CHAPTER – 1

INTRODUCTION TO POLARIZATION OF LIGHT
1.1 Introduction to polarization of light waves

Waves are basically two types: 1. Transverse waves and 2. Longitudinal waves. A wave in which every particle of the medium oscillates up and down at right angles to the direction of wave propagation is called a transverse wave. Ripples on water waves and waves on a rope are examples of transverse waves. A wave in which particles of the medium oscillate to and fro along the direction of wave propagation is called a longitudinal wave. Waves produced on string and sound waves are examples of longitudinal waves. In a longitudinal wave all directions parallel to the wave propagation are equivalent. On the other hand, in a transverse wave, a preferential direction normal to the wave propagation exists. The preferential direction is the direction of vibration of the particles and it differs from all other directions.

1.1a. Polarization of waves

The existence of a preferential direction for a transverse wave leads to the characteristic phenomena known as polarization. Polarization is not found with longitudinal waves as they do not possess a directional property \[1\]. Thus, polarization is specific to transverse waves. If, in a transverse wave, the directions of oscillations at all points are strictly confined to the same single plane, the wave said to be polarized. It is called a plane polarized wave or a linearly polarized wave. A plane polarized wave is the simplest kind of transverse wave.
Fig 1.1 plane polarized wave

Fig 1.2 The end on view of un polarized beam of light
The wave shown in Fig 1.1 is a plane polarized wave in which the oscillations are confined to the page.

The oscillations do not always occur in one plane. They may take place in any plane normal to the direction of propagation. An unpolarized wave is a mixture of such transverse waves whose planes of vibration are randomly orientated about the direction of propagation. Such random orientation of vibration planes gives rise to symmetry about the wave propagation direction.

1.1b. Polarization of light

According to electromagnetic theory, light is an electromagnetic disturbance in which electric fields and magnetic fields are varying rapidly with time perpendicular to each other and to the direction of propagation. The vibrating electric vector $E$ and the direction of wave propagation constitute a plane called the “plane of vibration”. It has been found experimentally that it is the electric field $E$ that produces the optical polarization which we are considering $^[2]$. 

As we know light is emitted by atoms when in an excited state. In each wave train, the variations in the magnitude of $E$ are confined in one plane at right angles to the direction of propagation of light.

A beam of natural light consists of millions of such wave trains emitted by a very large number of radiating atoms and molecules in the light source and, therefore the vibrations are in all transverse directions with random orientations. In other words, the natural light(un polarized) can be looked upon as a mixture of waves plane (linearly) polarized in all possible transverse directions $^[3]$.  


Fig 1.3  
a) Representation of plane polarized wave 
b) End on view of fig 1.3a
The end on view \([\text{Fig 1.2}]\) of such un polarized beam of light is shown in Fig 1.2 in which different lines with double arrows represents the electric vectors of different waves.

A light wave in which the electric vector \(E\) is confined to a plane is called a plane polarized light wave. Fig 1.3a shows a plane polarized wave represented using the plane of vibration alone.

Fig 1.3b is an end on view of Fig 1.1c when the wave is observed along the direction of propagation. Only the \(E\) vibrations are observed. The central dot denotes the propagation direction which is towards the reader.

1.1c. Representation of polarized light

The diagrammatic representation of natural un polarized light consisting of linear vibrations in all transverse direction is given in Fig 1.4a.

For simplicity, the amplitudes of the electric vectors in fig1.4b may be resolved in to their components along any two mutually perpendicular axes, say \(x\) and \(y\) axes. If the length of vectors is ‘\(A\)’ and their angles with X axis are \(\theta_1\), \(\theta_2\) etc, the \(x\)-component of all vectors is equal to \(A\cos\theta_1+A\cos\theta_2+\ldots\) and \(y\)-component is equal to \(A\sin\theta_1+A\sin\theta_2+\ldots\).
Fig 1.4  

a) Representation of natural un polarized light  
b) Resolving the amplitudes along X,Y axes  
c) Natural light as two vibrations only  
d) Pictorial representation of natural light
In that case, natural light may be thought of as consisting of two kinds of vibrations only, the two sets of waves vibrating in planes at right angles to each other as in Fig 1.4c. A typical pictorial representation of natural light is shown in Fig 1.4d, where double headed arrows represent vibration of the electric vector in the plane of the paper and dots are the front views of the harrows that are oriented normal to the plane of paper.

1.1d. Types of polarization

It is found that light exhibits three types of polarization apart from partially polarized and un polarized states [5].

