Presentations

The previous year 1973 was of particular importance in the history and development of science and technology in Poland for two reasons. We were celebrating the 500 birthday of Mikołaj Kopernik the most distinguished Polish astronomer and the 200 anniversary of the foundation of the National Education Commission one of the first Ministries of Education in Europe. Another important fact of actual significance was the Second Congress of Polish Science and Technology, which was organized that year. Under these circumstances the Editorial Board of the Optica Applicata decided those days to publish a paper on the development and the present state of affairs of Polish Optics. Consequently, the Editorial Committee addressed all the scientific centres in Poland working in optics asking them to send the respective materials. However, the papers provided appeared to be so interesting and extensive and simultaneously so individual in style and concept that the Editorial Committee revised its former intention and decided to replace the idea of one summarizing paper by a series of papers under a common tittle PRESENTATIONS, in which the main achievements of all the scientific institutions will be presented without essential changes in the sent material. Hereafter, the first three important Research Centres are being introduced to the Reader. The next presentations will be successively submitted for publication in the subsequent numbers of *Optica Applicata*.

Laboratory of Non-linear Optics and Chemical Physics,
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Development in Non-linear and Coherent Optics

Arkadiusz Piekara

Introduction

The research work in the field of new optics, which originated after the discovery of the laser action and the design of the first lasers, was initiated in the Poznań scientific centre as the first in Poland. Precisely, it was the Dielectrics Department, Institute of Physics, Polish Academy of Science (PAN) and the Experimental Physics Department, the Adam Mickiewicz University in Poznań, which started the research in this field. The investigation is being continued mainly at the Poznań University and partly at the Institute of Physics, PAN. In 1966, a new centre involved in the research in the field of non-linear optics and holography was founded in the Department of Physics, Faculty of Chemistry, University of Warsaw, and the investigation is now being continued at the Laboratory of Non-linear Optics and Chemical Physics, Institute of the Fundamental Problems of Chemistry, University of Warsaw. For the sake of clarity of this presentation both the theoretical and experimental works to be reported will be devided into five groups: 1. self-trapping of light, 2. dye lasers, 3. Kerr effect, 4. liquid crystals, and 5. holography.

1. Self-trapping of High Power Light Beams

1.1. Phenomenological Theory of Light Self-trapping

The phenomenon of self-focusing of light beams occurs when a pulsed high power light beam produced

by a Q-switched laser enters a fluid or some solids. The beam narrows and focuses. A very slender optical channel appears at this place, which is usually built up of a number of optical filaments of diameter ranging between 5 and 10 μm. The latter part of the phenomenon is called self-trapping. This effect appears as a consequence of an increase in the refractive index caused by the action of the strong electric field existing in the light wave. In the years 1966–1968 a theory of the optical filaments was worked out on the basis of a phenomenological relation between the refractive index and the field strength. This relation may be expressed by the following empirical formula

$$\varepsilon = \varepsilon_0 + \varepsilon_2 E^2 + \varepsilon_4 E^4 + \varepsilon_6 E^6, \tag{1}$$

where the electric permittivity $\varepsilon_0 = n_0^2$ for the optical frequencies, while ε_2, ε_4 and ε_6 are non-linearity coefficiens of an arbitrary transparent medium. For the electric field existing in the light wave the effective value of the permittivity, which follows from the calculation of its time-average value

$$\varepsilon_{\text{eff}} = \varepsilon_0 + \frac{1}{2}\varepsilon_2 E^2 + \frac{3}{5}\varepsilon_4 E^4 + \frac{5}{16}\varepsilon_6 E^6 \tag{2}$$

should be taken into account.

In the face of the condition (2) the wave equation of CHIAO, GARMIRE and TOWNES [1] takes the form

$$\frac{d^2E^*}{dr^{*2}} + \frac{1}{r^*}\frac{dE^*}{dr^*} - E^* + E^{*3} + \alpha E^{*5} + \beta E^{*7} = 0, \tag{3}$$

where

$$\alpha = \frac{3\varepsilon_4}{4\varepsilon_2}\left(\frac{E_0}{E^*}\right)^2, \tag{4}$$

$$\beta = \frac{5\varepsilon_6}{8\varepsilon_2}\left(\frac{E_0}{E^*}\right)^4, \tag{5}$$

and E^* is a dimensionless amplitude of the field E, r^* — denotes a dimensionless distance of a given point in the medium from the light beam axis; the respective normalizing procedure being presented in the papers [1] and [2]. The values of the non-linearity coefficients ε_2, ε_4 and ε_6 indicate the right way of looking for a process responsible for increase of ε_{eff} as well as for the self-trapping resulting from this increase.

Figure 1 shows a relative value of the change $\frac{\varepsilon_{\text{eff}} - \varepsilon_0}{\varepsilon_0}$ versus E_0. The values of the non-linear coefficients

$$C_2 = \frac{\varepsilon_2}{\varepsilon_0}, \quad C_4 = \frac{\varepsilon_4}{\varepsilon_0}, \quad C_6 = \frac{\varepsilon_6}{\varepsilon_0}, \tag{6}$$

which are expressed in the CGS-system of units, are used there as parameters. The variation range of $\frac{\varepsilon_{\text{eff}} - \varepsilon_0}{\varepsilon_0}$ is small as it is clear from the graph and

