The Photon as Birotation

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1 Introduction

In an earlier paper,[1] I have discussed some of the conditions under which a scalar motion manifests in the conventional spatial reference system, and shown that the simple harmonic motion (SHM) of the photon is really a birotation. While it is clear that a SHM underlies the photon from the phenomena of interference and diffraction, the genesis of SHM, given only uniform speed (as in scalar motion), is not possible except through rotation. In a subsequent paper,[2] I have elaborated on the characteristics of rotation and birotation, and shown how they result in observed phenomena, like circular polarization and angular momentum of photons.

In the present paper, several other characteristics of the photon phenomena that demonstrate, directly or otherwise, that the photon is basically a birotation are considered.

2 The Angular Momentum of Photons

We have seen[1] that the photon is comprised of two equal and opposite rotations about an axis, with the axis being, normally, in the direction of translation of the photon. The total energy, E, of the photon is the sum of the energy of translation, T, and the internal energy of rotation, R. In the absence of any biasing factor, one can see that E is equally partitioned into T and R. Let

      m = apparent mass of each component of the photon
      I = moment of inertia of each component of the photon
      ±ω = angular velocities of either component
      ħ = Planck's constant, h, divided by 2π
      λ = wavelength of the photon
      v = frequency of the photon = ω / 2π
      c = the speed of light = λ·v

Then

$$T = R = \frac{1}{2}E = \frac{1}{2}\hbar\,\omega \tag{1}$$

Considering both component rotations:

$$T = 2\left(\frac{1}{2}m c^2\right) = \frac{1}{2}\hbar\,\omega$$
$$or$$
$$m = \hbar\,\frac{\omega}{2 c^2} \tag{2}$$

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1 K.V. K. Nehru, "The Law of Conservation of Direction," *Reciprocity* XVIII (3), (Autumn, 1989), pp. 3-6.
2 K.V. K. Nehru, "On the Nature of Rotation and Birotation," *Reciprocity* XX (1), (Spring, 1991), pp. 8-12.

 Rev. 13

$$R = 2\left(\frac{1}{2}I\omega^2\right) = \frac{1}{2}\hbar\,\omega$$
or
$$I = \frac{\hbar}{2\omega}$$

(3)

Turning now to angular momentum, ζ, of each component rotation, we obtain using Equation (3)

$$\zeta = I\omega = \pm\frac{1}{2}\hbar$$

(4)

The $\pm$ sign occurs since ω could be $\pm$. The angular momentum of the photon itself works out to be

$$L = \pm\hbar \quad or \quad 0$$

(5)

since the two component rotations could either be parallel ($+\zeta$ $+\zeta$ or $-\zeta$ $-\zeta$) or antiparallel ($+\zeta$ $-\zeta$ or $-\zeta$ $+\zeta$). It might be noted that L is independent of ω and turns out to be the same for photons of all frequencies. This agrees with experimental observations.

3 The Doppler Shift

R. A. Waldron[3] extends the above analysis to the calculation of Doppler shifts. Suppose a photon of frequency v_0 was emitted by a source that is stationary with respect to the observer, then

$$E_0 = h v_0 = T + R = mc^2 + mc^2 = 2\,mc^2$$

(6)

since T = R.

However, if the observer is approaching the source with a velocity v, then the translational energy would be 2 [½m ($c + v$)²] instead of 2 (½mc^2), while the rotational energy remains unchanged at $I\omega^2 = mc^2$. The measuring apparatus absorbs this energy, but this *cannot* be distinguished from the effect of absorbing a photon of frequency v such that

$$E = h v = m(c+v)^2 + mc^2$$
$$= 2\,mc^2\left(1 + \frac{v}{c} + \frac{1}{2}\frac{v^2}{c^2}\right)$$

Substituting from Equation (6) in the above and writing $v/c = \beta$, we have

$$\frac{v}{v_0} = 1 + \beta + \frac{1}{2}\beta^2$$

(7)

Changing frequencies to wavelengths, we have the Doppler shift formula

$$\frac{\lambda}{\lambda_0} = \left(1 + \beta + \frac{1}{2}\beta^2\right)^{-1} = 1 - \beta + \frac{1}{2}\beta^2 - \frac{1}{4}\beta^4 + ...$$

(8)

which agrees well with the orthodox Doppler formula

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3   Waldron, R. A., "The Spinning Photon," *Speculations in Science and Technology,* Volume 5, Number 2, (1983), pp. 171-181.

$$\frac{\lambda}{\lambda_0} = \left(\frac{1-\beta}{1+\beta}\right)^{1/2} = 1 - \beta + \frac{1}{2}\beta^2 - \frac{1}{2}\beta^3 + \frac{3}{8}\beta^4 - \dots \qquad (9)$$

(since β is usually small, terms of order greater than 2 could be ignored).

