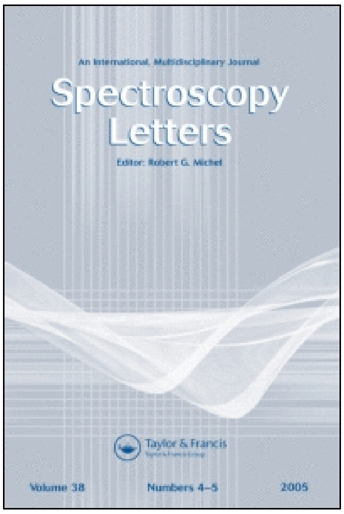

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D. Zhechev[a]
[a] Institute of Solid State Physics, Sofia, Bulgaria

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INCOHERENT SIGNAL AT HANLE EXPERIMENTS IN A HOLLOW CATHODE DISCHARGE

D.Zhechev
Institute of Solid State Physics,BAS,Sofia1184,Bulgaria

Key words: Alignment, Hanle signal, Background

INTRODUCTION

The excited level self-alignment is a logical extension of the classical properties[1,2] of the hollow cathode discharge(HCD).As a result of the magnetic distruction of the aligned levels a Hanle signal with amplitude, width and shape depending upon the plasma parameters, experimental geometry and, finally upon the upper level relaxation constants can be measured.

Here we shall consider another aspect of this kind of HCD experiments, i.e. the appearance of an incoherent signal at given experimental geometry.In some cases with magnetic fields H_o typical for Hanle experiments a line intensity dependence $I(H_o)$ is observed, but the measured level radiative width does not coincide with the already obtained corresponding relaxation constant; here the sign of the function $I_1(H_o)$ does not depend on the selected plane polarization of their registration and, thereforethis signal can not be referred to the level alignment destruction. Errors might arise measuring a "true" interference signal as well as from the wrong identification of the Hanle signal. This fact imposes a more detailed analysis of these signals in HCD.

ANALYSIS

1. Measuring the dependence $I_1(H_o)$, i.e. the intensity of the spectral line from the self-aligned level at given polarization I_1 as a function of the magnetic field, three components can be obtained:

$$I_1(H_o) = I^o + I_p(H_o) + I_s(H_o)$$

where the component I^o does not depend on H_o and includes also the optical system polarization properties; the $I_p(H_o)$ describes the magnetic field influence on the discharge; the $I_s(H_o)$ is the true interference signal. Since I_s is proportional to the corresponding spectral line intensity, we can write:

$$I_s(H_o) = \alpha(I^o + I_p)S(H_o)$$

(the function $S(H_o)$ describes the Hanle signal shape). Then

$$I_1(H_o) = I^o + I_p(H_o) + \alpha I^o S(H_o) + \alpha I_p(H_o)S(H_o) \qquad /1/$$

or $I_1(H_o) = (1 + \alpha S)\left[I^o + I_p(H_o)\right]$

but taking into account the relation $I_p \ll I^o$ the product $\alpha I_p S(H_o)$ may be neglected in most of the cases. The terms between the square brackets do not depend on the choice of the polarization at observation of the signals. It is clear that the interference component arrises by the sum $I^o + I_p$, therefore the analysis of the observed signal $I(H_o)$ including its shape requires a quantitative evaluation of the influence of this sum.

2.The reported data[3,4,5] and our investigation on the Hanle effect allow the possible variations of HCD parameters caused by the typical H_o values to be neglected in $I_p(H_o)$- the reason is the lack of well expressed $I(H_o)$ dependence or its slight and uniform behaviour.In relation to the observed incoherent signal we will consider another effect concerning (I^o+I_p) sum and connected with H_o field influence on the source image localization on the monochromator entrance slit plane.

3.Selecting different directions of H_o, a certain type or part of the coherence caused by processes with symmetry orthogonal to H_o might be destructed.Some of our experiments at a low pressure of the filling gas demonstrate a slight source image shift.The shift direction is orthogonal to the slit height when this height, the cathode axis (an axis for observation) and H_o are mutually orthogonal.As a consequence, each set of H_o value corresponds not only to a Hanle signal ordinate, but also to different source image parts.On the other hand because of the radial intensity distribution $I^o_\lambda(R)$ in HCD[6], every image part has a different weight in the complete detected signal $I_\lambda(H_o)$.We consider this circumstance as a reason for a Hanle signal background depending on spectral line wavelength λ, gas pressure p and H_o values.Thus,the $S(H_o)$ function is determined by λ and p parameters too.

