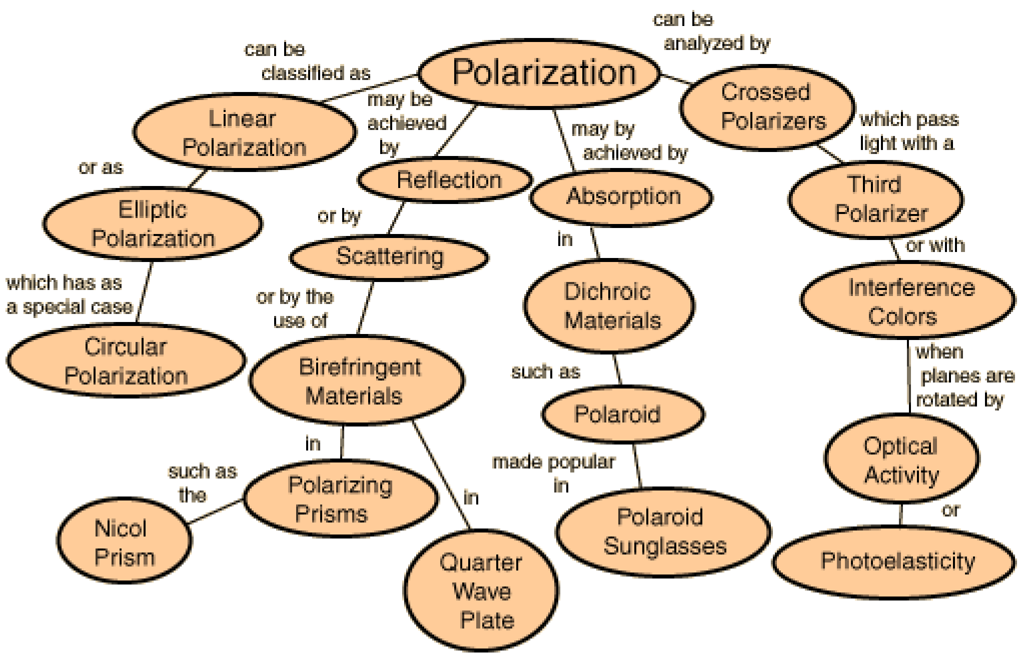
M9. Optical rotation of solutions. Measurement of the concentration of optically active substances by using a polarimeter.

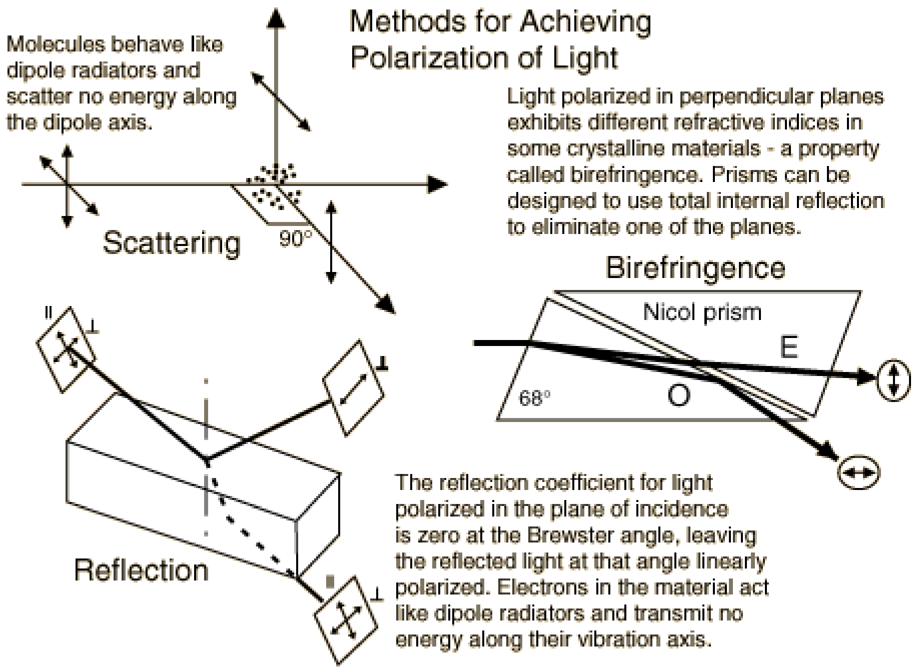
Problems to be prepared:

- Electric field [1] – Chap. 22-2
- Magnetic field [1] – Chap. 28-3
- Maxwell's equation [1] – Chap. 32-5
- Wave theory of light [1] - Chap. 33
- The phenomenon of polarization [1] – Chap 33-7. Ways to polarize the light.
- Polarizers. Prism Nicola. Phenomena occurring during the passage of light through a prism [1] – Chaps. 33-8 through 33-10
- Optically active substances.
- Rotation of the plane of polarization. Specific optical rotation.

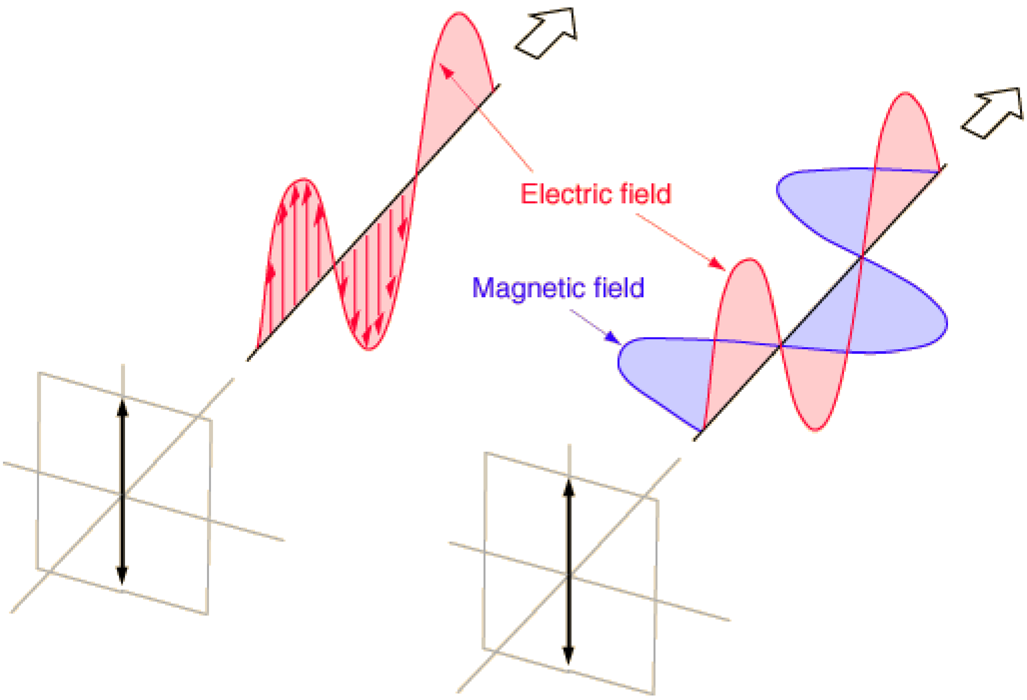
Polarimetry is a sensitive, nondestructive technique for measuring the optical activity exhibited by inorganic and organic compounds. A compound is considered to be optically active if linearly polarized light is rotated when passing through it. The amount of optical rotation is determined by the molecular structure and concentration of chiral molecules in the substance.