4 Dispersion

In ordinary refraction, a light beam incident on a medium at an angle i, changes direction and gets refracted at an angle r in the medium. This change in direction could be shown as being due to the reduction in the speed of light from c to v in the medium, and that the following relation holds good:

$$\frac{\sin(i)}{\sin(r)} = \frac{c}{v} = n \qquad (10)$$

This ratio n is called the index of refraction. The fall in speed is, of course, due to the additional time involved in the net time displacement of the material medium through which the photon traverses. At this juncture we would also like to note that, for a given substance, the refractive index n increases as a power function of the frequency of light, which implies that the fall in speed on entering the medium is more for higher frequencies. This, of course, results in the phenomenon of dispersion, which is defined as the change in speed of light in a medium that is engendered by a change in wavelength or frequency of the light. Larson has computed the refractive index and the dispersion coefficient of several substances from the first principles of the Reciprocal System.[4]

The relation between the refractive index n of a medium and the frequency v could be derived from the theory we have been developing as follows. On entering the medium, the photon is located in the time displacement of the atom, instead of the space unit of the outward progression; rather, it is the atom, which has been moving inward in space, enters the photon, the latter being stationary with regard to the natural reference system. Consequent to this, the datum (initial) level from which the photon's apparent mass is reckoned gets altered.

It might be noticed that we have been calling m the apparent mass of the photon. Since mass is three-dimensional inverse speed, whereas the photon is only a one-dimensional (rotational) speed, the photon does not have a true mass. However, it does have intrinsic angular momentum, since the photon is rotation *per se*, and this manifests as an apparent mass, given by

$$m = I\frac{\omega^2}{c^2} \qquad (11)$$

We may truly call it "spin mass." The reason why the translational energy of the photon equals its rotational energy (Equation (1)) should now be obvious,

$$T = m c^2 = \left(I\frac{\omega^2}{c^2}\right)c^2 = I\omega^2 = R$$

The apparent mass of the photon is entirely spin mass.

Let ω_1, be the rotational speed of the atom of the medium. The reference level for the rotational energy of the photon on entering the atom gets changed since it must now be reckoned from the level of the

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4   Larson, D. B., *The Structure of the Physical Universe*, (North Pacific Publishers, Portland, OR, 1959), pp. 125-131.

atomic rotation, and not that of free space. Consequently, the change in rotational energy could be expressed as:

$$I\omega^2 - I\omega_1^2 \tag{12}$$

The introduction of the new datum level for rotation has, of course, a corresponding effect of changing the datum level of the spin mass. This we express by writing (using Equation (11)):

$$m_1 = I\frac{\omega_1^2}{c^2} \tag{13}$$

where m_1 is the mass equivalent of the datum shift of rotation.

In the general situation, a unit of the apparent mass of the photon need not be equal in (natural) magnitude to a unit of the apparent mass pertaining to atomic rotation, since the latter has a different reference point and is contingent on the chemical composition and the crystal structure. This engenders a scale difference between the two. Let this scale factor be f. Then m_1 units of the apparent mass from the point of view of the atomic rotational system are equivalent to $f·m_1$, units from the point of view of the photon rotational system. Thus, the apparent mass of the photon, as reckoned from the atomic system in which it is now located, turns out to be:

$$m - f\,m_1 \tag{14}$$

With the new initial levels in the medium, the speed of propagation readjusts itself such that the rotational and the translational energies of the photon become once again equal, with reference to these new initial levels. Thus:

$$I\omega^2 - I\omega_1^2 = (m - f\,m_1)v^2 \tag{15}$$

where v is the speed of light in the medium. Substituting from Equations (11) and (13), and dividing throughout by I:

$$\omega^2 - \omega_1^2 = (\omega^2 - f\,\omega_1^2)\frac{v^2}{c^2}$$

or

$$\frac{c^2}{v^2} = \frac{\omega^2 - f\,\omega_1^2}{\omega^2 - \omega_1^2} = 1 + \frac{(1-f)\omega_1^2}{\omega^2 - \omega_1^2} \tag{16}$$

Let

$$a = \frac{1}{f-1} \quad and \quad b = 4\pi^2\frac{a}{\omega_1^2} \tag{17}$$

Since $c/v = n$, we finally arrive at

$$n^2 = 1 + \frac{1}{a - bv^2} \tag{18}$$

It might be noted that the relation derived from the conventional electromagnetic theory[5] is identical to this. Comparison with data shows that the equation is quite accurate (correlation coefficient > 0.999).