To increase the optical channel light strength in Hanle experiments the monochromator slit is often diaphragmless.In this general case, which we will consider, the slit separates an almost rectangular part from the source image.That's why the transmitted light beam Φ will be determined by the rectangular plane B and $I^o_\lambda(R)$ distribution:

$$\Phi(r) = B(r)\overline{I_\lambda(r')}$$

where $\overline{I_\lambda(r')}$ is the radial distribution, averaged along the corresponding chord.For a round image with radius R_1 and a slit width **a**:

$$\Phi(r) = 2a\sqrt{R_1^2 - r^2}\;\overline{I_\lambda(r')}$$

where **r** is a running co-ordinate, determing the image centre shift to the slit centre at every H_o value.It is obvious that the B variation might be significant for the levels requiring more intensive magnetic field.

An analysis of the experimental data in ref.6,7,8 and our data too shows a different behaviour of $I^o_\lambda(R)$ at the experimental conditions.Since we consider this function at Hanle experiment conditions, its behaviour is interesting at low gas pressures, e.g. lower than 0.3 ÷ ÷ 0.4 torr.The experimental obtained $I^o_\lambda(R)$ distributions at these pressures may be approximated by $I^o_\lambda(R)=I_o(1-\frac{r^n}{R_1^n})$ functions where **n** becomes 1/2,1,3/2,2,5/2, etc., the low members corresponding to lower gas pressure in the tube. At $H_o \neq 0$ and image shifted at distance **r** the transmitted light beam $\Phi_n(r)$ will be:

$$\Phi_n(r) = 2aI_o\sqrt{R_1^2-r^2}\,(1-r^n/R_1^n) \int_{-(R_1^2-r^2)^{1/2}}^{(R_1^2-r^2)^{1/2}} \left(1 - \frac{r'^n}{(R_1^2 - r^2)^{n/2}}\right)dr'$$

(Fig.1A).Since $\mathbf{r}=\mathbf{r}(H_o)$ and the experimental data imply linear character of this dependence, i.e. $r = \beta H_o$, $[\beta] = [mm.Oe^{-1}]$ integrating the generalized expression we have:

$$\Phi_n(H_o) = \frac{4naI_o}{(n+1)R_1^n}\left[R_1^2 - (\beta H_o)^2\right]\left[R_1^n - (\beta H_o)^n\right] \qquad /2/$$

Fig.1B illustrates the background type calculated for $\beta=1$, $n=2,3/2,5/2,7/2$ and $R_1=10$mm.At $S(H_o)=\left[1+(H_o/2\Delta H_{1/2})^2\right]^{-1}$ and taking into account the expressions /1/ and /2/ for the transmitted polarized light beam we obtain:

$$\Phi_{\parallel}(H_o) = \Phi_n(H_o)\left[1 + \alpha S(H_o)\right] = \frac{4naI_o}{(n+1)R_1^n}\left[R_1^2-(\beta H_o)^2\right]\times$$
$$\times\left[R_1^n - (\beta H_o)^n\right]\left\{1 + \alpha\left[1+(H_o/2\Delta H_{1/2})^2\right]^{-1}\right\} \qquad /3/$$

$/2\Delta H_{1/2}$ is the Hanle signal width/.

DISCUSSIONS

1.As it follows from the expression /3/, the interference signal lies on a dynamic background, which parametters depend on the experimental conditions.The signal amplitude-to-background ratio is characterized by α value, depending on discharge conditions.In positive discharge column $\alpha \simeq 10^{-3}$ (Ref.9).Our experi-