1. Plane polarized light / linearly polarized light

If the electric vector \( E \) vibrations are parallel and adhere to the same plane perpendicular to the directions of propagation, the wave is said to be plane polarized. It is represented as shown below.

Fig 1.5a represents a plane polarized light traveling to the right and consisting of vibrations which are normal to the plane of the paper. Similarly Fig 1.5b shows plane polarized light traveling to the right and consisting of vibrations in the plane of the paper.

2. Circularly polarized light

Imagine that we are looking into the light source and perceive the rotation of the \( e \) vector. We observe that the tip of the \( e \) vector
Fig 1.5  

a) Plane polarized light with vibrations normal to the plane of paper
b) Plane polarized light with vibrations in the plane of the paper
traces a circle on the plane perpendicular to the ray direction. If the rotation of the tip is clockwise it is said to be right circularly polarized. On the other hand, if it rotates anti clockwise, the light is said to be left circularly polarized light.

3. **Elliptically polarized light**

Similarly in this case we observe the tip of E vector traces an ellipse on the plane perpendicular to the ray direction. If the rotation of tip is clockwise it is said to be right elliptically polarized. On the other hand if it rotates anticlockwise the light is said to be left elliptically polarized light.

1.1e. **Production of plane polarized light**


1.1f. **Polarizer and Analyzer**

A polarizer is an optical device that transforms unpolarized light into polarized light (Fig1.6). It reduces the symmetry of vibrations inherent in the unpolarized light \[^{[6]}\].

An analyzer is a device which is used to identify the plane of vibration of a polarized wave. Nicol prisms and Polaroid sheets are used as polarizer and analyzers. These components are appropriately, mounted in metal ring structures such that the transmission axis can be rotated and the amount of rotation may be read from the graduations marked on the ring.
If a polarizer is kept in the path of natural light, linearly polarized light is obtained as shown in Fig 1.6.

The state of polarization of the light emerging from polarizer P can be examined with another polarizer A which is for convenience is called an analyzer A. When the transmission axis of the analyzer is parallel to that of polarizer, then light passes unhindered through the analyzer (Fig 1.7a). If the transmission axes are at an angle $\theta$, light is partly transmitted, as shown Fig 1.7b. When the axes are at right, no light is transmitted. The analyzer blocks the light, as shown in Fig 1.7c. The configuration of a polarizer and analyzer where the transmission axes are perpendicular to each other is called crossed configuration.

1.1g. Intensities

When un polarized light passes through a polarizer, the intensity of the transmitted light will be exactly half that of the incident light. From Fig 1.4c, it follows that un polarized light can be always resolved into components polarized parallel to the transmission axis and components polarized perpendicular to the axis. These two components will be, on an average, equal. When natural light is incident on a polarizer, the components parallel to the axis are transmitted and then intensity of transmitted light is therefore, half the incident intensity (Fig 1.8).
Fig 1.6 Polarizer
Fig 1.7
a) Polarizers in parallel
b) Polarizers with some angle
c) Polarizers in crossed position
Fig 1.8 Intensities

Unpolarized  Polarizer  Polarized

$I_0$  $I = I_0/2$
1.2 OPTICAL ACTIVITY

In 1811 the French physicist Dominique F.J. Argo \(^7\) first observed the phenomenon known as optical activity. He discovered that the plane of vibration of a beam of plane polarized light underwent a continuous rotation as it propagated along the optic axis of a quartz plate as shown in the fig 1.9.

At about the same time Uean Baptiste Biot \(^7\) saw this same effect while using both the vaporous and liquid forms of various natural substances like turpentine.

Any material that causes the E field of an incident plane polarized wave to appear to rotate is said to be optically active. Those substances like quartz, sugar in solution, cinnabar and sulphate of strychnine etc which rotate the plane of vibration are known as optically active substances.

There are two types of optically active substances \(^8\).

1) Dextro rotatory or right handed substances, which rotate the plane of vibration in the clock wise direction when looking against the incoming light.
   Ex: Cane sugar

2) Laevo rotatory of left handed substances, which produces anticlockwise rotation.
   Ex: Fruit sugar.
Quartz

Fig 1.9 Optical activity
In 1822, Sir John F. w. Herschel recognized that D-rotatory and L-rotatory behavior in quartz actually corresponded to two different crystallographic structures. Although the molecules are identical, quartz crystal can be either D or L depending on the arrangement of those molecules.

