# The historical background of the founding of electrogyration

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## Abstract.

190 years is passed from the first observation of optical activity by Arago and more then 30 years - from the first experimental observation of the first known induced spatial dispersion effect by electrical field - electrogyration. The aim of the article is to show the physical and historical fundamentals founding of the electrogyration and development of studying of this effect in the last thirty years.

**Key words:** electrogyration, optical activity, crystallooptics.

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In the solid state physics one can find the problem of optical activity in crystals that is historically quite complicated. As a phenomenon of spatial dispersion [1-3] it has come into notice of scientists and discussion among them beginning from the first observed optical activity in quartz crystals by D. Arago in 1811. But it was only the natural optical activity, however the electrogyration, consisting in the appearing or changing optical activity under the external electric field, had been recognized as new physical phenomena after the number of quite complicate investigations with their success and failures. It could be explained by the fact that electrogyration being an effect of a higher-order smallness in many cases is accompanied by the electro-optical effect and by light ellipticity. Since, electrooptical effect or errors of the geometry of experiments that lead to the rotation of the polarization ellipse was often taking into account as electrogyration. A detailed analysis of the scientific and history aspects of this problem as well as the results obtained till 1983 may be found in the review book and review article [4,5]. Their attention is paid only to the most important directions of the studying of the electrogyration and the history aspects of the investigations of this effect.

The change of optical activity sign under the external electric field at first time was observed in the ferroelectric crystals $LiH_3(SeO_4)_2$ by H. Futama and R. Pepinsky in 1962 [6] at the switching of the enantimorphic ferroelectric domains (change of the point group of symmetry is 2/m↔m). The observed phenomenon was mistakenly explained by a specific domain structure (replacement of the optical axes at the switching) but not as electrogyration induced by spontaneous polarization. Since, then the problem of electrogyration did not arise at that time.

Two years latter (1964) on the base of relations of tensor crystallooptics, I. Zheludev [7] predicted possibility of appearance or changing of optical activity in crystals that is proportional to the external electric field. The idea of the appearance of the optical activity induced by spontaneous polarization was developed by K. Aizu [8] for the proper ferroelectrics, while L. Shuvalov and N. Ivanov [9] following a symmetry approach discussed the problem of the change of sign of the optical activity at ferroelectric domains switching.

The first searching of the induced electrogyration in a few laboratories did not lead to any positive results. For example P. Lenzo et al [10-12] mistook the photorefraction effect of $Bi_{12}SiO_{20}$ crystals at the application of external electric field as electrogyration. In the geometry of their experiments electrogyration can not appear in general. About the observation of the linear electrogyration in the centrosymmetrical $SrMoO_4$ crystals was reported by Yu. Shaldin [13], however, he made a mistake: the electrooptic effect was evidently mistaken as electrogyration. Later in 1983 [14] the authors of [13] admitted their mistake and found electrogyration in these crystals to be by two orders smaller than in the previous experiment.

The first reliable results of the observation of the quadratic electrogyration in quartz crystals were obtained in 1969 (O.Vlokh) [15,16] (in these papers at the first time the term of “electrogyration” was used) on condition of the presence of the linear birefringence and then the linear electrogyration in $\alpha$-$HJO_3$ (1971) [17] $LiJ0_3$ (1974) [18] crystals. The results concerning the linear electrogyration in quartz crystals [19] were subjected to revision and later were explained theoretically [20]. It is interesting to note that Pockels effect in quartz crystals (linear electrooptics) was observed latter than Kerr effect (quadratic electrooptics). In pure case the quadratic electrogyration was observed for the first time only in 1989 in $TeO_2$ crystals by R.Vlokh et al. [21]. The founding of the large linear electrogyration effect in centrosymmetrical $PbMo0_4$ crystals (1975)[22] is principal and unambiguous. The quadratic electrogyration in quartz crystals was soon confirmed by V. Shamburov and N. Romanova (1976) [23] and the linear electrogyration in $PbMo0_4$ by M.Kostov et al. (1979) [24]. Continuous studying of the electrogyration in transparent dielectric quickly increases the number of special investigations of electrogyration. For example the studying of H. Weber and S. Haussiihl (1974-1983) [25-27] is devoted to the investigation of electrogyration and circular dichroism induced by electric field in the alums. The number of studying of the optical activity in the ferroics crystals was made by J. Kobayashi and Y. Uesu by HAUP method [28-33] and J.Etxebarria [34]. The investigations of the influence of electrogyration on the photorefractive grating recording in $Bi_{12}SiO_{20}$ crystals was held by M.Kukhtarev et al. [35, 36].

As to the founding of optical activity in the ferroelectric phase transition, it should be noted that the priority in experiments belong to two groups of researches (1970). One of them is K. Hermelbracht and H. Unruh [37] which detected it in TGS crystals but authors did not connect this effect with spontaneous polarization. The other group is O. Vlokh et al.. that obtained the similar results in the same crystals simultaneously [38, 39] and analogycally to the electrooptical effect induced by the spontaneous polarization, this effect was called electrogyration induced by the spontaneous polarization [38] as well as its description on the base of third-rank axial tensor of the paraelectric phase was proposed.

