Zeitschrift: Helvetica Physica Acta
Band: 46 (1973)
Heft: 5

Artikel: Detection by Hanle effect of the alignment-orientation coupling process induced by the Stark effect

Autor: Faist, A.

DOI: https://doi.org/10.5169/seals-114502

Helvetica Physica Acta
Vol. 46, 1973.

Birkhäuser Verlag Basel

Detection by Hanle Effect of the Alignment-Orientation Coupling Process Induced by the Stark Effect

by **A. Faist**

Ecole de physique, Genève[1])

(31. V. 73)

Abstract. An atomic vapour is optically pumped with linearly polarized light. The state of alignment obtained this way is coupled by an electric field to the orientation state of the vapour. Thus the re-emitted light is partially circularly polarized. The existence of this circular polarization can be shown off by means of the Hanle effect.

Introduction

The Zeeman effect is widely used in atomic spectroscopy and leads to the Hanle effect with its numberless applications. The Stark effect has been somewhat forgotten for a long time but is now actively studied again. It leads to the alignment-orientation coupling process [1]. Some recent experiments involve both Stark and Zeeman effects. It has been shown [2] that when the initial state of the system is a state of orientation the system evolves, in the presence of an electric field, to a state of alignment. By the addition of a magnetic field, perpendicular both to the electric field and to the alignment, one produces an easily detectable Hanle effect on this alignment [3]. We would like to analyse here the situation in which the initial state of the vapour is a state of alignment.

The System

We consider the sub-levels of an atomic excited state of angular momentum $J = 1$ ($I = 0$) optically pumped from a unique ground state ($m = 0$) by linearly polarized light with polarization vector

$$\vec{e_\lambda} = \frac{1}{\sqrt{2}}(\vec{[x]} + \vec{[z]}).$$

A static electric field parallel to the Oz axis $\vec{E} = E\vec{[z]}$ is applied and gives rise to a coupling between the initial state of alignment of the vapour and the state of orientation having the Oy axis as support [4].

---

[1]) Actual address: Laboratoire de physique théorique EPF, Lausanne.

An additional and slowly variable magnetic field H is applied and its support is parallel to the initial alignment of the vapour:

$$\vec{H} = H \frac{1}{\sqrt{2}}([\vec{x}] + [\vec{z}]).$$

This field allows the transverse orientation created by the electric field to precess, giving rise to a transversal Hanle effect [5] that we can detect by observing the linearly polarized light re-emitted in the Ox direction [2, 6].

The Hamiltonian

We shall treat this problem in the matric density formalism. In the presence of the electric field only the Hamiltonian is

$$\mathscr{H}_0 = \mathscr{H}_{\mathbf{Atom}} + \mathscr{H}_{\mathbf{Stark}}.$$

The axis of quantization Oz is parallel to the direction of the electric field, so that the energies of the excited state sub-levels are

$$E_0^{\pm} = 0 \quad \text{for } |e, m = \pm 1\rangle$$

and

$$E_0^0 = aE^2 = \beta \quad \text{for } |e, m = 0\rangle$$

where a is the Stark constant.

The magnetic field can be divided into two components. The Oz component of intensity $H/\sqrt{2}$ gives rise to a Zeeman effect

$$\frac{1}{\sqrt{2}} m\gamma H = \frac{1}{\sqrt{2}} m\Omega,$$

where Ω is the Larmor precession frequency.

The Ox component gives rise in first-order approximation to a coupling between the sub-levels of the excited state:

$$\gamma \frac{H}{\sqrt{2}} \langle e, 0|J_x|e, \pm 1\rangle = \frac{\gamma H}{\sqrt{2}} = \frac{\Omega}{2}.$$

The complete Hamiltonian is then:

$$\mathscr{H} = \mathscr{H}_0 + \mathscr{H}_{\mathbf{Zeeman}} + \mathscr{H}_{\mathbf{Coupling}}$$

$$\mathscr{H} = \begin{pmatrix} \dfrac{\Omega}{\sqrt{2}} & \dfrac{\Omega}{2} & 0 \\ \dfrac{\Omega}{2} & \beta & \dfrac{\Omega}{2} \\ 0 & \dfrac{\Omega}{2} & -\dfrac{\Omega}{\sqrt{2}} \end{pmatrix}.$$