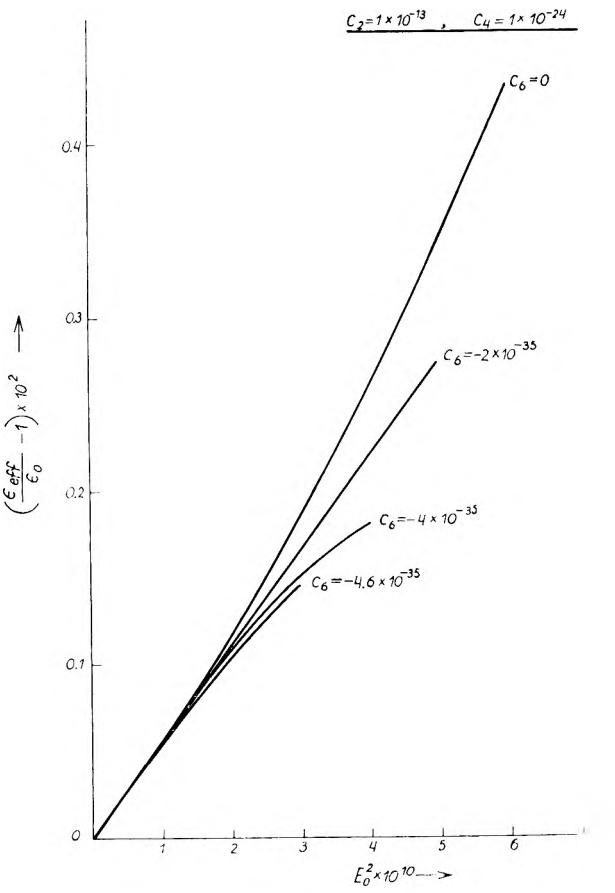

Fig. 1. Variation of $\frac{\varepsilon_{\text{eff}} - \varepsilon_0}{\varepsilon_0} = \frac{n^2_{\text{eff}} - n_0^2}{n_0^2}$ as a function of squared electric field E^2 of the light wave according to formula (2). The variation interval $f_0\, n^2_{\text{eff}}$ for $C_6 < 0$ may be observed which is sufficient for light self-trapping (initiation of light filaments). There exists no visible self-trapping for $C_6 = 0$

amounts to as little as few promilles. This range is, however, sufficient to evoke a dramatic tightening of the light beam down to the diameters of order of 5–10 μm, which are observed in the experiment.

For computing the beam diameter the eigenfunctions of the equation (3) were to be estimated with the IBM 7094 computer for various values of the parameters ε_4 and ε_6 and by the same means for α and β. From the function $E^*(r^*)$ the half width of the light filament $2\, r^*_{1/2}$ may be calculated in dimensionless units and defined as the width at the half power level. The filament diameter is considered to be equal to the doubled value of the half width expressed in microns. The light power introduced into the light beam is calculated from the formula

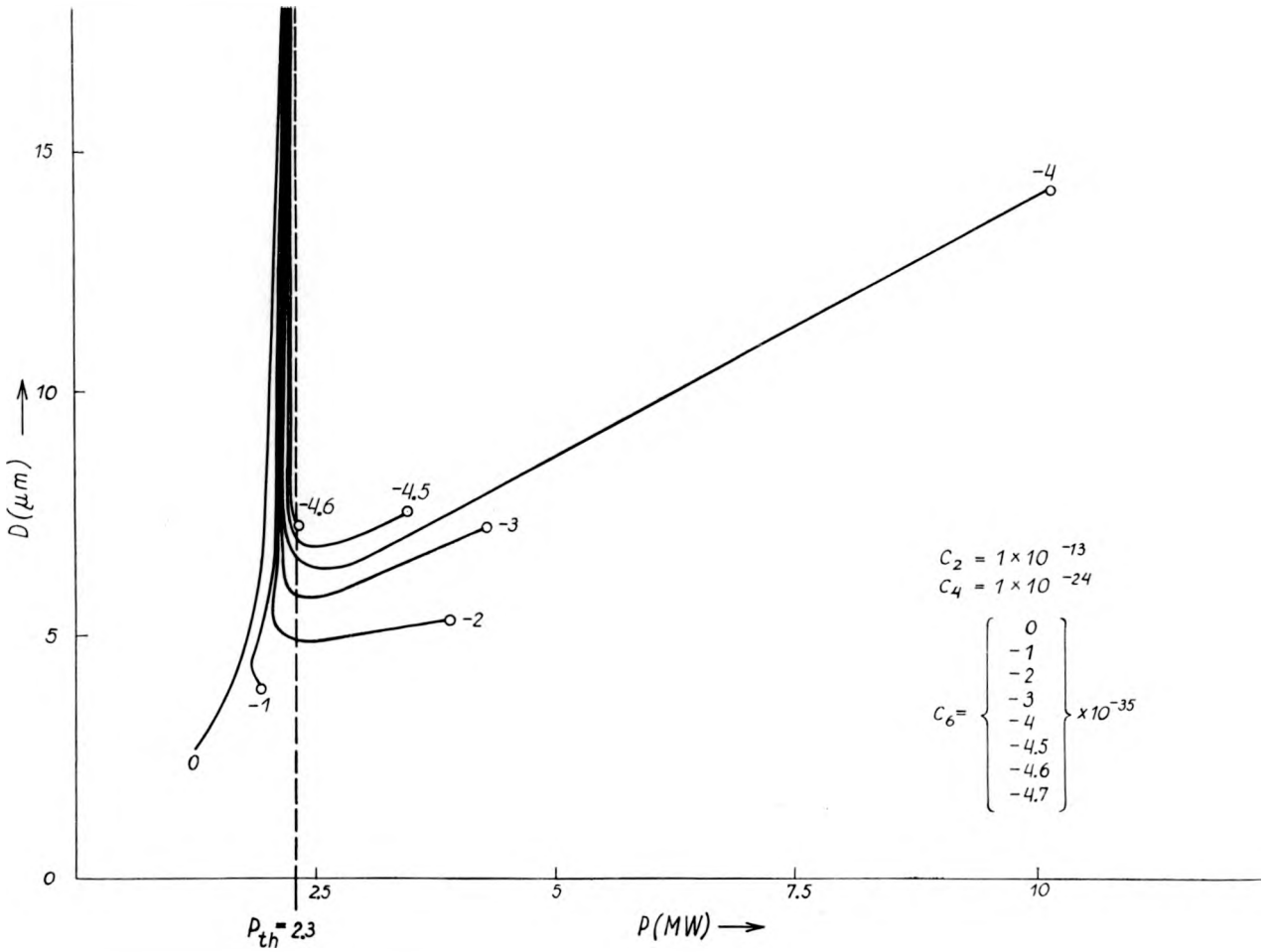

Fig. 2. The light filament diameter as a function of the power to the beam P fedinto for different values of C_6 (cf. Fig. 1). There appears no visible self-trapping for $C_6 = 0$