Important point in investigating the optical activity in ferroelectric crystal was the founding of the optical activity at phase transition in $NaNO_3$ by M.-J. Chern and R. Phillips in 1972 [40], $Pb_5Ge_30_{11}$ crystals by H. Iwasaki et al.. in 1971 crystals [41, 42], and founding of the abnormally large induced electrogyration in $Pb_5Ge_3O_{11}$ crystals and in solid solutions on their base (O.Vlokh et al.., 1977) [43]. The latest measurements were confirmed by C. Konak, J. Fousek and H. Kiirsten (1978) [44]. In expecting the detection of a large electrogyration in the Curie point region the author of [17] began from the fact that in the case of a not clamped crystals electrogyration should be determined by a contribution of piezogyration caused by piezoelectric deformation, i.e. it should possess anomalies temperature dependence as well as piezoelectric coefficients.

Thus, electrogyration has come to be extensively used as a method of investigation of the ferroelectric phase transitions. Here one should mention the pioneer investigations conducted by J. Kobayashi and Y.Uesu (1979) [45,46] where the method of quadratic electrogyration was used for the investigations of pseudo- proper (improper, in their definition) phase transition in KDP crystals. Their results were confirmed and latter developed by O.Viokh et al.(1985)[47, 48]

The obtained results have given the propulsion in the creation of the microscopic theory of electrogyration based on the lattice dynamics. I. Stasyuk and S. Kotsur (1982) [49, 50] applied the method of Green's function and obtained general expressions of the electrogyration tensor components in dielectric crystals of an ion type. The application of this kind of approach, of course, does not mean that the limit of phenomenology [19] thermodynamics [7] or oscillatory models [51] is enhaust, but reveals the nature of this phenomenon in certain crystals. The founding of the electrogyration gives the pulse of investigations of the piezogyration [52], magnetogyration [53, 54], aqoustogyration diffraction of the light [55], gradient piezogyration [56], combined magneto-electrooptical activity [57] self-induced electrogyration [58] and giant self-induced electrogyration in the exciton absorbtion region [59]. In the end of this paper it is necessary to remember that the electrogyration is the first phonomenon of the gradient nonlinear optics [60]. Really from the point of view of the nonlinear electrodynamic the existing of the gradient of the electrical field of the optical wave in the limit of the unit cell corresponds to the macroscopic gradient of the external electrical field taking into account the frequency transposition.

## Reference

1. Agranovich V.M. and Ginzburg V.Z. Crystallooptics with the accounting of the spatial dispersion and theory of exitons. Nauka, Moscow (1979) (in Russian).
2. Fedorov F.I. Theory of the gyrotropy. Nauka i tekhnika, Minsk (1976) (in Russian).
3. Kizel V.A. and Burkov V.I. The gyrotropy of crystals. Nauka, Moscow (1980) (in Russian).
4. Vlokh O.G. The spatial dispersion phenomenas in parametrical crystallooptics. Vyshcha Shkola, Lviv (1984) (in Russian).
5. Vlokh O.G. Ferroelectrics (1987) **67** p.177.
6. Futama H. and Pepinsky R. J. Phys. Soc. Japan (1962) **17** p.725
7. Zheludev I.S. Crystallography (1964) **9** p.501 (in Russian).
8. Aizu K. Phys. Rev. (1964) **1933** p.1584.
9. Shuvalov L.A. and Ivanov N.I., Crystallography (1964) **9** p.363 (in Russian).
10. Lenzo P.V., SpenserE.G. and Ballman A.A., Appl. Opt. (1966) **5** p.1688.
11. Lenzo P.V. and Spenser E.G. Phys. Rev. Lett. (1967) **19** p.641.
12. Moore G.F., P V Lenzo, Spenser E.G. and Ballman A.A. J. Appl. Phys. (1969) **40** p.2361.
13. Shaldin Yu.V. Pep. Acad. Sciens. USSR, (1970) **191** p.67 (in Russian).
14. Belogurov D.A., Okorashvili T.G., SivokonT.A. and Shaldin Yu.V. Phys. of Solid State.(1979) **21** p.2524 (in Russian).
15. Vlokh O.G. Ukr.J.of Phys. (1970) **15** p.759 (in Ukrainian).
16. Vlokh O.G. Lett.Exp. and Theor.Phys (1971) **13** p.118 (in Russian).
17. Vlokh O.G., Lazko L.A.and Nesterenko V.Ya. Crystallography (1972) **17** p.1248 (in Russian).
18. Vlokh O.G., Lazko L.A., Zheludev I.S. Crystallography (1975) **20** p.654 (in Russian).
19. Vlokh O.G. Ukr. J. of Phys. (1971) **16** p.734 (in Ukrainian).