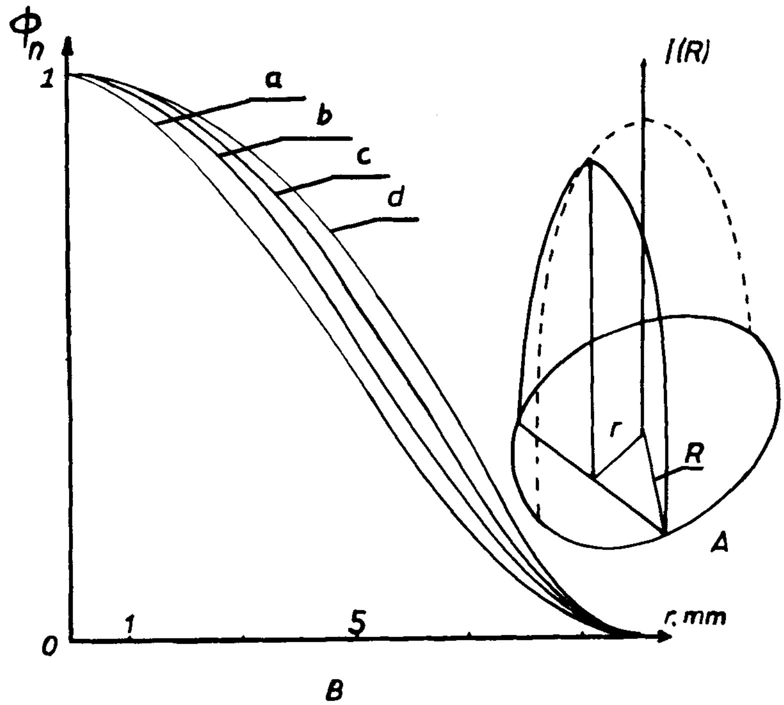

FIG.1. A - geometrical sheme to the background $\Phi_n(r)$ expression; B - $\Phi_n(r)$ function for n=3/2 (a), n=2 (b), n=5/2 (c), n=7/2 (d).

mental data and evaluations show $\alpha \geqslant 10^{-3}$. Fig.2 illustrates certain $\Phi_{\parallel}(H_o)$ functions calculated at two orthogonal polarizations for $\beta=0.5$ mm.Oe^{-1}, n=1.5, $2\Delta H_{1/2}=$ 0.5, 4.0 Oe and $\alpha=10^{-3}$, 10^{-2}, 10^{-1}. Some $\Phi_{\parallel}(H_o)$ curves confirm the principle difficulties for Hanle signal identification - the photocurrent signal is formed mainly by the background. Curves 1 and 1' ($\alpha=10^{-3}$),

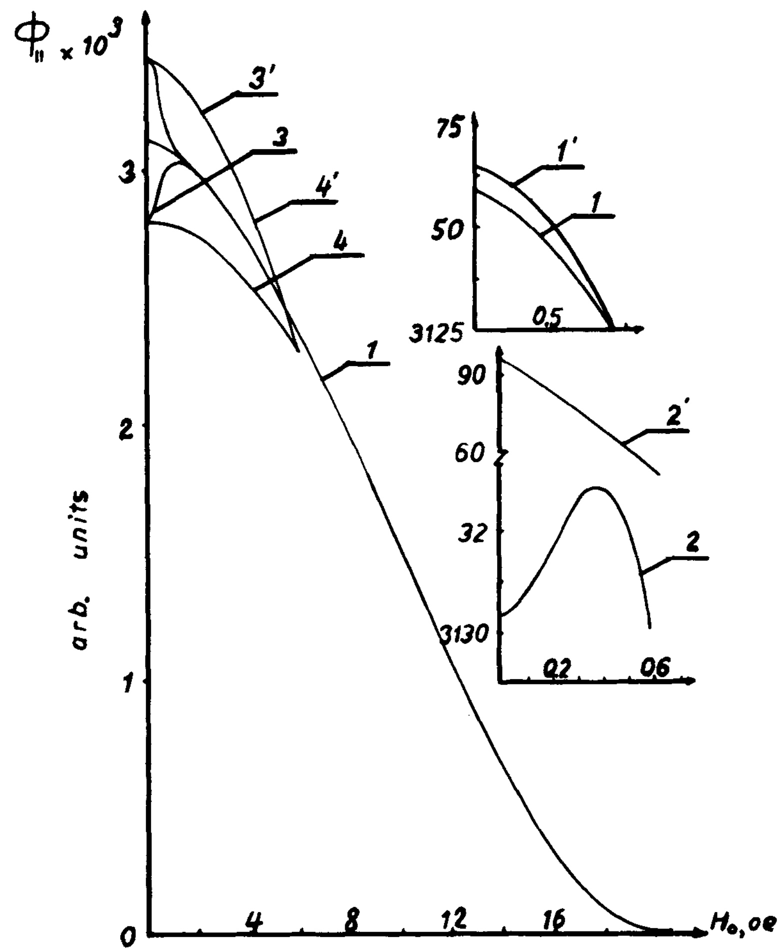

FIG.2. The transmitted light beam $\Phi_{\parallel}(H_o)$ in two crossing polarizations at B=0.5 mm.Oe^{-1} and n=3/2: 1 - α=10^{-3}, 2- α=10^{-2}, 3 - α=10^{-1} /1 + 3 - 2$\Delta H_{1/2}$=0.5 Oe/; 4 - α=10^{-1} /2$\Delta H_{1/2}$=4.0 Oe/.

$2\Delta H_{1/2}$ =0.5 Oe) are nondistinguishable each ether and from the background too; their correct identification and analysis need a higher detection system sensitivity as well as a preliminary information.These two requirements weaken at $\alpha > 10^{-3}$, although for the Hanle signal identification at $\alpha = 10^{-2}$ two polarizations are needed (curves 2,2').