$$P = \frac{c\lambda^2}{16\pi^2 n_2} \int_0^\infty E^{*2} r^* dr^* \tag{7}$$

(see the papers quoted). From the curves representing the eigenfunctions and the equation (7) the dimensionless field strength $E^*(0)$ in the middle of the filament may be calculated as well as the integral appearing in (7). Also, $r^*_{1/2}$ may be estimated. Hence, the filament diameter D may be evaluated as a function of the power P. The graphs representing the relation $D(P)$ are shown in Fig. 2 for examplified values of the non-linearity coefficients C_2, C_4 and C_6.

It is visible from those curves that the light filament diameters obtained for the following values of the parameters

$$\begin{aligned} C_2 &= 1 \cdot 10^{-13}, \quad C_4 = 1 \cdot 10^{-24}, \\ C_6 &= -1 \cdot 10^{-35} \div -4.6 \cdot 10^{-35}, \end{aligned} \tag{8}$$

(the latters being expressed in the electrostatic CGS-system) range really within the limits observed in the experiment. If $C_6 = 0$, then C_4 must be negative, so that the solutions of the equation (3) represent the stationary self-trapping processes. This is equivalent to existence of a minimum diameter in the graphs $D(P)$. The value of C_2 determines the self-focusing threshold, i.e. the minimum power P_{th}, for which the self-focusing process begins for $C_4 < 0$. For $C_4 > 0$ the self-focusing process starts slightly below the threshold value P_{th}, provided that $C_6 < 0$.

The authors of the work are:
M. S. Feld, J. S. Moore, M. I. T., Mass., Cambridge, U.S.A.
A. Piekara, Warsaw University, Warsaw.

1.2. Mechanism of the Picosecond Light Pulses Interaction with Matter in the Self-trapping Effect

In the phenomenological theory the existence of the light filaments was explained on the basis of the non-linear wave equation. The mechanism of the refractive index increment occuring at the presence of the optical field remained, however, still unsolved.

Initially, i.e. in the course of the years 1964–1967, it was generally believed that the effect consisted in reorientation of the anisotropic molecules in the electric field of the light wave. This mechanism was quantitatively elaborated by A. PIEKARA and S. KIELICH [3] already in 1958, i.e. two years before discovery of the laser. However, new experiments carried out in the field of light self-focusing have showed that independently of the molecular reorientation phenomenon there must exist some other phenomenon — unknown at those days — which played a fundamental part in increasing the index of refraction in the optical field.

The facts, which pointed out a necessity of looking for a new self-focusing mechanism, appeared first in the years 1968–1970. They were the following:

1. The self-focusing occurs even under the influence of picosecond pulses, while the reorientation of molecules in such short time is believed to be impossible [4, 5].

2. The self-focusing was recently observed in such liquids like CCl_4 liquid argon and others, molecules of which exhibit a symmetry close to spherical [6].

3. The self-focusing was observed also in ionic crystals [7, 8].

In the face of these facts the proper self-focusing mechanism should be sought rather among the very fundamental phenomena. As the first phenomenon the Kerr effect was examined [1]. However, this process did not seem to be responsible for the self-trapping, because the Kerr effect did not cause saturation of the electric permittivity, i.e. did not make the value of ε_4 negative, but on the contrary, generated positive ε_4 (see eq. (9) below). The author suggests a different process consisting in interaction of induced dipol — induced dipol type [10]. This interaction causes a transient enhancement of the thermal lattice vibration in the medium (either solid or liquid), which gives a momental increment of all the components of polarizability for the optical frequences

$$\varepsilon = \varepsilon_0 + \varepsilon_2 E^2 + \varepsilon_4 E^4 + \ldots . \tag{9}$$

If we assume that a given molecule of spherical symmetry vibrates jointly with its two neighbours, all the three being positioned along the direction of the electric field of the light wave (what corresponds to the end of the Brillouin zone of high frequency), then we obtain the equation

$$\ddot{x} + \left(\omega_0^2 - \frac{kE^2}{m}\right) x = 0. \tag{10}$$

This equation shows that the vibrational frequency decreases while the average value of the amplitude increases with E^2 [10]. On the basis of this 1ε and C_2 may be calculated and it appears that the value of C_2 for different fluids is of order of 10^{-13} as it is requested by the experiment [11].

For the media built of the anisotropic molecules the mechanism of the interaction is more complex. In addition to the interaction described above, i.e. to the radial interaction, an orientational interaction originating in reorientation appears, which causes libration of molecules [5]. Consequently, a picosecond pulse of light, entering the medium, initiates transient vibration of the molecules of both the translational and librational character. It may be also said that it causes translational and librational shocks of the lattice.

The crystal lattice occuring in a solid body or liquid is not neccessary to produce this phenomenon. In a disordered set of molecules interacting with each other, i.e. as in a sufficiently condensed gas, the value of ε_2 may be also positive and consequently the self-focusing may also occur see 1.6 below. An attempt to evaluate ε_4 is now being made.

The author of this work is: A. PIEKARA, University of Warsaw.