20. Vlokh O.G.and Kobylyanskij V.B. Crystallography (1977) **22** p.562 (in Russian).
21. Vlokh R.O., Pyatak Yu.A., Skab I.P. Crystallography (1989) **34** p.498 (in Russian).
22. Vlokh O.G., Zheludev I.S.and Klimov I.M. Rep. Acad. Sciens.USSR (1975) **223** p.1391 (in Russian).
23. Romanova N.F. Electrooptical effect in the crystalls with elliptical birefringence (1977) Doctor Thesis Moscow (in Russian)
24. Kostov M.K, Shuvalov L.A. and Volnyan–skij M.D. Crystallography (1979) **24** (in Russian).
25. Weber H.J. and Huassuhl S. Phys. Stat. Sol. (1974) (8) **65** p.633.
26. Weber H.J. and Haussuhl S. Acta Cryst. (1983) A32.
27. Weber H.J. Crystallography (1983) **28** p.320 (in Russian).
28. Kobayashi J., Takahashi T., Hosakawa T. and Uesu Y. J. Appl. Phys. (1978) **49** p.309.
29. Kobayashi J. and Uesu Y. Appl. Cryst. (1983) **16** p.212.
30. Kobayashi J., Uesu Y. and Sonmachi H. Ferroelectrics (1978) **21** p.345.
31. Uesu Y., Sonmachi H. and Kobayashi J. Phys. Rev. Lett. (1979) **42** p.1427.
32. Kobayashi J. Uesu Y. and Yamada Y. J.Phys. Soc. Japan (1980) **49,** p.113.
33. Uesu Y., Hosokawa T. and Kobayashi J. News Acad.Sciens.USSR (1977) **41**(in Russian).
34. Etxebarria J., Ortega J. And Breczewski T. J.Cond.Matter (1992) 4 p.6851-6858.
35. Kukhtarev N.V. Pub. by Inst of Phys Ukr. Acad of Sciens. (1985) N85/8 23p.(in Russian).
36. Kuktarev N.V. Muravyev V.V., Semenec T.I. Pub. by Inst of Phys Ukr. Acad of Sciens. (1986) **N19** 21p. (in Russian).
37. Hermelbracht K. and H G Unruh H.G. Zeit. angew. Phys. (1970) **28** p.255.
38. Vlokh O.G. Abs. of VII Soviet conference on ferroelectricity /Voronezh,1970/(in Russian).
39. Vlokh O.G., Kutny I.V. Lazko L.A. and Nesterenko V.L. Rep. Acad. Sciens. USSR (1971) **35** p.1872 (in Russian).
40. Mao-Jin Chern and R A Phillips J. Appl. .Phys. (1972) **43** p.496.
41. Iwasaki H.and Sugn K. Appl. Phys. Lett. (1971) 1992.
42. Iwasaki H. Miyazawa S., Koizumi H., Sugn K.and Niizeki N. Appl. Phys. (1972) **43** p.4907.
43. Vlokh O.G., Sinyakov E.V., Lazko L.A., Monya V.G. and Klimov I.M. Phys.of Solid State (1977) **19** p.1031 (in Russian).
44. Konak C., Fousek J.and Kursten H.D. Ferroelectrics (1978) **21** p.347.
45. Kobayashi J. Memoris of the School of Science, Engineering Waseda Univ. (1979) **40**.
46. Kobayashi J. and Uesu Y., Proceedings of the 2nd Meeting on Ferroelectric Materials and their Applications (1979) A-3 p.117.
47. Vlokh O.G., Klepatch N.I.and Shopa Y.I., Abst. Of the Sixth International Meeting on Ferroelectrics, Koba, Japan, (1985) p.50.
48. Vlokh O.G., Klepatch N.I. and Shopa Y.I.Ferroclectrics (1986).
49. Stasyuk I.V. and Kotsur S.S. Ed. of the Inst. of Theor. Phys. Acad Sciens. Ukr.SSR ITP-82-161P Kiev (1982) p.35 (in Russian).
50. Stasyuk I.V. and Kotsur S.S. Phys. Slat. Sol. (b) (1983) **117** p.557.
51. Miller A. Phys. Rev (1972) **8** p.5902.
52. Zilbernstain A.H., Kozicyn S.Yu., Solovyev L.E. Optics and spectroscopy (1976) **41** p.513-515.
53. Vlokh O.G. News of Lviv Univ. (1982) **16** p.5-12 (in Ukrainian).
54. Vlokh O.G., Sergatyuk V.A. Rep. Acad. Sciens. USSR (1986) **291** p.832-835 (in Russian).
55. Vlokh R.O., Pyatak Yu.A., Skab I.P. News of Acad.Sciens.USSR (1989) **53** p.1339-1341(in Russian).
56. Vlokh R.O., Pyatak Yu.A., Skab I.P. Ukr. J. of Phys. (1989) **34** p.845-846 (in Ukrainian).

57. Vlokh O.G., Vlokh R.O. Optics and spectroscopy (1990) **69** p.458-459 (in Russian).
58. Akhmanov S.A., Zhdanov B.V., Zheludev N.I., Kovrigin A.I.,Kuznecov V.I. Lett.J.Exp. and Theor.Phys. (1979) **29** p.294-298.
59. Zheludev N.I., Kostov Z.M. Giant nonlinear polarization self-action of light in the exciton region of GaAs. Printed by Moscow Univ. (1985) 5p.
60. Vlokh R.O. Phys. Stat.Sol (b) (1991) **168** k47.