1.2a. Specific rotation

For light of a given wavelength and at a given temperature, the angle through which the plane of vibration of a plane polarized light is rotated, depends on the following factors:

1. The thickness of the optically active substance $L$
2. The concentration of the solution $C$
3. The nature of the substance $S$

Therefore $\theta = SLC$

Where $L$ is in decimeters, $C$ is in gm/cm$^3$ of solution and $S$ is a constant depending upon the nature of the substance and is known as specific rotation.

Therefore $S = \frac{\theta}{LC}$

If $L = 1$ dm, $C = 1$ gm/cm$^3$, then $S = \theta$

Hence specific rotation is defined as the rotation produced by one decimeter length of the solution containing 1 gm of the optically active substance per cm$^3$ of the solution.

For a given wavelength and temperature, $S$ depends upon the molecular structure. Therefore it is material constant. It varies from material to material depending upon the structure. Therefore $S$ is the characteristic value of an optically active substance.
1.2b. Polarimeter

Polarimeter is the instrument used for finding the optical rotation of different solutions. When they are calibrated to read directly the % of cane sugar in solution, they are named as saccharimeters. Polarimeters can be used to find the specific rotation of the solution or if the specific rotation is known, they can be used to find its concentration.

1.3 PRINCIPLE AND WORKING OF POLARIMETER

1.3a. Principle

A pair of Nicols (polarizers) is said to be crossed if they are arranged co-axially with their shorter diagonals at right angles to each other. If un polarized light is incident upon one Nicol. Polarized light emerges out of it and this light will be extinguished by the second Nicol. So on viewing through the second Nicol, the field of view appears dark. If now a tube of optically active substance is placed between the two crossed Nicols, the substance rotates the plane of vibration of the light passing through it and consequently the field of view through the second Nicol becomes somewhat bright. By rotating the second Nicol once again, the light can be extinguished and the angle through which the second Nicol has to be rotated is equal to the angle through which the plane of polarization is rotated by the substance. This is the principle employed in Polarimeter.

It is difficult to judge exactly the position for complete extinction of light. So Polarimeters are usually provided with some device by
which judgment has to be made for brightness of two fields, and this judgment can be more accurately done than the previous one.

1.3b. LAURENT'S HALF SHADE POLARIMETER

Construction

The essential parts of a Laurent’s half shade polarimeter are shown in Fig 1.10. S is a monochromatic source of light and L is a convex lens which renders the incident light into a parallel beam, N1 and N2 are two Nicol prisms. N1 acts as polarizer while N2 acts as analyzer. N2 is capable of rotation about a common axis of N1. The rotation of analyzer N2 can be read on a graduated circular scale. The verniers are also provided to read the fraction of a degree. Light after passing through polarizer becomes plane polarized with its vibrations in the principle plane of the Nicol N1. The plane polarized light now passes through a half shade device (HS) and through a tube T containing the optically active substance. The emergent light on passing through analyzer N2 is viewed through a telescope T. The telescope is focused on the half shade H. It divides the field of view into two halves which can be adjusted to appear equally dark, or equally bright.

To find the specific rotation of a solution, the analyzer is first set in the position for equal darkness without solution in the tube G. Next the tube is filled with the optically active solution of known concentration because of which the field of view will not be dark. The difference between the two positions of analyzer read on the circular scale gives the angle of rotation of plane of polarization caused by the solution. Knowing the value of \( \theta \), \( L \) and \( C \), the specific rotation can be determined.
Fig 1.10 Laurent's half shade polarimeter
LITERATURE REVIEW ON EXPERIMENTAL METHODS FOR POLARIMETER
1.4a. LITERATURE REVIEW ON EXPERIMENTAL METHODS FOR POLARIMETER

Chiragadze and Venyaminov [11] presented the construction of a highly sensitive automatic recording spectropolarimeter for the range from 0.5 to 2.3 um which was created based on ORD-UV-5 instrument of the Jasco firm. The maximum sensitivity of the spectropolarimeter is $2 \times 10^{-4} \degree$.

Reinbold and Pearson [12] described the modifications made to a Perkin-Elmer 141 polarimeter which enabled the acquisition of continuous optical rotatory dispersion data over the spectral region of 650-240nm. The modifications basically consisted of replacing the existing light source of the Model 141 polarimeter with a double grating monochromator and a high intensity xenon light source.

Troitskii and Generalov [13] designed the photoelectric spectropolarimeter for the operation under conditions that radically reduces the light incident on the photomultiplier. The instrument can be used for operation with strongly colored or turbid solution and likewise in performing measurements in the far UV range of the spectrum.