1.3. An Interaction of the Optical Kerr Effect with the Lattice Vibrations Stimulated by a High Power Pulsed Light Beam

An important conclusion follows from the phenomenological theory of self-trapping as well as from a comparison of this theory with the experiment made with the aid of nanosecond pulses. Namely, the mechanism of the molecular reorientation for the anisotropic molecules is consistent with the values of C_2, C_4 and C_6 (see 1.1. above), only if it may be assumed that the effective number of molecules in the medium, which take part in the reorientation occuring under the influence of the light wave electric field, amounts to about 2^{0}_{0} of the total number of molecules [11]. What hinders so much the rotational motion of the molecules? This question has been answered by T. K. GUSTAFSON and C. H. TOWNES [12] in the following way: Lack of free space in a dense set of anisotropic molecules for performing the reorientation causes that the fluid compressibility plays a part in this phenomenon. By assuming a non-linearity of the compressibility of the form

$$-\frac{1}{V_0}\frac{V}{p} = a + b\frac{p^2}{2} \tag{11}$$

the authors estimated that the effective number of molecules taking part in the reorientation diminishes from 100^{0}_{0} in gas to about 10^{0}_{0} in fluids for the an-

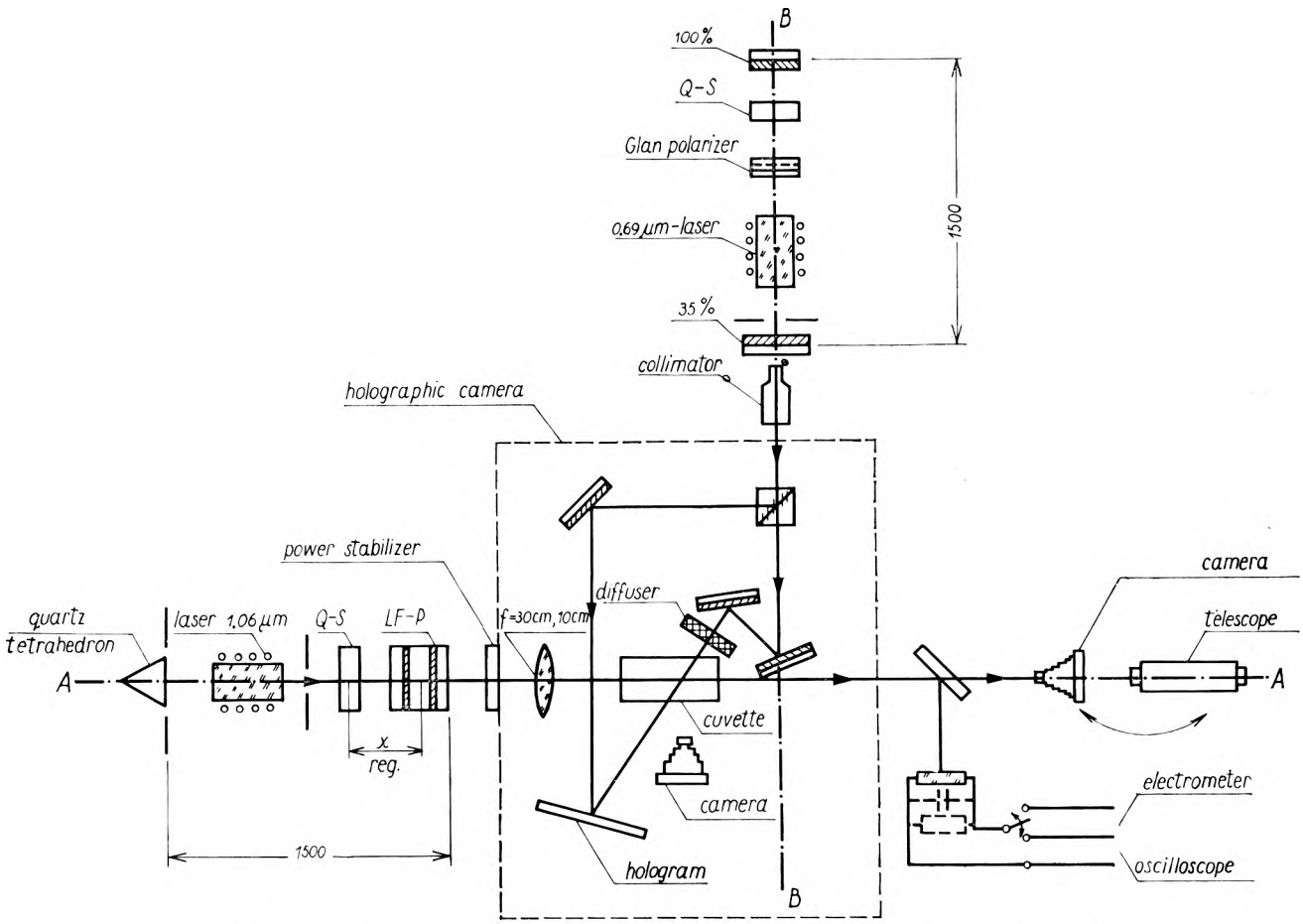

Fig. 3. A scheme of the measuring system for observing the self-trapping by holographic method

isotropic and elongated molecules. This result cleared only partly the situation as the evaluated numbers remained still too great by one order of magnitude.

In the work by T. K. GUSTAFSON and A. H. PIEKARA [13] it has been assumed that in addition to the compression — generated strains an effect of induced dipol — induced dipol interaction is to be taken into account (see 1.2). This effect further diminishes the free space, in which the anisotropic molecules may reorient. Inclusion of this fact into calculation reduces the earlier estimation from 10% to 1%, which appears to be in perfect consistence with the experiment.

The authors of this work are:
T. K. GUSTAFSON, University of Berkeley, California, U.S.A.
A. H. PIEKARA, University of Warsaw, Warsaw.