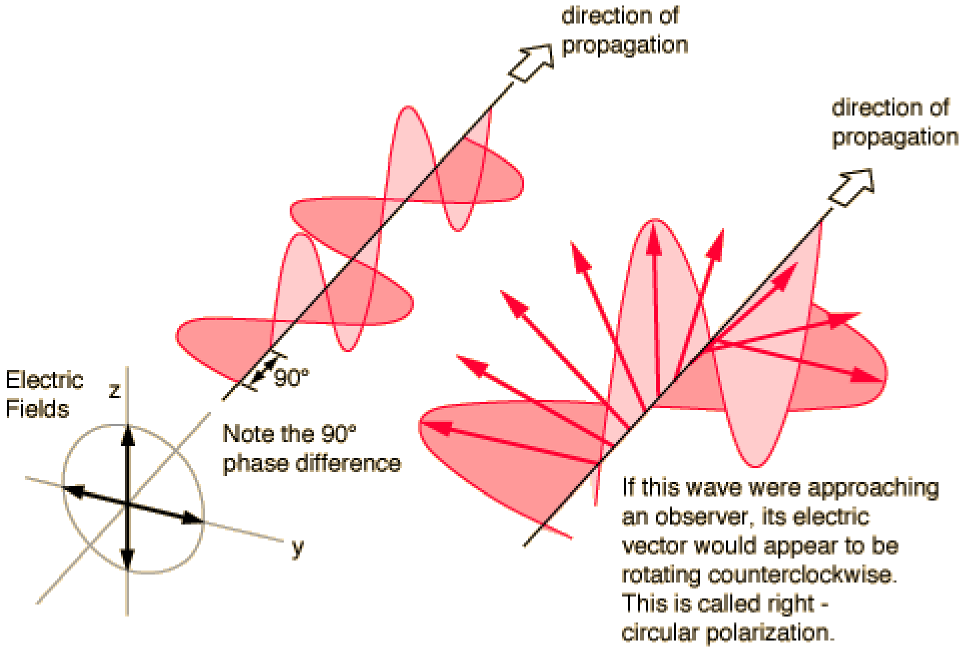
Normal monochromatic light contains light that possesses oscillations of the electrical field in all possible planes perpendicular to the direction of propagation. When it is passed through a polarizer (e.g. Nicol prism, Polaroid film), only light oscillating in one plane will leave the polarizer.



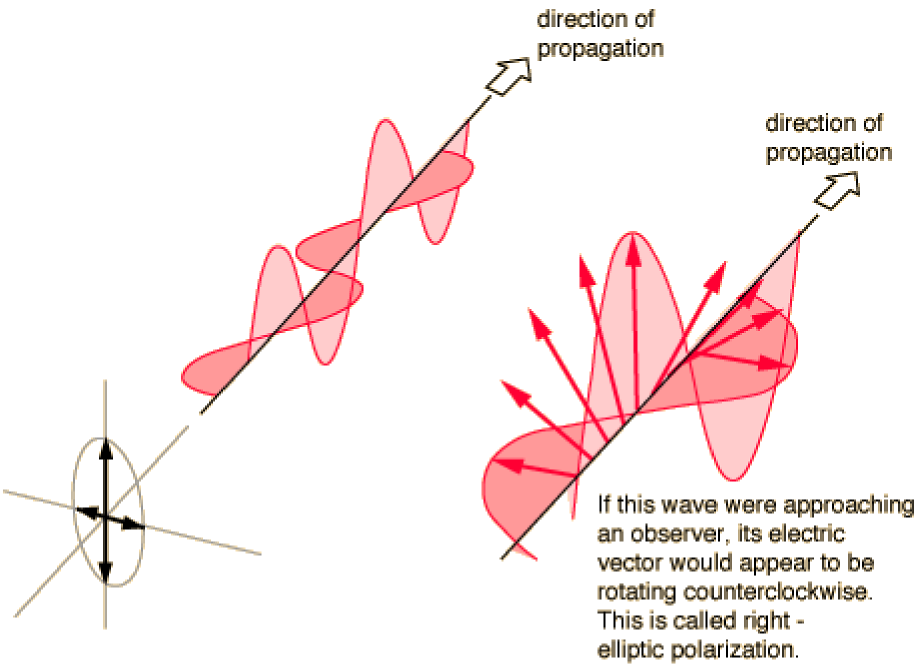
Linear Polarization. A plane electromagnetic wave is said to be linearly polarized. The transverse electric field wave is accompanied by a magnetic field wave as illustrated.



Circular Polarization Circularly polarized light consists of two perpendicular electromagnetic plane waves of equal amplitude and 90° difference in phase. The light illustrated is right-circularly polarized.