Simon and Pearson [14] described a completely modified Perkin and Elmar model 141 polarimeter. The Bosch and Lomb monochromator containing a double grating modified CZERMU-TURNER mounting provides twice the dispersion of a single grating monochromator and increased spreading of the spectrum permits the use of wider slits for a given band pass than those used in a single grating monochromator. The extremely low stray light of the double
grating B and L monochromator allows entire spectrum to be obtained with out the necessity of additional operations on the optical system and subsequent changes in sensitivity. The high intensity xenon lamp source can be used over the entire wavelength range (650 to 240nm) thus eliminating the necessity of changing lamps to cover the spectral region.

Grivoryey and Karasik [15] presented a spectropolarimeter of simpler design than available commercial instruments and suitable for study of the Faraday Effect in magnetic fields with an intensity as high as $8\times10^4$ A/M in addition to studies of natural optical activity. The instrument in a slave system with automatic tracing of the optical rotation curve. Its spectral range is 250 to 700nm and its error is $\pm 0.004^\circ$.

Victor C. Zadnik et al [16] described the modification made to a Perkin-Elmer model 241 polarimeter to both interface it to an on-line microcomputer data system, and convert it to a microcomputer automated scanning optical rotatory dispersion spectropolarimeter with a range of 650-240 nm. The modifications described in this paper have resulted in a unique computer automated scanning optical rotatory dispersion spectropolarimeter which has a range of 650-240nm and a number of attractive features. The Bausch & Lamb monochromator, containing a double grating modified Cherry-Turner mounting with its low stray light characteristics and excellent dispersion, allow the entire spectrum to be obtained without the need of additional operations on the optical system and subsequent changes in sensitivity. The high intensity xenon lamp source can be used over the entire wavelength range of 650-240 nm, therefore eliminating the
need to change lamps to cover the spectral region. The modifications installed to allow for control of the scanning and data acquisition by the microcomputer result in the rapid and easy acquisition and analysis of optical rotatory dispersion data. The advantage of having a spectrum run by the computer, and having the data digitized and stored for future recall on a disk in a computer readable format, is that time and effort is saved. Calculations and data retrieval can be performed immediately at the completion of a scan, or at any time in the future, without a great deal of effort. With a computer to both perform the scan and analyze the data, an extremely powerful, yet easy to use, scanning spectropolarimeter system was obtained, which excluding the cost of the existing microcomputer and monochromator systems, required less than $400 to construct.

Reinbold and Pearson [17] presented the modifications to a Perkin-Elmer model 141 polarimeter to obtain continuous optical rotatory dispersion data over the entire spectral region which can be obtained with the original calcite polarizing and analyzing prisms and the IP 28 photomultiplier detection systems. The modifications are not extremely difficult and require only a minimum of technical services. The modification consisted essentially of adding an optical bench which contain high intensity light source.

Abramov and Gassakovskii [18] designed a spectropolarimeter for measuring optical activity with no modulator. He explains that when modulation is used in spectropolarimetric measurements only the plane polarized component of the total light flux that passes through the polarimeter polarizer is modulated. Its informative part can then be analyzed by isolating the variable component of the total
photomultiplier current. Modulation is normally carried out either mechanically for example by oscillating the polarizer at a specified frequency or by using magneto optical or electro optical modulators. The first method requires a high precision mechanical system capable of maintaining a specified modulation amplitude and frequency. The use of magneto or electro optical modulators demands a signal generator capable of providing relatively high frequencies. The use of mains current at 50 HZ always causes difficulties because of noise having the same frequency. Thus the use of a modulator as part of a reasonably high sensitivity spectropolarimeter has certain difficulties.
The method that he suggested for measuring the angle of rotation of plane polarized light by the optically active substance is based on the same principle of detecting only the plane polarized component of the light flux, but does not require modulation.

Leksikov A.A et al [19] designed an automatic spectropolarimeter with electromechanical compensation of the rotation of the polarization plane of the light is based on a KSP-4 recording potentiometer. Because of the application of stabilizing feedback introduced from the rotation sensor, a sensitivity of 0.005° has been achieved.