1.4. Investigation of the Light Self-trapping by Holographic Methods

In the Non-linear Optics Laboratory a device has been designed and built to examine the light self-trapping in liquids as it is shown in Fig. 3. A neodymium laser has been installed along the A–A axis with a possibility of Q-factor modulation. This way the self-trapping of light is produced in a liquid. Along the B–B axis a system with a ruby laser is placed in order to take holograms of the phenomenon of self-trapping. Operation of both the lasers is synchronized by releasing electronically the pulse generators of two Pockels cells mounted in lines A–A and B–B. In order to obtain high quality holograms a selector has been applied for the axial and transversal modes in the system B–B. The above arrangement enables measurements of the changes in the refractive index, which take place in the region of self-trapping channel.

The authors of the work are:
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Laboratory of Non-linear Optics and Chemical Physics, University of Warsaw, Warsaw.

1.5. An Examination of Permittivity and Refractivity Changes of a Medium under the Influence of the High Power Light

In this investigations the nanosecond pulses from a neodymium laser providing the radiant power in the infra-red ($\lambda = 1.06$ μm) equal to about 100 MW were employed. Its second harmonic ($\lambda = 0.53$ μm) was applied to measure the refractive index.

In the experiments some traces of the light filaments (of dimensions: 130 mm in the length and 10 μm in the diameter) appeared within the neodymium glass during the laser action with the modulation of the Q-factor (giant nanosecond pulses). They have been photographed by a system presented in Fig. 4, while the picture taken is shown in Fig. 5.

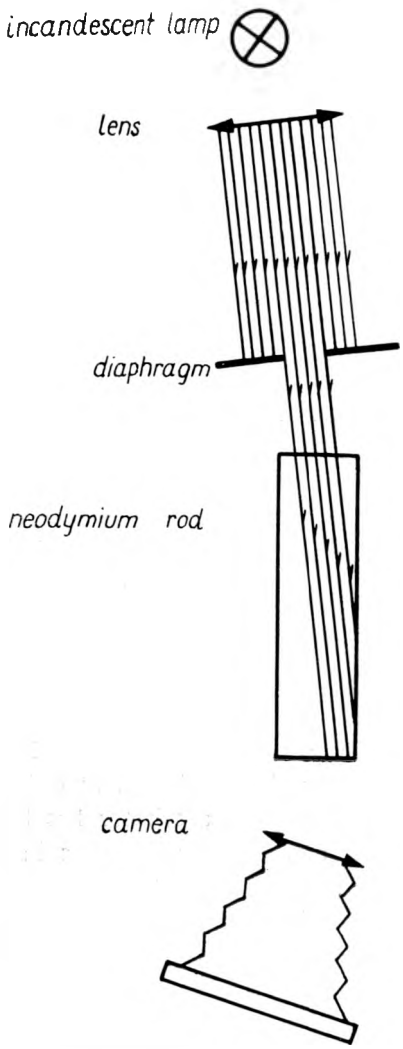

Fig. 4. A scheme of the system used to photograph the light filaments in the neodymium rod

The filaments traces are visible as bright points in the plane of focus and as cones interapidly spreading to the left (downwards the rod) or to the right (upwards the rod) from this plane.

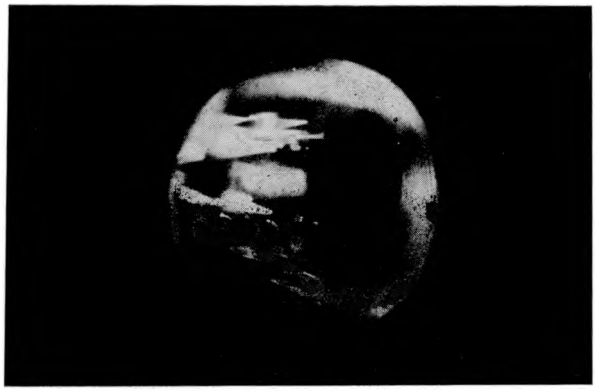

Fig. 5. A picture of the damages in the neodymium glass caused by light filaments. These damages are shaped in the form of filaments, which in the photograph are represented by bright point traces at the plane of focus and spread into diffused cones at the planes located in front of and behind the plane of focus

The authors of this work are:
A. Drobnik, Institute of Physics Technical University of Łódź, Łódź.
W. Majewski, I. P.P.Ch., University of Warsaw, Warsaw.

1.6. Self-focusing of Light in the Gaseous Hydrogen under the Pressure of 100 atm

In co-operation with the Wave Processes Department, Lomonosov University in Moscow, the self-focusing of the green light (the second harmonic of the neodymium laser light) in the condensed hydrogen of pressure approaching 100 atm was examined. The obtained photographs of the beam trace show a narrowing of the beam. For the beam of flux power density amounting to 300 kW/cm^2 the changes in the refractive index $\Delta n \simeq 2 \cdot 10^{-6}$ were observed.

The authors of this work are:
A. Drobik, Institute of Physics, Technical University of Łódź.
V. Protasov, Wave Processes Dept., Lomonosov University of Moscow.

2. Dye Lasers

In the Non-linear Optics and Chemical Physics Group, Institute of Fundamental Problems in Chemistry, University of Warsaw, the laser action in liquid solution of organic dyes are currently under examination. The laser action in dyes may be iniciated by illuminating them with laser pulses (also recently with C.W. lasers as it was shown) or with the flash lamps.

The dye lasers based on different dyes may produce light of arbitrary wavelength within the range of 330 nm — 1100 nm. These lasers may be turned mechanically so that they produce beams of spectral width of order of fraction of Å.

The dye laser can produce high power beams. The dye solution offer an advantage of not being damaged during the laser action. A treatment concerning the dye lasers excited by flash lamps may be found in the paper [14] by A. Baksik.

