

Properties of Light Waves

A recent survey of our readership has highlighted the need for the dissemination of more tutorial-type information. Conversations with readers, researchers in the field, and instrument company representatives, among others, seem to confirm that both novices and experienced analysts alike could benefit from such review information on the basics of all areas of spectroscopy. We introduce "The Baseline" to tackle a variety of topics to meet this need. David Ball of Cleveland State University will be coordinating the series. We welcome your comments and contributions and hope that you find this first installment useful.

Sherrie Steward
Editor

People involved in technical areas never lose the need for straightforward, tutorial-like sources of information on the techniques they use. Adequate information sources are not always available on a particular topic (we've all felt the frustration of not having the manual). New and improved methodologies and instruments are constantly being introduced, so our knowledge must be constantly updated. And, it may just be that the information "didn't stick" the first time around.

This new column will present tutorial articles on topics in spectroscopy. The column is not intended to talk down to the reader; rather, it is meant as a review of the basics, an opportunity to acquaint oneself with a new area, and a forum for troubleshooting.

We will start with — naturally enough for a column on spectroscopy — the nature of light, but there's no need to follow a sequence. Topics can and will include window materials, basics of various spectroscopic techniques, how to build your own MCD spectrometer, historical development, computer interfacing . . . topics are limited only by your imagination.

Do you have an idea for a column? Are you itching to write about your area of knowledge? If so, touch base with me before you begin — it may save time to know that your own idea may already be in the works (see my address at the end of this column). And, of course, comments and constructive criticism are appreciated.

David W. Ball
Contributing Editor

What better way to inaugurate a new column in a spectroscopy magazine than to discuss the nature of light?

Under most conditions, light acts as a wave. According to Maxwell's equations, light is composed of oscillating electric and magnetic fields that pass through space at a certain constant velocity, c . The electric fields and magnetic fields are perpendicular to each other, and both are perpendicular to the direction of travel (1) (see Figure 1). The electric and magnetic fields have specific directions as well as magnitudes, and so are properly thought of as vectors. It is interesting to note that two aspects of light have particle-like behavior: its energy (a fact deduced by Max Planck) and its momentum (first observed by Arthur Compton in 1923).

Like anything that acts as a wave, the behavior of light can be

described by a mathematical equation. Perhaps the simplest way to describe the magnitude of the electric (E) and magnetic fields (M) is to use a general equation in terms of the sine function:

$$E = A_e \sin\left(\frac{2\pi z}{\lambda} - 2\pi\nu t\right) \quad [1]$$

$$M = A_m \sin\left(\frac{2\pi z}{\lambda} - 2\pi\nu t\right) \quad [2]$$

where A_e and A_m are the amplitudes of the electric and magnetic fields, respectively; λ is the wavelength of the light; and ν is the frequency of the light. The variable z represents the position along the propagation axis (where we assume that the light is moving along the arbitrarily designated z axis), and t is time (that is, the field varies in time). The existence of another (usually) constant term *inside* the sine function implies that the magnitudes of the