Ramamurthy and Jeevankumar [20] designed a low cost instrumentation based on the principle of new dispersion relation for the study of ORD is developed. The success of the present method is tested in case of a few biomolecules and the use of refractometry as a two in one instrumentation is set modestly.
Alekseev S.A et al. [21] presented a polarimeter which is intended for measuring in laboratory conditions of polarization characteristics of solids and liquid objects and also for analysis of properties and determination of concentration of optically active components of biomedical solutions. This instrument is based on the photometric scheme with a rotating analyzer and digital Fourier detection of photo receiver output signals, control of a spectral source measurements and data processing are carried out by means of the IBM PC.
LITERATURE REVIEW ON POLARIMETER APPLICATIONS IN SCIENTIFIC FIELD
1.4b. LITERATURE REVIEW ON POLARIMETER APPLICATIONS IN SCIENTIFIC FIELD

Dubrovskii et al. [22] discussed the Problems of modern polarimetry and its application to laboratory medical diagnostics and to biomedical research. In this paper an optical scheme of the double-beam differential polarimeter is proposed. Optimization of the proposed configuration is analyzed theoretically, with the aim of improving its metrological parameters, with regard to specific features of the biological objects studied. Feasibility of the high-accuracy optoelectronic polarimeter, promising for dynamic studies of biological objects, is shown experimentally. A prototype of the optical differential polarimeter is developed.

Oshi et al. [23] studied Electric field dependences of optical activity and birefringence of Pb/sub 0.92/La/sub 0.08/(Zr/sub 0.7/Ti/sub 0.3)/sub 0.98/O/sub 3/(PLZT(8/70/30)) using the high-accuracy universal polarimeter (HAUP) method in a temperature region between 0 degrees C and 90 degrees C. PLZT(8/70/30) was optically active in the low-temperature and inactive in the high-temperature phases. Furthermore it was revealed that gyration and birefringence in the low-temperature phase manifested typical butterfly hysteresis loops with respect to electric fields. From analysis of Weissenberg photographs, the ceramics of both high- and low-temperature phases were found to consist of crystallites which were distributed in equal weight along the total solid angles. Using the combined evidence from HAUP and X-ray methods, it was clarified that the classes of the high- and low-temperature phases are T/sub h/ and C/sub 3/, respectively.
Kobayashi et al. [24] discussed by using the high-accuracy universal polarimeter, all the components of optical activity tensor $g$ and birefringence $\Delta n$ of Rb$_2$ZnCl$_4$, which were studied in limited part before, have been reexamined. A unique component, $g_{2/3}$, was definitely found to appear both in the incommensurate and ferroelectric phases, but all the other components vanished in the two phases. The previous report is revised. It manifests a similar temperature dependence to that found in [N(CH$_3$)$_4$]$_2$ZnCl$_4$; it changes the sign within the temperature region of the incommensurate phase. This phenomenon can be interpreted as due to the difference of optical gyration of soliton regions and that of the commensurate domains. It was confirmed that the critical exponent, approximately 0.42, of the temperature dependence of $g_{2/3}$ agrees with nearly constant values shown by other various A$_2$BX$_4$ crystals. However, temperature, where the multisoliton region emerges, was found to differ considerably from that of [N(CN)$_3$)$_2$ZnCl$_4$.

King et al. [25] explained the preliminary design of a noninvasive glucose sensor based on the polarization rotation of light produced by optically active molecules. The polarimeter developed for this investigation was unique when compared to previous investigations in that it utilized a single Pockels cell to both modulate the signal and provide feedback within the system. The intended application of this polarimeter is to measure glucose concentrations within the aqueous humor of the eye. The purpose of this investigation was to elucidate whether the theory of superposition and multispectral analysis can be applied to the measurement of glucose in the presence of ascorbic acid and albumin, the most significant rotatory confounders found in the
aqueous humor. The results of this investigation indicate that superposition of rotation at different wavelengths due to the above optically active molecules was valid for the in vitro experiments conducted. Utilizing two wavelengths of light, the concentration of hyperglycemic levels of glucose were derived in the presence of physiological concentrations of the optically active confounders ascorbic acid and albumin. It was found, except for one outlier, that the model predicted glucose concentrations to within 23%.

De Matos Gomes et al. [26] studied the optical rotatory power of SrS$_2$/O$_6$.4H$_2$O at room temperature along and perpendicular to the optic axis for a wavelength $\lambda$ = 633 nm. The values $p_{||}$ = 2.65 and $p_{\perp}$ = -0.6 degrees mm$^{-1}$ were obtained, where $||$ and $\perp$ mean along the perpendicular to the optic axis, respectively. For the measurements of the optical activity along a birefringent crystal section, the so-called HAUP device (high-accuracy universal polarimeter) has been used. The values of the different optical parameters have been successfully explained using the classical point-dipole-dipole polarizability theory and a recently determined ordered superstructure assigned to the space group P3$_1$. In this way, a connection between the absolute structure of the crystal and the sign of the optical rotation has been established. The conclusion is reached that the main contributors to the optical activity are the water oxygen atoms; in particular, the gyration along the optic axis is satisfactorily described by the exclusive effect of these atoms.