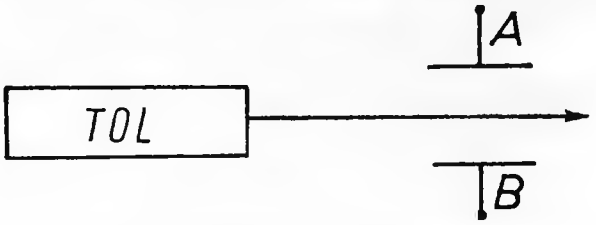

Fig. 6. A scheme of the measuring system for examining the dipole moments in the excited states

In June 1971 the first Polish dye laser has been set into operation our Laboratory. Several liquid solutions of 6G rhodamine dye were used as active substances while the solvents were different alcohols. The solutions were excited by a line xenon flash lamp.

It has been stated that when passing from the lower to higher alcohols in the homologous series of the monohydroxide alcohols the energy of the laser action decreases so much that already in the case of nonanol becomes unobservable. This may be explained by the fact that the dielectric permittivity also decreases [16].

The dye lasers which are tunable within the wavelength range from 330 nm up to 1100 nm may be applied in many fields of research, especially, in electron spectroscopy. Another important application of the dye lasers is in offering possibility of direct measuring the dipole moments of excited molecules in the liquid phase.

Fig. 6 shows the scheme of the measuring system. The solution under test which is contained between two plates of the condenser, is illuminated with the light from a tunable dye laser TDL. Consequently follows a transit of molecules to excited states. At that time a high frequency electric field is applied to the condenser measure increments of capacity. We expect a measurable change in the condenser capacity caused by changes of molecular dipole moments.

In the spring of 1972 a dye laser has been built. Its active substance was excited to lighten by an air flash lamp. The laser action was obtained in the ethanol solutions of coumarin (blue light), of fluorescein (green light), of rhodamine 6G (yellow light), and of rhodamine B (red light). The spectral band of the beams obtained is broad. At present another work is

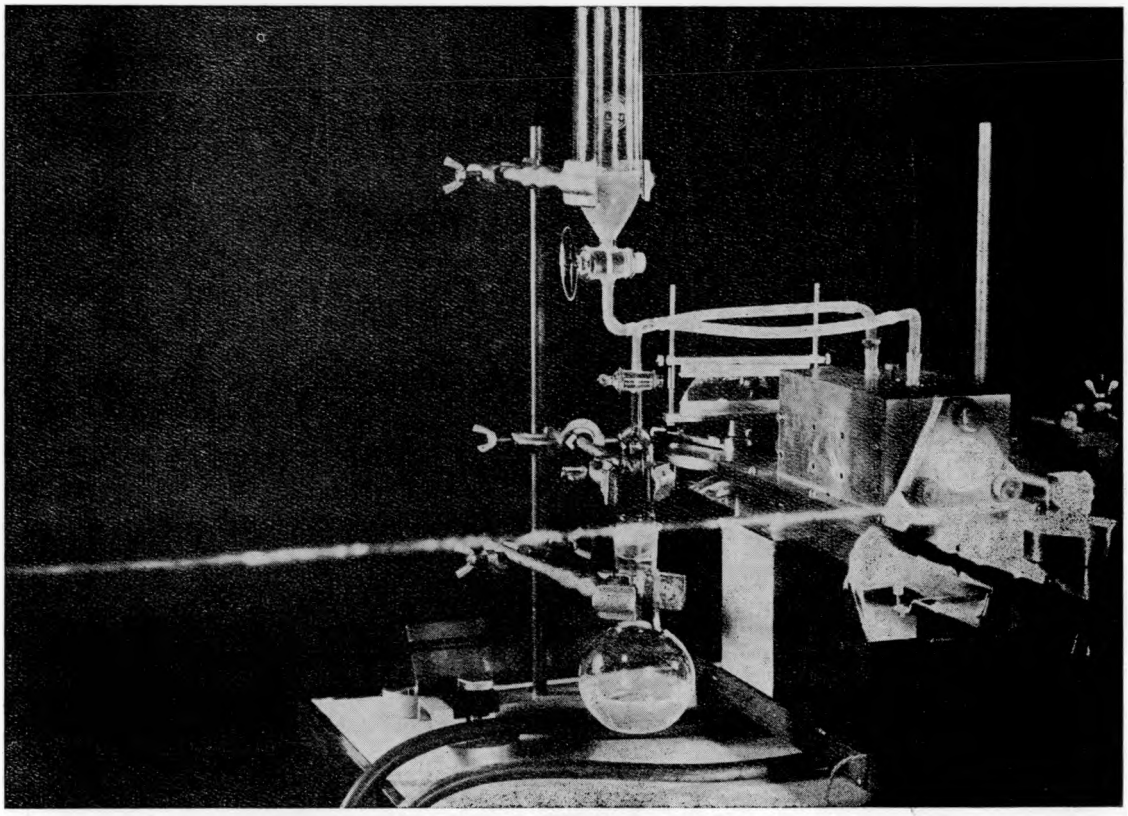

Fig. 7. A view of a tunable dye laser

being done aiming at setting a narrowband dye laser into operation, which would emit light of arbitrary wavelength within the visible range.

A tunable dye laser is presented in Fig. 7.

The authors of the work are:
A. Baksik, T. Kostrzyński, I. Słomka, I. F. P. Ch., University of Warsaw, Warsaw.

3. Kerr Effect

Investigation of electrical properties of molecules are carried out in the Laboratory for Non-linear Optics and Chemical Physics. One of the method applied is the Kerr effect.

In this method the birefringence of a liquid is stimulated by either pulsed or constant electric field. A collimated light beam passes through a polarizer and a suitably oriented Kerr cell filled with the liquid to be examined, and next enters an analizer crossed with a polarizer and finally falls on a photomultiplier working in a pulsed system. A signal from the photomultiplier being proportional to the incident light intensity is displayed on a oscilloscope screen simultaneously with the voltage pulse applied to the cell. In the case of a constant field and constant light intensity the measurement is carried out by means of the light beam modulation method.