In the case where there exists more than one rotation ω_1 in the medium, we proceed as follows. Let n_1 be the refractive index calculated on the basis of a single atomic rotation ω_1 (as though it exists alone) and let there be r such different rotations. It can be seen that the overall refractive index n_0 is the R.M.S. (root mean square) value of n_1. In other words

$$n_0^2 = \sum_{i=1}^{r} p_i n_i^2 \tag{19}$$

where p_i is the proportion of each ω_i among the total number of rotations, such that

$$\sum_{i=1}^{r} p_i = 1 \tag{20}$$

This is because the quantity n^2 ($= c^2/v^2$), being the square of the inverse speed in natural units, actually represents the time region equivalent of energy (remembering the second power relation pertaining to the time region). Consequently, Equation (19) gives simply the average time region energy, so that n_0 becomes the effective refractive index.

4.1   Anomalous Dispersion

Any complete theory of dispersion must also account for the so-called anomalous dispersion. Normally, the refractive index increases with an increase in frequency, but beyond some sufficiently high frequency, it is found that the refractive index becomes abnormally low. A prism made of an alcoholic solution of fuchsine (an analine dye), for example, refracts violet light less than red, although red, orange, and yellow appear in the normal order. An examination of Equation (18) reveals that this would indeed be the case when the frequency v is very near the value $\sqrt{\dfrac{a+1}{b}}$, but greater than it.

5   Birefringence

This is the phenomenon of double refraction and is exhibited by optically anisotropic crystalline substances, some examples being Icelandic spar, quartz, ice, tourmaline, apatite, borax, mica, topaz, etc. If a beam of light is made to pass through such a substance, it has been found that it gives rise to two beams, one of which corresponds to the single beam which would have been transmitted, had a substance like glass been used. This beam is called the ordinary (O) beam; the other, the extraordinary (E) beam.

Now in ordinary refraction, n is found to be constant for all incident angles. This is true of the O beam in the phenomenon of birefringence. But the E beam is found to vary with direction, thus implying that the speed of the E beam is dependent on direction. In some crystals, the E beam travels faster, and in some others, slower than the O beam. Moreover it is also observed that the O and E beams are plane polarized, with their planes of vibration being perpendicular to each other.

This behavior could readily be understood if we remember the birotational basis of the photon. If a certain quantity of rotational motion in the form of a birotation B(-α,+α) occurs in the crystal structure

5   Robertson, J. K., *Introduction to Optics*, (Affiliated East-West Press, New Delhi, India, 1965), p. 307.

such that its axis is parallel to the E beam, and phase coincident with that of the photons of the E beam, then the component angular speeds, $-\omega$ and $+\omega$ of the photon get changed such that they become $-(\omega+\alpha)$ and $+(\omega+\alpha)$. This apparent increase in frequency (relative to the medium) brings forth a corresponding fall in the translational speed, as in dispersion, causing the E beam to travel slower than the O beam. In the case that the operating birotation B compounds with the photon component speeds as $-(\omega-\alpha)$ and $+(\omega-\alpha)$, the result would be that the E beam travels faster than the O beam.

It might be noted, in passing, that the supervening birotation B does not interact with the O beam as their respective planes of vibration do not coincide. It must be understood that the altered value of the E beam frequency within the medium is an effect of the change of the initial (datum) level (of rotation), and not an absolute change in the magnitude of ω. Consequently, on emerging from the medium, the photon frequency shows up as $\pm\omega$ only.

6 Rotary Polarization

6.1 Optically Active Substances

There is a class of optically active substances which have the property of rotating the plane of vibration of light as it traverses them. Some rotate the plane of vibration to the left, and others to the right, and are consequently classified as *laevo-rotatory* and *dextro-rotatory*, respectively. It has been found that the angle of rotation is proportional to the thickness traversed, and also to the first approximation of the square of the frequency.