Goetz et al. [27] point out that current techniques for the quantification of blood glucose, particularly in the home environment,
have lacked precision. In their investigations into the rotary effects of glucose upon the polarization vector of light, the authors have developed a polarimeter capable of microdegree precision. At the present sensitivity, normal physiological levels of blood glucose could be measured within 0.1%. A linear regression of output voltage corresponding to optical rotation yielded a standard of deviation of 4.4 microdegrees and a coefficient of linear correlation of 0.99991. Current and future research is focusing on the elimination of confounding factors such as other optically active substances.

Kobayashi measured by using a high-accuracy universal polarimeter, all the components of the optical-activity tensor $g$ and birefringence $\Delta n$ of $[N (CH_3)_4]/ZnCl_4$ in its paraelectric, incommensurate, and ferroelectric phases. Only one component, $g_{23}$, was found to appear both in the incommensurate and ferroelectric phases, but all the other components vanished in the three phases. This fact mostly disagrees with the recent report of Dijkstra, Kremers, and Meekes (1992), but partly agrees with the authors previous result. It was confirmed that the paraelectric phase was optically inactive although Dijkstra, Kremers, and Meekes reported that most components of the gyration tensor were nonzero. The results for $\Delta n$ agree with those of Dijkstra, Kremers, and Meekes except for $\Delta n_{a}$. The sources of these experimental disagreements are discussed.

Asahi et al measured the gyro-optical properties of amino acids, temperature dependences of the gyration tensor components of L- and D-glutamic acids by using the HAUP (high-accuracy universal polarimeter). It was confirmed that the corresponding tensor
components of the two enantiomers are the same in magnitude but
opposite in sign. It is proposed that \( r = \frac{\rho_{\text{C}}^0 - \rho_{\text{S}}^0}{\rho_{\text{C}}^0} \) be defined as the 'chirality index', where \( \rho_{\text{C}}^0 \) and \( \rho_{\text{S}}^0 \) designate rotatory powers per molecule in a crystal and in a dissolved state in liquid, respectively. It represents a measure of structural contribution of optical activity (OA) in a crystal. This value is 0.992 in glutamic acids.

Kobayashi \cite{35} reviewed the methods of measuring optical activity of solid polymers. The extreme difficulty of the methods is exhibited in serious drawbacks of the traditional statistical methods. The invention of HAUP (high accuracy universal polarimeter) method by Kobayashi et al. has opened a way to perfect measurements of gyro-optical properties of any solids. As an example of application of the HAUP method to helical polymers, the process of analyzing the gyration tensor components of poly-L-lactic acid and poly-D-lactic acid is illustrated in detail.

Vlokh \cite{31} described a novel null-polarimetric method and experimental setup for complex measurements of birefringence, rotation of the optical indicatrix, and optical activity in birefringent crystal cuts. The origin of systematic errors in the use of the null-polarimetric method and the high-accuracy universal polarimeter is discussed. The analytical methods for determining the parameters of imperfection of polarizing prisms known in polarimetry are analyzed. The application of these methods is illustrated for the example of determining the optical activity of \((N(CH_3)_4)_2\)
2/ZnCl/sub 4/ dielectric crystals, which possess an incommensurately modulated phase.

Browne et al [32] in this paper discussed that certain organic molecules in solution, e.g. glucose, possess the property of optical activity, rotating the E vector of linearly-polarized light passed through the solution. A Gilham-based polarimeter uses crossed polarizers and E vector modulation to measure the amount of rotation of polarized light caused by a solution of a known path length. In the past, such systems have required the use of an expensive Faraday rotator and a high-voltage photomultiplier tube (PMT) to obtain resolutions down to the microdegree range. We have developed a modified low-cost Gilham polarimeter with microdegree resolution using a coil wound around the solution-under-test instead of a Faraday rotator, and a silicon photo-diode instead of a PMT.

Ching-Mei Feng et al [33] proposes a novel method, which uses an optical polarized heterodyne polarimeter and lock-in technique to detect the concentration of a glucose solution obtained from the detection of a phase sensitive heterodyning signal. In this experiment, the phase measurement relates only with the optical activity of the concentration of a glucose solution; it is irrelevant to the index refraction of the test sample in the interferometer. The polarized common path feature with respect to the left-hand and right-hand side circular polarized light is constructed in this experiment. The system stability and the advantage of the insensitivity to the environmental disturbance are also discussed.
Penkovskii \cite{34} in this paper described a simple high-precision digital polarimeter. It is intended for express measurements of the percentage of sugar, glucose, or other optically active materials in solutions, birefringence in glasses, liquids (Cotton-Mouton, or Kerr effects), and dichroism.