Elliptical Polarization. Elliptically polarized light consists of two perpendicular waves of unequal amplitude which differ in phase by 90°. The illustration shows right- elliptically polarized light.

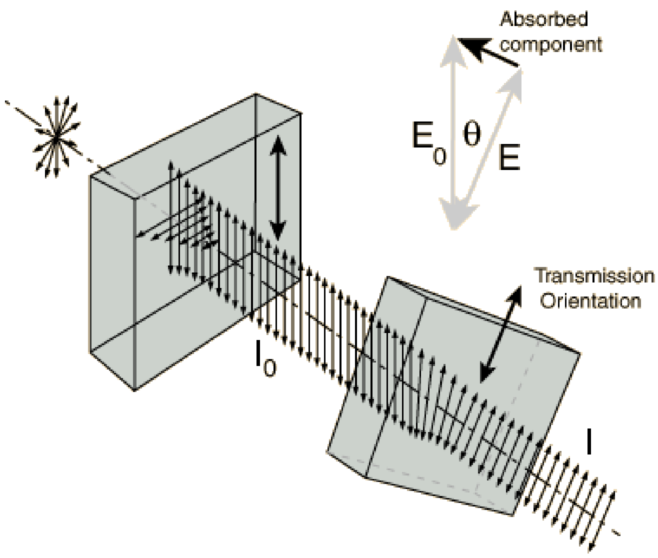


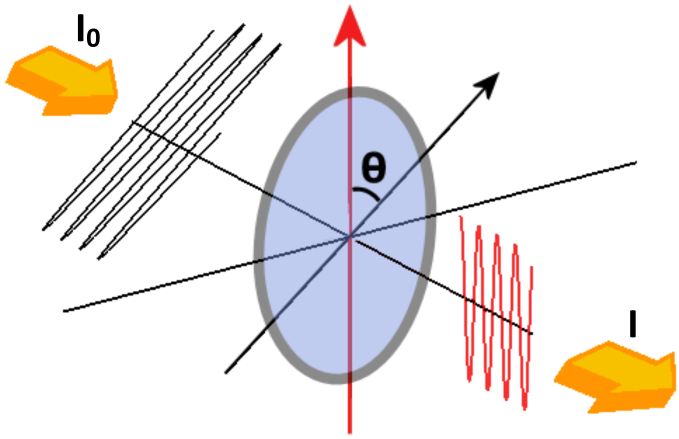
In a polarimeter, plane-polarized light is introduced to a tube (typically 10 cm=1 dm in length) containing a solution with the substance to be measured. If the substance is optical inactive, the plane of the polarized light will not change in orientation. The observer will read an angle of $\alpha=0^{o}$. If the compound in the tube is active, the plane of the light will be rotated on its way through the tube. In order to observe the maximum brightness, the observer (person or instrument) will have to rotate the axis of the analyzer back, either clockwise or counterclockwise direction depending on the nature of the compound. For clockwise direction, the rotation (in degrees) is defined as positive ("+") and called *dextrorotatory* (from the Latin: dexter=right). In contrast, the counterclock-wise direction is defined as negative ("-") and called *levorotatory* (from the Latin laevus=left). Unfortunately, there is no obvious correlation between the configuration [(D/L) in Rosanoff, (R/S) in Cahn-Ingold-Prelog nomenclature] of an enantiomer and the direction [(+) or (-)] in which they rotate plane-polarized light.

Polaroid filters absorb one component of polarization while transmitting the perpendicular components. The intensity of transmitted light depends on the relative orientation between the polarization direction of the incoming light and the polarization axis of the filter and is described quantitatively by Malus' law. The law stating that the intensity of a beam of plane-polarized light after passing through a rotatable polarizer (analyzer) varies as the square of the cosine of the angle through which the polarizer is rotated from the position that gives maximum intensity.