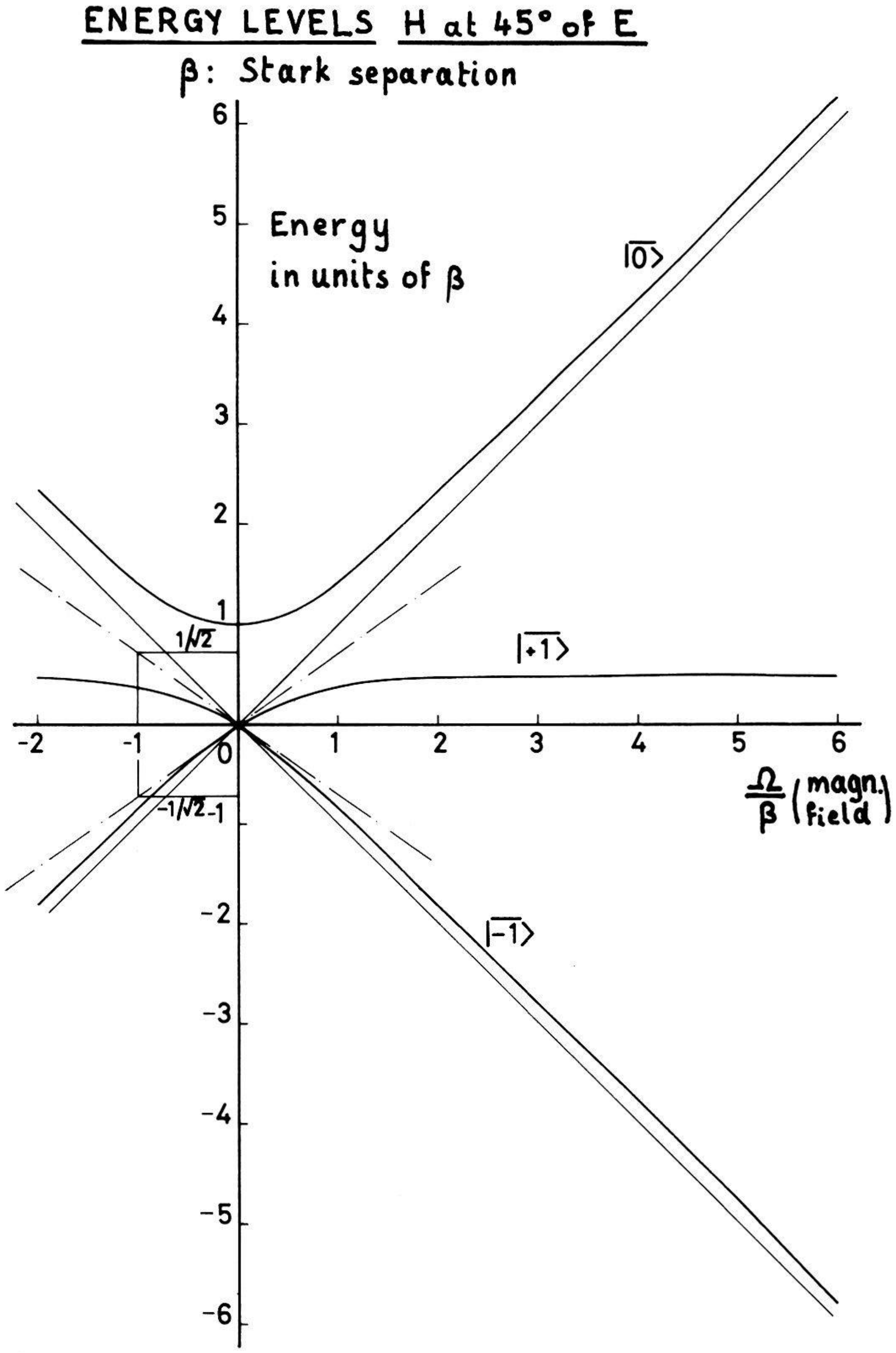

Figure 1.

If we look for the eigenvalues of the energy we have to solve a third-degree equation:

$$-\lambda^3 + \lambda^2 \beta + \lambda \Omega^2 - \beta \frac{\Omega^2}{2} = 0.$$

To study this equation it is convenient to express Ω as a function of λ and β. One gets

$$\Omega = \pm \lambda \sqrt{\frac{\lambda - \beta}{\lambda - \beta/2}}$$

and one sees immediately that

a) the solutions are symmetrical versus Ω,

b) for $\lambda \ll \beta \quad \lambda \cong \pm \dfrac{1}{\sqrt{2}} \; \Omega$,

c) for $\Omega = 0$ $\lambda = 0$ and 1,
d) for $\lambda \gg \beta$ $\lambda \cong \pm\Omega$,
e) $\lambda = \beta/2$ is asymptotically reached for $\Omega \to \pm\infty$.

All these properties appear in Figure 1.

The Evolution of the System

The evolution of the system is given by the solution at the pilot equation [7]

$$i\dot{\rho} = [\mathscr{H}, \rho] - i\Gamma\rho + iI\rho^0,$$

where

Γ is the inverse of the lifetime (natural linewidth),
I is proportional to the intensity of the pumping light,
ρ^0 is the density matrix which describes the initial conditions.