2.Besides the aforementioned considerations another circumstance complicates the correct Hanle signal interpretation.On account of the physical sence of the introduced number **n** the background width (Fig.2) and the Hanle signal width turn out to depend on the atom ensemble density in a similar way.The character of the obligatory Hanle signal width extrapolation $2\Delta H_{1/2}(p)|_{p\to 0}$ and the analogical one for the background is identical. This is a premise for a confusion of identification of background signal with Hanle signal, in particular at $\alpha \approx 10^{-3}$(Fig.2).

3.We will consider another consequance owing to the background presence.We suppose a different sensibility k^i of the channels in a differentiator detection: k'' of the parallel to the slit height polarization and $k^{\perp}$ of the orthogonal one.Let $k^{\perp} - k'' = \delta k$.According to the expressions /1/ and /3/ for each channel the photocurrent component $j(H_o)$, depending on the magnetic field may be expressed:

$$j''(H_o) = k''\Phi''_n(H_o) + k''\Phi''_s(H_o), \quad j^{\perp}(H_o) = k^{\perp}\Phi_n(H_o) + k^{\perp}\Phi_s(H_o).$$

Taking into account the logical relations:

$$\Phi_s''(H_o)=-\Phi_s^{\perp}(H_o)=-\Phi_s(H_o) \text{ and } \Phi_n''(H_o)=\Phi_n^{\perp}(H_o)=\Phi_n(H_o)$$

the amplifier detects a photosignal

$$\Delta j(H_o)= k(\delta\Phi_n \pm 2\Phi_s) = k\Phi_n\left[\delta \pm 2\alpha S(H_o)\right] =$$
$$= k\Phi_n(H_o)\left\{\delta \pm 2\alpha\left[1+ (H_o/2\Delta H_{1/2})^2\right]^{-1}\right\}.$$

When $\delta=0$ $k''=k^{\perp}=k$ and thus $\Delta j(H_o)= 2k\Phi_s(H_o)$.When there is an unbalance ($\delta\neq 0$) the Hanle signal lies on a background, which amplitude is determined by the δ value. Fig.3 illustrates some adopted signal-background curves, calculated at $ß=0.5$ mm.Oe^{-1} and $R_1=10$ mm.First of all we point out that the formal Δj structure is identical with that one of a Hanle signal, complicated by the coherence transfer[8].Curve 3 ($2\Delta H_{1/2}=6$ Oe, $\alpha=\delta$) demonstrates this identity when the upper aligned level **m** has a radiative lifetime τ_m, for the lower level **m'** $\tau_{m'}=0.5\tau_m$ and their Zeeman sublevels are equidistant.The noticed structure analogy hampers the Hanle signal identitification and its analysis in the selected differentiator detection.We will add that even an unballance of order $\delta=10^{-3}$ causes a background equality amplitude with the Hanle signal amplitude.

4.The abovementioned difficulties take place also at Hanle signal detection by H_o-modulation with an alternative component.Here the detected signal is close in form to the first derivative of $\Phi_{\parallel}$-beam on the magnetic field; the interference signal $\partial\Phi_s/\partial H$ lies on a back-