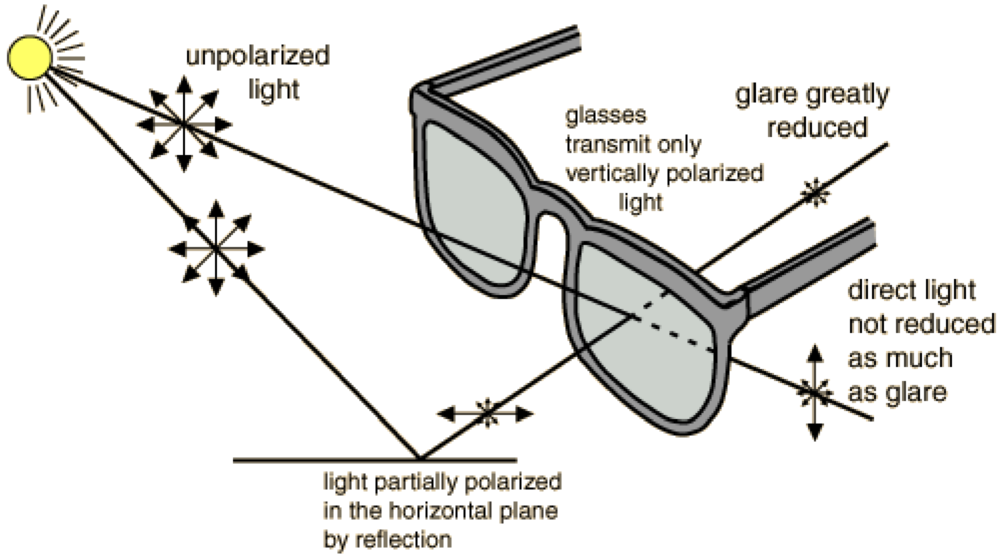
$$I = I_0 \cos^2 \theta$$

where I_0 is the incoming light intensity, I is the light intensity detected by the analyzer, and θ is the included angle between the polarizer's transmission axes and the analyzer's transmission axes.





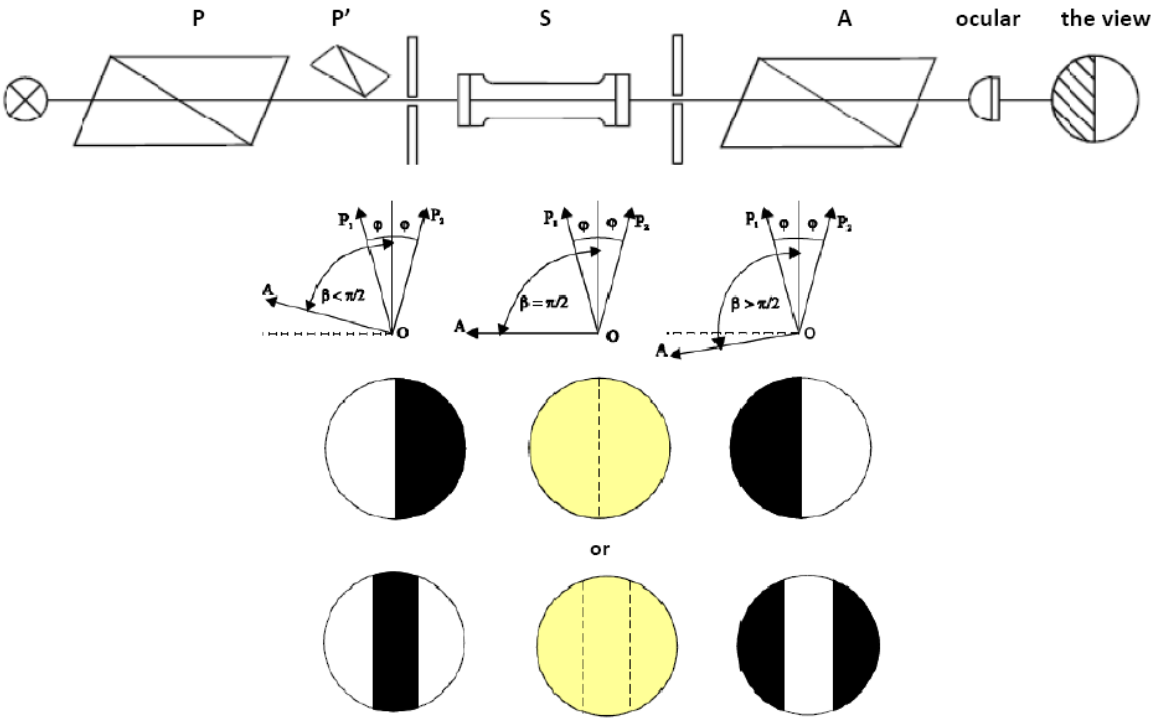
The polaroid material used in sunglasses makes use of dichroism, or selective absorption, to achieve polarization.