We look for the stationary solution ($\dot{\rho} = 0$). The problem is carried out with the aid of computational methods in the following way:

a) Assigning numerical values for the different parameters and variables, the $\mathscr{H}$ matrix is diagonalized

$$\mathscr{H}_{\text{diag}} = S\mathscr{H}S^{-1}$$

and the new eigenstates $|\mu\rangle$ are obtained from the initial ones $|m\rangle$ by the relation

$$|\mu> = S|m>.$$

b) The initial conditions given by $\rho^0_{mm'}$ are translated into the new basis

$$\rho^0_{\mu\mu'} = S\rho^0_{mm'}S^{-1}.$$

The solution of the pilot equation is then straightforward:

$$\rho^{\text{stat}}_{\mu\mu'} = \rho^0_{\mu\mu'}\frac{\Gamma}{\Gamma + i(E_\mu - E_{\mu'})}.$$

We then come back to the original basis

$$\rho^{\text{stat}}_{mm'} = S^{-1}\rho^{\text{stat}}_{\mu\mu'}S.$$

c) The fluorescent light is given by the relation

$$I_{\text{fl.}} = \text{const.}\sum_{m,m'}\langle 0|\vec{e}_\lambda\vec{D}|m\rangle\langle m|\rho^{\text{stat}}|m'\rangle\langle m'|\vec{e}_\lambda\vec{D}|0\rangle.$$

The excitation matrix $\rho^0_{mm'}$ is

$$\rho^0 = \tfrac{1}{2}\begin{pmatrix} \frac{1}{2} & -\frac{1}{\sqrt{2}} & \frac{1}{2} \\ -\frac{1}{\sqrt{2}} & 1 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{1}{\sqrt{2}} & \frac{1}{2} \end{pmatrix}.$$

In all the calculus we take the natural linewidth Γ as energy unit and use the normalized quantities Ω/Γ and β/Γ.

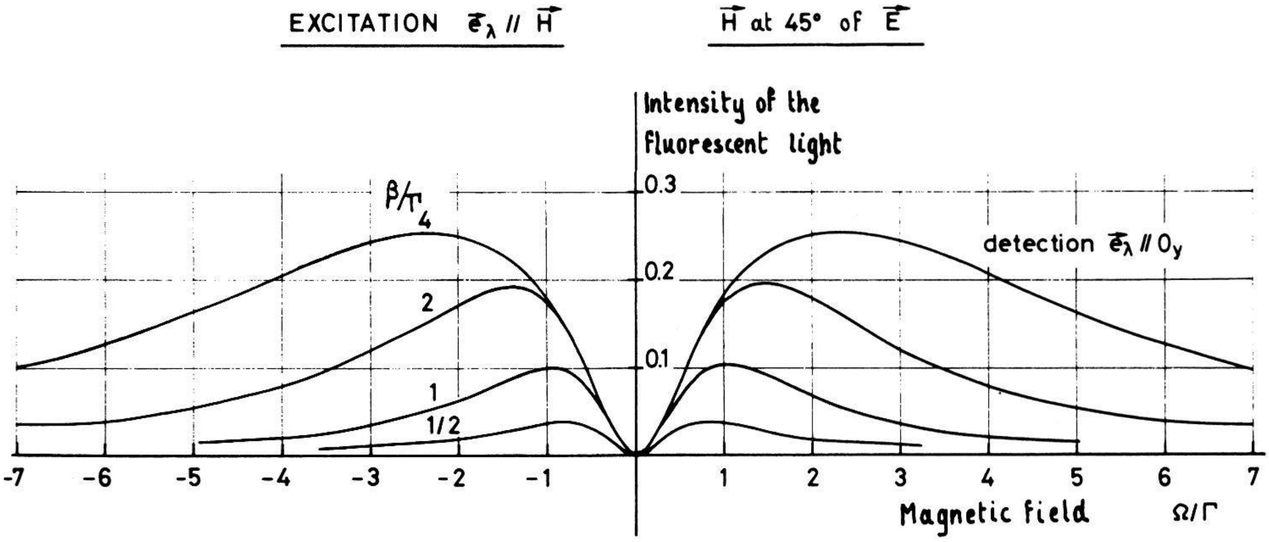

Figure 2.

Results

The aspect of the computed intensity of the fluorescent light is given in Figure 2. The remarkable fact is that, for weak values of the magnetic field, all the curves reduce to a part of an unbroadened resonance curve similar to a Hanle curve. For $\Omega/\Gamma = 2$ the central part of the curve is given by

$$I = 0.2666\left(1 - \frac{\Gamma^2}{\Gamma^2 + 2.11\Omega^2}\right) \cdot I_0,$$

whereas the real Hanle curve is proportional to $(1 - \Gamma^2/(\Gamma^2 + 2\Omega^2))$. This is shown clearly in Figure 3.

