHz; Ref. 10) are approximately the same as in (4), and that level may be thought of as an initial level. We do not rule out the possibility of a coherence with $\Delta M = 2$, which is also suggested by the sharp difference between (4) and the relaxation rate of the alignment in the $2s_5$ level (6.1 ± 1.1 MHz/Torr; Ref. 10).

To clarify the question, we will need some further and more accurate experiments. We also need a theoretical analysis of the specific features of the induction of a coherence of sublevels by electron impact and during quadrupole emission. In addition to the optical mechanism for the transport of coherence, we should also consider transitions which result from inelastic collisions with electrons, in which a deviation from an equilibrium velocity distribution is known[11] to be retained, despite some broadening.

[1)] A change in the population of a level due to the disruption by a magnetic field of the alignment in levels optically coupled with the level under study has been observed in fluorescence.[3,4]

[2)] The widths of the optomagnetic resonances in the dichroism and birefringence agree with each other, within the errors. In the measurement of the widths of the resonances, the distortions of the shape of the resonances by the modulation of the magnetic field were taken into account.

[3)] Other long-lived levels ($1s_3$ and $2s_3$) are nondegenerate levels, for which a coherence is impossible in principle.

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