Cote and Cameron \cite{35} reported a unique noninvasive optically base polarimetric glucose sensor capable of monitoring cell culture processes continuously and preferably noninvasively. The data were collected using a highly sensitive, lab-built polarimeter with digital feedback and a red laser diode source. A range of glucose concentrations was evaluated using both glucose-doped double-distilled water and a bovine serum-based medium. The serum-based medium is the nutritional environment in which the cell cultures are grown. Both media were examined across two glucose concentration ranges—a lower range of 100 mg/dl in 10-mg/dl increments and a higher range up to 600 mg/dl in 50-mg/dl increments. The linear regression in all experiments yielded standard errors of prediction of less than 8.5 mg/dl across both ranges.

Glushkova et al \cite{36} studied the optical activity of single crystals of trigonal quartz and its structural analog germanium dioxide, with the help of the photoelectric polarimeter. The rotatory power was recorded in the wavelength range 633-365 nm accurate to ±0.02 deg/mm. Our experiments showed that the value of rotatory power \( \phi \) for germanium dioxide was 1.5 times greater than that of quartz, and therefore, the former is more promising in optical applications. The dispersion dependences of the rotatory power for crystals under study analyzed within the framework of the Chandrasekhar's model allowed
us to estimate the wavelengths of the fundamental absorption bands that amount to approximately 0.1 µm for both objects. The effect of reactor irradiation on the rotatory power of quartz was also examined. These investigations showed that φ decreases with an increase in the dose, vanishing at $10^{20}$ n/cm$^2$. This fact is due to the local irradiation damage of the quartz lattice and its gradual amorphisation. It should be noted that the value of the characteristic wavelength for the irradiated quartz does not change within the whole dose range studied. This fact provides evidence that the silicon-oxygen tetrahedron remains as a structural unit of quartz even in its metamict phase.

Kiezun et al [37] presented the theoretical idea describing a new technical solution of a polarimeter for a measurement of the rotation angle of the plane is presented. The detecting part of a polarimeter consists of a linear phase shifter, an analyzer placed at suitable azimuth behind them and a detector. The phase shift between the orthogonally polarized waves is controlled by a computer. A change of the detector signal is assigned to a change of the phase shift on the linear phase shifter. In this way, the location of the light polarization plane before the linear phase shifter may be measured. Theoretical considerations have been corroborated by experimental results.

Shopa and Kravchuk [38] studied the optical activity in La$_3$/Ga$_5$/SiO$_{14}$ crystals using the experimental technique related to the HAUP (high-accuracy universal polarimeter). During the course of measurements of the optical activity in the polarizer-crystal-analyzer system, the parameter $\gamma = p - q$ ($p$ and $q$ are the parasitic ellipticities of polarizer and analyzer, respectively) is taken into
account, that introduces a systematic error. Two independent methods for determining the gamma value are employed, the first using optically inactive crystal samples and the second basing on rotating the investigated sample by 90 degrees in the polarimetric system. A comparison of the results obtained has shown that the above methods should be used if the value of the measured eigenwave ellipticity k in the crystal is in the order of magnitude of 10^{-3}.

Kawamura [39] in this paper explained that a low concentration aqueous solution operates as a Faraday cell by applying magnetic field to the solution. A new polarimeter is developed by taking advantage of this effect. The function of this polarimeter is confirmed by measuring low concentration (~1000 [mg/dl]) glucose and saccharose aqueous solutions.

Kobayashi [40] explained that although measurement of the optical activity of solids had been impossible for 170 years since its discovery by Arago (1811), we have developed a method called HAUP (high accuracy universal polarimeter), which enables one to measure simultaneously optical activity, birefringence, and rotation of the indicatrix of any crystals, even those belonging to the monoclinic and triclinic systems. Thus the HAUP has opened a new research field in condensed matter physics. This article reviews our applications of the HAUP method to studies on several unsolved problems in this science. It includes an understanding of the origin of structurally incommensurate phases, a revelation of the twinning mechanism of the ferroelectric domains, the first exploration of optical properties of monoclinic crystals, the determination of correct crystal symmetries of transparent PLZT ceramics, first measurements of anisotropic
gyrations of helical polymers, and measurements of reciprocal and non-reciprocal optical activity of high temperature superconductors. It is important to note that these problems could be solved only by making use of the crucial property of optical activity. Summing up the present study, we should like to emphasize the necessity of the new research field, 'chiral physics' where axial tensors like gyration can play major roles.