The explanation of the phenomenon comes out naturally from the birotational nature of the photon. Let, as before, $-\omega$ and $+\omega$ be the angular speeds of the two components of the photon. As it traverses this type of substance, it encounters a rotation, say $R(+\alpha,+\alpha)$, pertaining to the molecules, and the component rotations get modified as $-(\omega-\alpha)$ and $+(\omega+\alpha)$. This decrease and increase in speed magnitudes of the two rotational components respectively engender corresponding changes in the speeds of propagation, as in dispersion. This phenomenon may aptly be called circular birefringence. This produces a phase difference between the two rotational components of the photon which is proportional to the thickness. The end result is the rotation of the plane of vibration of the photon.

From the theory we have been developing, the angle of rotation of the vibrational plane can easily be worked out as follows. Let $-(\omega-\alpha) = -\omega_1$ and $+(\omega+\alpha) = +\omega_2$. If t is the thickness of the medium, the time taken by the component ω_1 to traverse it is

$$\tau_1 = \frac{t}{v_1} = \frac{t}{c} n_1 \tag{21}$$

where v_1 and n_1, are the speeds of propagation, and the refractive index, respectively, of the component. Thus, the angle turned by this component during time τ_1 is

$$\theta_1 = \tau_1 \omega_1 = \frac{t}{c}\left(n_1 \omega_1\right) \tag{22}$$

Considering similarly the other component ω_2 of the photon, the net angle turned through by the vibration plane will be

$$\phi = \frac{\theta_2 - \theta_1}{2} = \frac{1}{2}\frac{t}{c}\left(n_2\omega_2 - n_1\omega_1\right) \tag{23}$$

since θ_1 and θ_2 are in opposite senses.

Changing from ω to v and adopting Equation (18) for n and expanding the right hand side in series, we arrive at the following result

$$\phi = \frac{1}{2}\frac{t}{c}\left(A + Bv^2 + Cv^4 + ...\right) \tag{24}$$

where the constants A, B, C, etc., are dependent on the material, and are functions of α, and the powers of v are all even. Both the dependence on t and v, of f are very accurately represented by Equation (24) as may be checked from observational values.

The parity of this rotatory polarization would be opposite to that of the above if the encountered rotation in the medium is R(-α,-α), instead of R(+α,+α). In this case, the photon component rotations would be respectively -(ω+α) and +(ω-α). It should also be noted that if the beam is reversed the original rotation (of the vibration plane) is annulled.

7   Rotation by Magnetic Field

It is also known that when some substances—many solids, liquids, and gases—traversed by a beam of plane polarized light are placed in a strong magnetic field, a rotation of the vibration plane occurs. The angle of rotation is found to be proportional to the strength of the magnetic field, and also the length of travel.

This is what is to be expected, since we know that the magnetic field is a two-dimensional rotational vibration. As explained earlier, this super-imposed rotation speeds up one component of the photon birotation, and slows down the other, resulting in the phase difference and consequent rotation of the vibration plane. The dependence on the field strength and the path length are likewise understandable. But what is not so readily apparent, is the result that if the beam is reversed, keeping the field direction the same, the sense of the rotation (of the vibration plane) will be opposite to the previous. So much so, that if a beam is reflected back and forth along the lines of force, the amount of rotation should be greater for the greater the number of reversals. This, of course, is exactly established experimentally.

8   Direct Measurement of the Photon's Angular Momentum

Elsewhere,[1] I had already mentioned how the angular momentum of photons could be directly measured. Richard Beth[6] had devised an ingenious experimental setup that directly detected and measured the effect. The heart of his apparatus consists of a circular half wave plate of quartz, hung by a fine filament and free to rotate. Beth contrives to pass a circularly polarized light beam through this plate twice, such that each time the beam passes, its circular polarization changes from CW to CCW, and thereby imparts to the disk, four times the angular momentum which would otherwise have been given, were the beam merely to be absorbed. Avoiding absorption also eliminates the problem of heating and pressure.

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6   Beth, R. A., "Mechanical Detection and Measurement of the Angular Momentum of Light," *Physical Review,* Volume 50 (July, 15, 1936), pp. 115-125.