Description of experiment

The aim of exercise is to determine the concentration of optically active substances in solution, and calculate the specific optical rotation α_0 of this substance.

To measure the rotation angle of the plane of polarization is the Lippich's polarimeter (Fig. 1). Monochromatic light from the sodium lamp ⊗ passes through a polarizer (P) (Nicol prism). Polarized light beam passes through the cuvette (sample) with optically active substance (S). Next it goes through the Nicol prism, analyzer (A), and falls into ocular. Nicol prism (P') serves as the half-shadow polarizer.



If the analyzer A is perpendicular to the polarizer P, the free half of the field of view is dark, and if it is perpendicular to the half-shadow polarizer, the covered half is dark. If the analyzer is set to a middle position, the two halves of the field of view are equally bright. This zero position can be adjusted very precisely because deviations from it are clearly seen due to the opposite changes in brightness on the two fields.
In the experiment the rotation of the plane of polarization by a sugar solution is measured as a function of the concentration, whereby the concentration is changed in small steps. The angle of rotation strongly depends on the wavelength of the light. Therefore a yellow colour filter is used in the experiment.

Instruction

1. By using the knob on the right side of the instrument set the analyzer (A) in order to the angular scale indicated zero. Adjust the focus by turning the eyepiece. Gently rotate the knob away from you and to yourself to see achievable field of view. Set the analyzer to see the two halves of the field of view are equally bright. The scale should show zero or be slightly deflected from zero. Read and note the indication in the table as α_1.
2. Fill the cuvette with the solution No. 1. Cuvette must be completely filled with a solution. Place the cuvettes into the holder. Set the analyzer to see the two halves of the field of view are equally bright. Read the angle α_2 and calculate the angle of rotation of the polarization plane α:

   $$\alpha = \alpha_2 - \alpha_1$$

   Set the analyzer to zero position and repeat all operations twice.
3. Follow the same procedure with the other solutions, including the solution of unknown concentration c_x.
4. Calculate the average angle of rotation of the polarization plane α for each of the solutions. Present the results in table.
5. Plot the data ($f(\alpha) = c$) and perform linear fit using GrafPad Prism application. Print the graph.
6. Knowing the parameters obtained from linear fit calculate C_x. Mark C_x on the printed graph.
7. Calculate the specific optical rotation α_0 of this substance.

   $$\alpha_0 = \frac{b}{length\ of\ the\ path\ traveled\ by\ light\ in\ a\ solution}$$

   where:

b – the slope calculated by computer

length of the path travelede by light In a solution = 2 dm.

Oszacuj $u(\alpha_0)$. Zastanów się dlaczego w ten sposób możemy policzyć α_0.

8. The results present in the table, fill in the missing units. Make the conclusions.

<table>
<tr><th>No.</th><th>c (%)</th><th>c(g/cm^3)</th><th>α_1(°)</th><th>α (°) = α_2-α_1</th><th>α_{av}(°)</th><th>α_0(.........)</th></tr>
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α_0 $u(\alpha_0)$</td></tr>
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<tr><td rowspan="3">c_x</td><td rowspan="3">–</td><td rowspan="3">..........(.........)
c_x $u(c_x)$</td><td></td><td rowspan="3"></td></tr>
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[1] Walker J., Halliday and Resnick, *Principles of physics : international student version*, 9 th ed., extended, Hoboken : John Wiley & Sons, Inc., 2011. , ISBN 978-0-470-56158-4