Shopa and Kravchuk \(^{141}\) proposed an experimental method related to the HAUP (high-accuracy universal polarimeter) for measuring the optical activity and other parameters of optical anisotropy and a respective automatic high-accuracy polarimeter is built. Parasitic ellipticities of a polarizer and an analyzer p and q and the angular error delta /sub chi / (the miss-setting of the crossed polarizer position) are taken into account. For determination of the gyration tensor component g/sub 11/ in La/sub 3/Ga/sub 5/SiO/sub 14/, previous experiments with optically inactive samples are used to find gamma =p-q and delta /sub chi /. Quantitative analysis shows that systematic errors essentially influence the final results.

Cameron and Kote \(^{142}\) explained the development of a non-invasive glucose sensor that would be beneficial to patients inflicted with diabetes mellitus. In this study, polarimetric glucose sensing using both water and the aqueous humor of the eye doped with glucose are investigated. The polarimeter developed for this research differs from previously investigated systems in that it utilizes a digital closed-loop control system. In vitro results were obtained for both water and bovine aqueous humor mediums using a hyperglycemic concentration range of 100-600 mg/dl in 50 mg/dl increments. Both
water and aqueous humor data sets exhibit a high degree of linearity with correlation coefficients of 0.9997 and 0.9925, respectively. The computed linear regression models yielded standard prediction errors of 4.207 mg/dl and 20.24 mg/dl, respectively. Future research will focus on coupling light in and out of the eye as well as problems encountered due to the birefringence of the cornea.

Asahi et al [43] measured gyro-optical properties of amino acids that build up proteins, all the components of the gyration tensor and the birefringence of L-aspartic acid as a function of temperature although the crystal belongs to the monoclinic system. The temperature dependence of the rotation of the gyration surface around the crystallographic b axis was also clarified. It is of interest that the chirality index of this crystal was found to be almost the same as that of glutamic acid, another amino acid.

Kobayashi and Ashai [44] explained the development of HAUP and its applications to various kinds of solids. Optical activity was found in 1811 by Arago. However, optical activity of solids is extremely small and overwhelmed by existing birefringence, so it could not be measured until the high accuracy universal polarimeter (HAUP) was developed by them in 1983. The HAUP method enables to measure optical activity and birefringence of any solids even belonging to monoclinic and triclinic systems. The principles of the HAUP and the more generalized one are given. The applications of the HAUP method to various kinds of solids, i.e., the elucidation of the origin of the incommensurate state of ferroelectrics, optical activities or monoclinic crystals, huge optical activity of high polymer sheet, and the first measurement of a protein, lysozyme, and crystal are
described. These applications illustrate that axial tensorial consideration provides otherwise inaccessible insight of previously unsolved problems. Therefore we stress the necessity of developing a new research field defined as chiral physics, where axial tensors play essential roles.

Zirk et al [45] described the development of a miniaturisable high sensitive polarimeter as detector of an implantable glucose probe. From a clinical point of view, an implantable telemetric probe for monitoring the blood glucose profile is highly desirable. It should be capable of monitoring the blood glucose level continuously or at regular brief intervals, if necessary requirement-controlled. Apart from blood, measurement can also be made in intercellular tissue fluid, for example, in subcutaneous connective and fatty tissue, because this fluid accurately reflects blood glucose levels after only a brief, but negligible, time lag. Since the functional lifespan of an implantable probe is of decisive importance, only physical sensors, but not biosensors can be considered. We are in the process of developing a very sensitive miniaturised detector based on polarimetry, capable of determining the measuring parameter-the spatial orientation of the in-plane vibration of a polarised light beam-with extreme accuracy. This is a very important point, since the physiological and pathological glucose levels modify the in-plane vibration by only a very tiny angle of rotation. The high level of accuracy is achieved by various specific optical amplification mechanisms, and amplification of the electric signal. Two purely optical amplification methods are described here. Simple linear elongation of the optical path of a laser beam within the sample, resulting in a proportional amplification of the measuring signal, is obviously strictly limited in an implantable probe. Therefore
they developed a technique that preserves the polarization state of the light beam during reflection. This technique makes possible multiple passage of the light beam through the fluid being sensed, thus elongating the optical path by "folding" the light beam without the need to enlarge the measuring cuvette. In a second possibility, enlargement of the rotation angle can be achieved by reflecting the light beam from a suitable surface, when the orthogonal components of the polarized light beam are reflected to different extents.