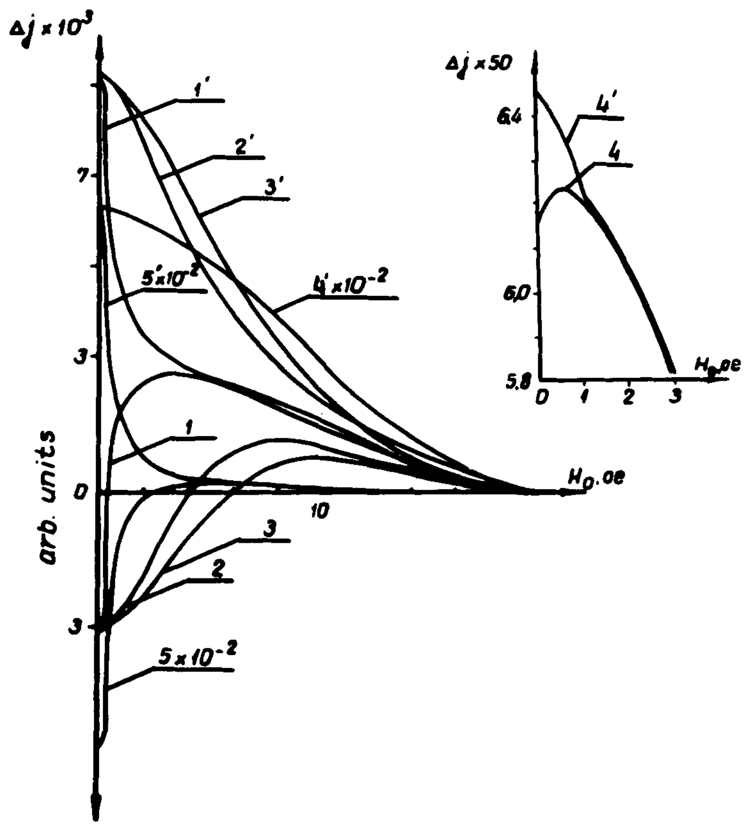

FIG.3. Photosignal $\Delta j(H_o)$ in differentiator $\Phi_{\parallel}(H_o)$ detection:

1 - $2\Delta H_{1/2}$=0.5 Oe, 2 - $2\Delta H_{1/2}$=4 Oe,
3 - $2\Delta H_{1/2}$=6.0 Oe /1÷3 - $\alpha=\delta=10^{-3}$/;
4 - $2\Delta H_{1/2}$=0.5 Oe /$\alpha=10^{-3}$, δ=10/;
5 - $2\Delta H_{1/2}$=0.5 Oe /$\alpha=10^{-2}$, $\delta=10^{-3}$/.

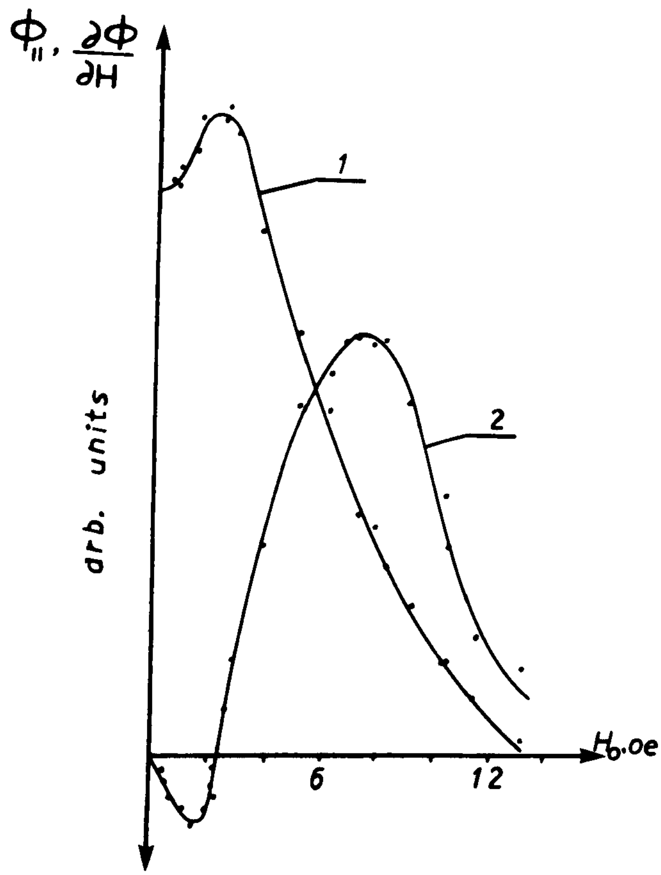

FIG.4. Experimental signals $\Phi_{\parallel}^{E}(H_o)$ (curve 1) and $\partial\Phi_{\parallel}^{E}/\partial H$ (curve 2) for HeI 501.6 nm spectral line /i_d =7.5 mA, P_{He} =0.22 Torr/.

ground $\partial\Phi_{H}/\partial H$ .Fig.4 contains two curves - the simultaneously recorded $\partial\Phi_{\parallel}^{E}/\partial H$ and $\Phi_{\parallel}^{E}(H_o)$ - signals. To derive correctly the useful $\partial\Phi_{B}/\partial H$ signal an optimisation of the detection set up parameters is needed.

5. At Hanle experiments a negligible H_0 influence on the HCD emission characteristics has been noted. On the other hand in some cases H_0 field might change the exciting process balance; this effect is similar to a gas -pressure increase[10]. Therefore in such H_0 field the background will be characterized by a variable **n** parametter, e.g. $\mathbf{n}=n(H_0)$; then **n** variability will cause a background decreased slope.

CONCLUSION

The discussed analysis concerns a type of Hanle signal bacground, caused by mutual orthogonalization of the entrance slit height, the direction of H_0 and the HCD axis (the axis of observation). We consider that this result, based on the transmitted light beam analysis, interpret acceptably the background character. We would like to point out that the reported results concern generally the magnetic-optical measurements in HCD too.

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