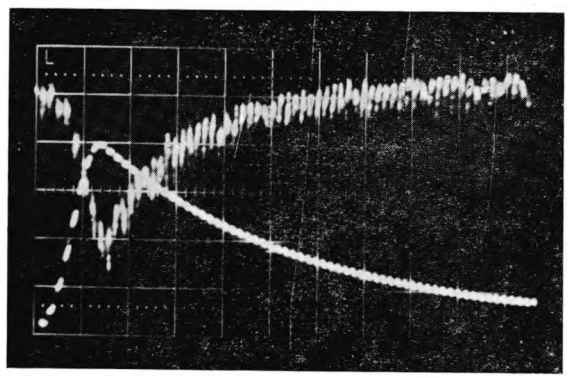

Fig. 8. Measurement of the Kerr effect in benzene by using the pulse method
Lowercurve: the raltage pulse, upper curve: signal from the photomultiplier

The measurement of greater effects, when the phase difference is $\delta > \pi$ are carried out by means of the Piekara and Konopka method [17]. Smaller phase differences are determined basing on the formula

$$I = I_0 \left\{ \cos^2(\alpha-\beta) - \sin 2\alpha \sin 2\beta \sin^2 \frac{\delta}{2} \right\},$$

where α and β are the angles between the vibration planes in the polarizer and analizer, respectively, and the electric field direction [18]. I denotes the intensity of the light tracing the system oriented as defined above; I_0 is the maximum light intensity, which may be determined from the Malus Law.

This setup enables an examination of the Kerr effect and its dispersion in the visible light with a maximal accuracy of the measurement of B amounting to $1 \cdot 10^{-8}$.Pulsed or steady fields up to 30 kVcm^{-1} are applied, what is sufficient to study the saturation of the Kerr effect in macromolecular media.

Actually, the apparatus is used for determining the dipole moments as well as the anisotropy of optical polarizability in solutions of biopolymers.

The measurement of the Kerr effect in benzene by means of the pulse method is shown in Fig. 8.

The author of this work is:
W. Pyżuk, Laboratory of Non-linear Optics and Chemical Physics, University of Warsaw.

4. Optical and Electrical Properties of Liquid Crystals

Examination of changes in the electric permittivity in the p, p' — azoxyanisole (PAA) existing in the nematic phase (116–135 °C) caused by an electric field of strength ranging between 0 and 25 k/cm has been carried out. This investigation is an extention of the earlier measurements made by Jeżewski [19] for the field of strength contained between 0 and 1 kV/cm.

Since molecules in the nematic PAA exhibit an ordering by walls within the zone close to the measuring condenser electrodes the measurements were made for two different distances between the condenser electrodes ($d = 0.48$ mm and $d = 1.50$ mm). The changes in the electric permittivity $\Delta\varepsilon = \varepsilon_E - \varepsilon_0$ were determined using a beat method at a measuring frequency of 1.5 MHz. The measurements were performed for the fresh PAA samples, the electric conductance of which amounted to about $10^{-10}\Omega^{-1}$ cm^{-1}.

Negative values of $\Delta\varepsilon$ have been measured reaching their minimum value for the fields of strength ranging within 5–10 kV/cm (Fig. 9). For low tem-

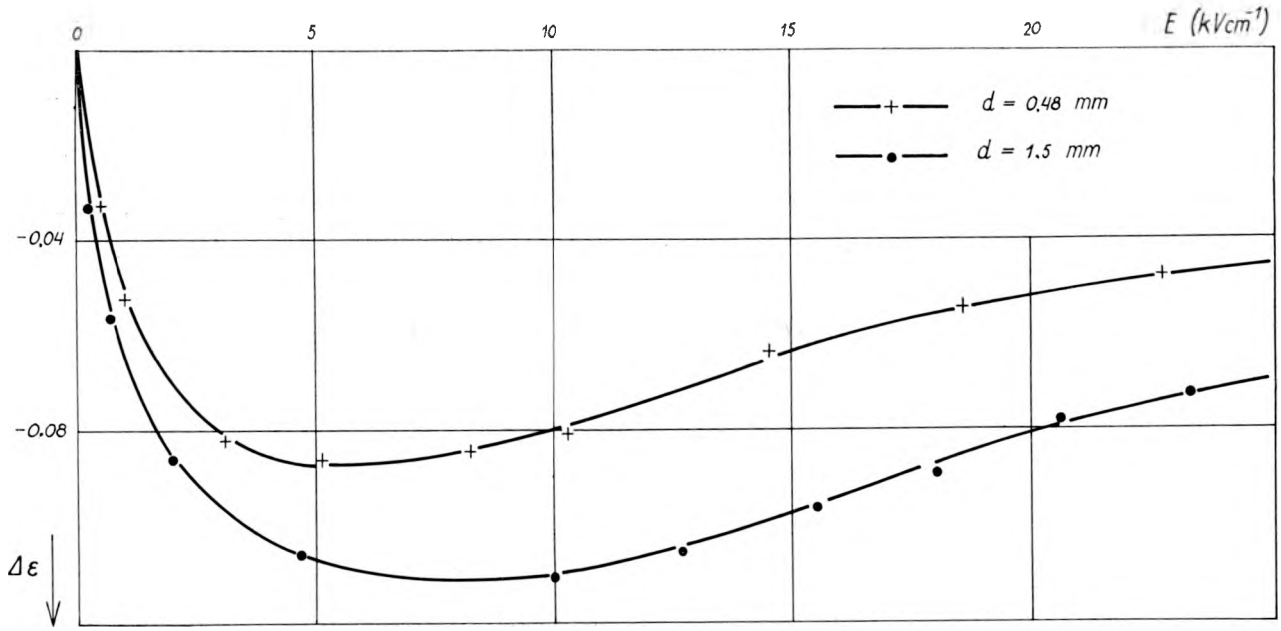

Fig. 9. Nematic p, p' — azoxyanisole. Changes in permittivity vs. electric field strength ($t = 119$ °C).

peratures of the nematic phase the depth of the minimum as well as its position depends, to great extent, upon the distance between the condenser electrodes. At the presence of higher temperatures the minimum $\Delta\varepsilon$ disappears and so do the differences in results which are caused by the different distances between the condenser plates. The appearance of the minimum indicates that the mechanism of the nematic phase orientation in the electric field is more complex than that suggested in the earlier works (JEŻEWSKI [19], G.W. GRAY [20]), when it was generally believed that at the presence of strong fields an asymptotic diminishing of ε should be expected due to complete dielectric saturation, which then occurs.