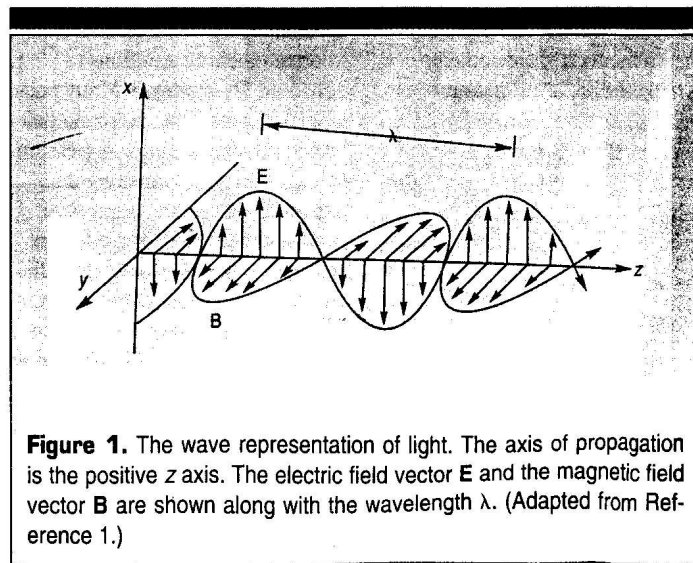


Figure 1. The wave representation of light. The axis of propagation is the positive z axis. The electric field vector E and the magnetic field vector B are shown along with the wavelength λ . (Adapted from Reference 1.)

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electric and magnetic vectors are not zero when z and t equal zero; we refer to this as a *nonzero phase*.

Theoretically, the ratio of the magnitudes A_e/A_m equals c , so the electric field has a much larger amplitude than the magnetic field. Equations 1 and 2 relate how the amplitude of the electric and magnetic fields vary with time t and distance z .

Typically, absorption and emission spectroscopy depend on an ability to measure the amplitude of the light waves, because for light waves, amplitude is related to intensity. (For classical waves, amplitude is related to energy; Planck deduced that the energy of light was related to frequency. All forms of spectroscopy require an ability to differentiate between the differing energies of light.)

The above equations do not address the vector property of the electric and magnetic fields; in fact, the equations are more properly written as

$$\mathbf{E} = \mathbf{A}_e \sin\left(\frac{2\pi z}{\lambda} - 2\pi\nu t\right) \quad [3]$$

$$\mathbf{M} = \mathbf{A}_m \sin\left(\frac{2\pi z}{\lambda} - 2\pi\nu t\right) \quad [4]$$

where A_e and A_m are vector amplitudes and indicate the specific direction of the fields.

The vector amplitudes are very important because certain specialized forms of spectroscopy depend on the exact direction of the fields; that is, certain techniques are more dependent on the direction of the field vector than on its magnitude. That is polarization spectroscopy. Because propagation is along the z axis and the fields are perpendicular to the z axis, the vector amplitudes can only exist in the x and y directions; hence, the vector amplitudes can be written generally as

$$\mathbf{A} = A\boldsymbol{\pi} = A(\pi_x\mathbf{i} + \pi_y\mathbf{j}) \quad [5]$$

where \mathbf{A} represents either the electric or magnetic amplitude. A is the scalar value of the amplitude, and $\boldsymbol{\pi}$ is a unit polarization vector, possibly complex, that describes the polarization properties of the light. The terms \mathbf{i} and \mathbf{j} are unit vectors in the x and y directions, and π_x and π_y are their relative magnitudes; the only constraint is that

$$|\pi_x|^2 + |\pi_y|^2 = 1 \quad [6]$$

The relative magnitudes of the \mathbf{i} and \mathbf{j} vector in \mathbf{A} determine the polarization of the light. Let us consider the electric vector of a set of light waves (which is most common, given its larger magnitude). If each light wave has its own characteristic values of π_1 and π_2 , it has no preferential vector direction, and the light is considered *unpolarized*. If for all waves $\pi_1 = 1$ and $\pi_2 = 0$, the amplitude vector would exist only in the x dimension:

$$\mathbf{A} = A\mathbf{i} \quad [7]$$

We would speak of this light as being polarized in the x direction. Because all waves are lined up in the same direction, we can also refer to this as *linear polarization*. Light waves can also be polarized in the y direction, which would correspond to $\pi_1 = 0$ and $\pi_2 = 1$. Z -polarized light is not defined because the z direction is usually considered the direction of propagation.