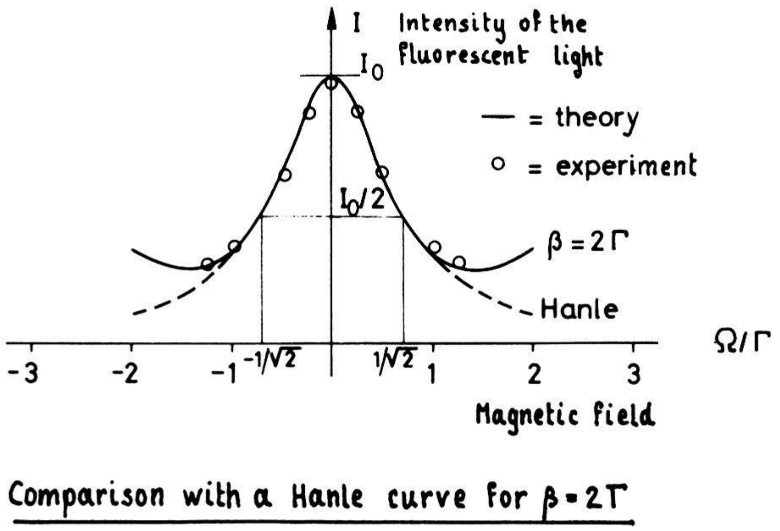

Figure 3.

The theoretical treatment presented above is based on the experimental work carried out by E. Geneux on the $5^3 P_1$ state of Cd [8] and given in Figure 4. The agreement between theory and experiment is good. Recent measurements made by M. Aeschlimann and P. Cornaz [9] show good agreement for values of Ω/Γ increasing to 7.

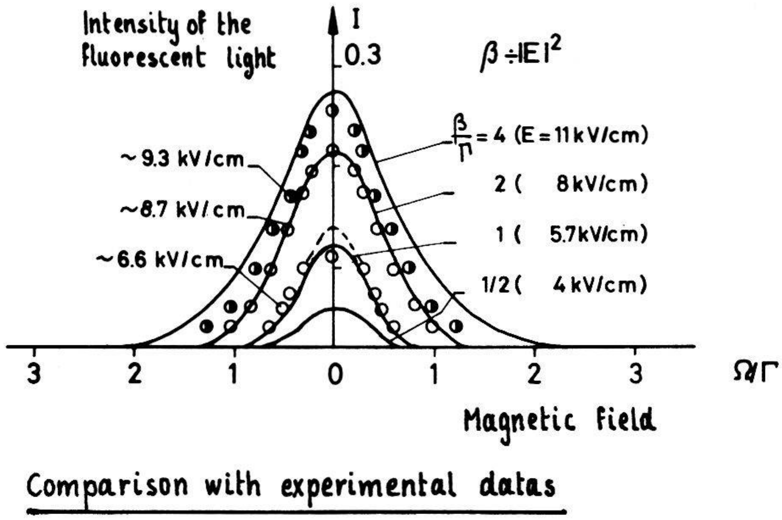

Figure 4.

Conclusion

It has been shown that the resonance curves observed by E. Geneux can be assimilated to Hanle curves for weak values of the magnetic field, and that they are completely different from these for higher values of the field.

The geometric disposition of the electric and magnetic fields and of the initial alignment is the only one in which the state of orientation of the vapour can be detected by the Hanle effect without unnecessary perturbation of the initial state of alignment.

Acknowledgments

The computational work has been done by J. Weber, Ecole de physique, Geneva. I am indebted to Dr. E. Geneux for many fruitful discussions and for reading the manuscript.

REFERENCES

[1] L. Lombardi, Thesis, Grenoble, 1969.
[2] A. Faist, Helv. Phys. Acta *44*, fasc. 4, 519 (1971).
[3] J.-J. Forney and E. Geneux, Phys. Lett. *20*, 632 (1966); M. Glass-Maujean and J. P. Descoubes, Opt. Comm. *4* (5), 345 (1972).
[4] A. Faist, Helv. Phys. Acta *45*, 755 (1972).
[5] C. Cohen-Tannoudji and S. Haroche, C. R. Acad. Sc. Paris *261*, 5400 (1965).
[6] A. Faist, Thesis, 1970, unpublished.
[7] C. Cohen-Tannoudji, C. Ann. Phys. *7*, 423 (1962).
[8] E. Geneux, private communication.
[9] M. Aeschlimann and P. Cornaz, private communication.