The investigation of the electric saturation carried out for PAA in the isotropic phase (above 135°C) did not show any measurable influence of the electric field on the dielectric permittivity of PAA within the field strength range 0–25 kV/cm, which is consistent with the earlier observations made by Jeżewski.

Under investigation is the phenomenon of dynamic scattering mode (DSM) in N-(p-methoxybenzylidene)p-n-butylaniline (MBBA) which is a liquid crystal possessing nematic properties at the room temperature.

The influence of both the electric field strength and the temperature on the turbulence connected with DSM is registered by a microphotographic device.

The authors of this work are:
T. KRUPKOWSKI, W. VIETH, W. RUSZKOWSKI, Laboratory of Non-linear Optics and Chemical Physics, University of Warsaw, Warsaw.

5. Holographic Interferometry

In the Holographic Laboratory of the Non-linear Optics and Chemical Physics Group, University of Warsaw, investigations of dielectrics are carried out by means of holographic interferometry methods [21], [22]. As a coherent light source an argon laser is applied to register holographically the images. Fig. 10 shows a scheme of the holographic setup used.

As a result of double exposure a simultaneous holographic registration of an object before and after deformation is taken on the same photographic plate. During the hologram reconstruction step a system of interference fringes appears on the reconstructed image. These fringes are generated by the defor-

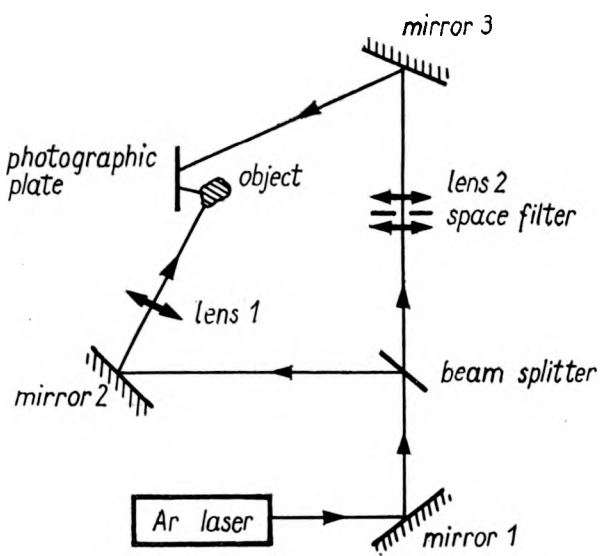

Fig. 10. A scheme of the holographic setup

mations to be examined in the material. The following experiments were made: a) There were examined the interference fringes on a teflon cylinder, which resulted from mechanical stress (i.e., loading the sample with weights from 0 to 100 g); b) A piezoelectric deformation of a pill made of ceramic barium titanate was examined [23]. The voltage ranging from 0 to 1500 V was applied to the pill of 13 mm in diameter and 1 mm in thickness, the electrodes of which were deposited with silver film (Fig. 11, 12). An increase of deformation was observed: a) with the increment of load, b) with the increment of external electric field strength. An exact quantitative elaboration of the experimental results is now being performed.

The authors of the work are.

B. Janowska, J. Szydłowska, I. Słomka, Laboratory of Non: linear Optics and Chemical Physics, University of Warsaw-Warsaw,

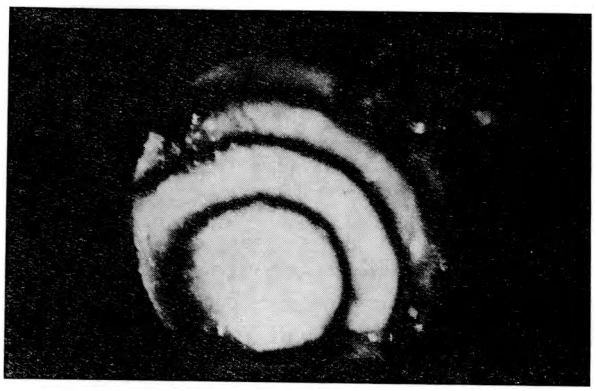

Fig. 11. An image reconstructed from the hologram. An interferogram of a pill with deposited electrodes to which a 1000 V-voltage is applied

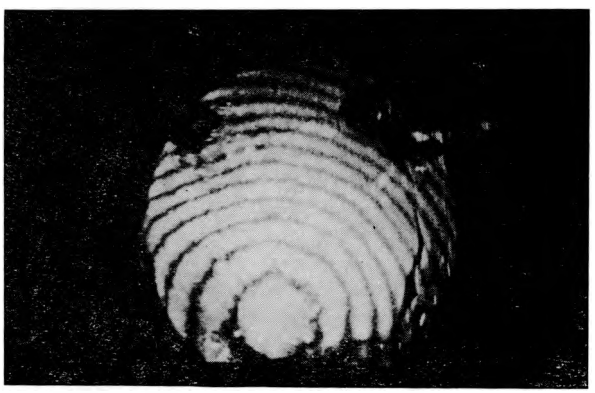

Fig. 12. An image reconstructed from the hologram. An interferogram of a pill with deposited electrodes to which a 1500 V--voltage is applied

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