Finally, consider what would happen if $\pi_1 = 1/\sqrt{2}$ and $\pi_2 = i/\sqrt{2}$, where i is the square root of -1 . In this case, the polarization vector $\boldsymbol{\pi}$ becomes

$$\boldsymbol{\pi} = \left(\frac{1}{\sqrt{2}}\mathbf{i} + i\frac{1}{\sqrt{2}}\mathbf{j}\right) \quad [8]$$

(Do not confuse the two i 's in equation 8!) The net result of this is to make the propagation vector a corkscrew or helical shape, which in a right-handed coordinate system is considered a left-handed helix. Light having this polarization vector is called *left*

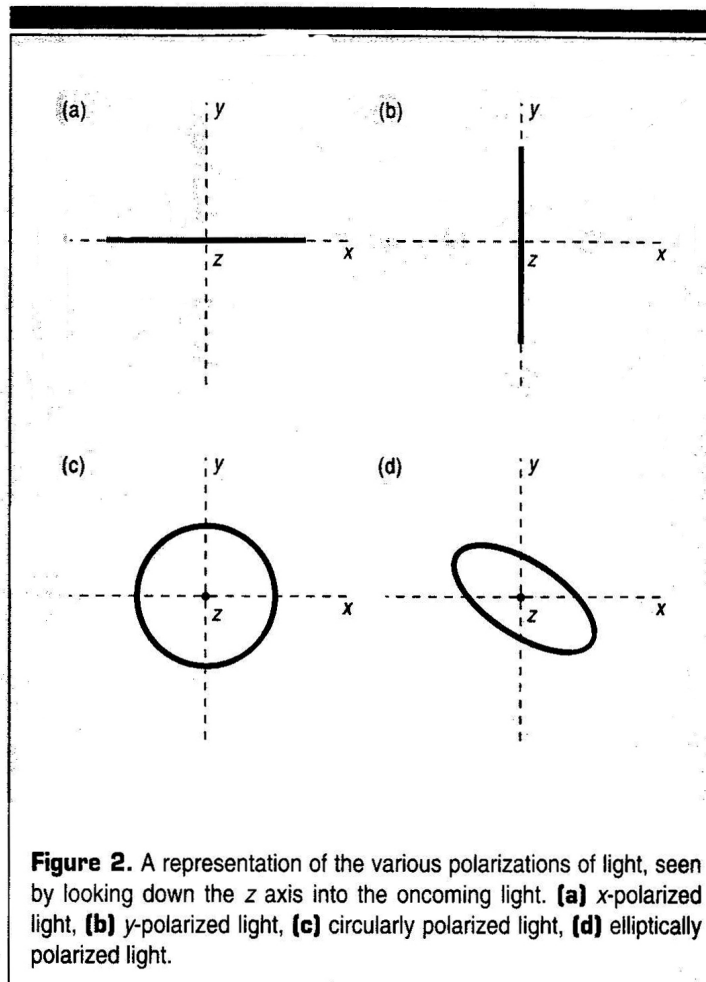


Figure 2. A representation of the various polarizations of light, seen by looking down the z axis into the oncoming light. **(a)** x -polarized light, **(b)** y -polarized light, **(c)** circularly polarized light, **(d)** elliptically polarized light.

circular polarized light. If the two summed terms in equation 8 are subtracted instead of added, the light becomes *right circular polarized* light. If π_1 and π_2 have different but constant values, subject to equation 6, the wave is called *elliptically polarized*. The various polarizations are illustrated in Figure 2. For Figure 2(c) and (d), the specific polarization can be either clockwise (right circularly/elliptically polarized) or counterclockwise (left circularly/elliptically polarized).

All of these properties of light waves — frequency, wavelength, phase, amplitude, intensity, energy, polarization — are of interest to spectroscopists. When light interacts with matter, one or more of these properties of the light wave changes. If none of them changed, then spectroscopy wouldn't be possible. As such, it is important that spec-

troscopists realize which properties of light waves they are altering in order to have a better understanding of the spectroscopic technique.

REFERENCE

- (1) I.N. Levine, *Molecular Spectroscopy* (John Wiley & Sons, New York, 1975).

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