9   The Zeeman Effect

When a light source is placed in a magnetic field, a single spectral line is replaced by a number of others. This separation of the spectral lines resulting from the action of a magnetic field on the source is called the Zeeman Effect. In the so-called normal Zeeman effect, when the direction of the light beam is perpendicular to the magnetic lines of force, instead of one spectral line, three are found; one with a wavelength the same as when the field is absent, a second with a wavelength slightly greater, and a third with a wavelength slightly less than the first. It is also found that all the three wavelengths are plane polarized, the vibration plane of the first line being along the lines of force, and that of the other two at right-angles to this direction. This is called the *transverse* Zeeman Effect.

On the other hand, if the direction of the field lines is parallel to the beam direction, we have the *longitudinal* Zeeman Effect. In this case, the original wavelength is replaced by two, one with a wavelength slightly greater, and the other with a wavelength slightly less than the normal; the beams being circularly polarized in opposite senses.
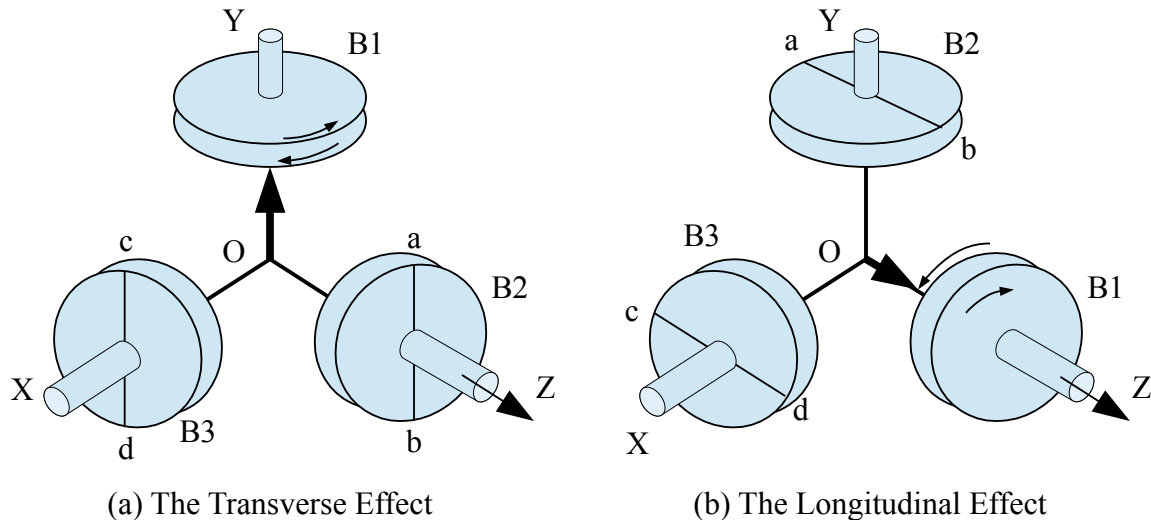

(a) The Transverse Effect   (b) The Longitudinal Effect

Figure 1: The Normal Zeeman Effect

Both these effects can be seen to follow directly from the birotational basis of photons. In Figure 1, the three mutually perpendicular dimensions of space are shown by the lines OX, OY, and OZ. The beam direction is OZ. The direction of the magnetic field is indicated by a thick arrow. The three possible orientations for the birotation in the system are shown by B1, B2, and B3. In Figure 1(a), the field direction is along OY (being perpendicular to OZ). One or the other of these three birotations can emit photons with corresponding rotational components. The magnetic field has two effects on the birotations. Firstly, since the magnetic motion is rotational, the two components of the birotation with the axis parallel to the field direction alter their speeds of rotation, $\pm\omega$, one component speeding up and the other slowing down. In Figure 1(a) this happens to B1. Because of this, these two circular motions of B1 appear as vibrations of two different frequencies with their plane of vibration perpendicular to the field direction. Secondly, in the case of the two birotations B2 and B3, the plane of vibration will be parallel to the field direction. Thus, the vibration emitted from these will be along ab or cd (Figure 1(a)); in either case, the vibration appears plane-polarized in the direction of the field and its frequency, ω, is unaltered.

In Figure 1(b), we have the field direction coincident with OZ. The first result is the change in the speeds of the components of B1, which, therefore, emit two circularly polarized photons, one in the CW direction, and the other in the CCW direction, with the respective frequencies slightly less and slightly more than ω. Since the vibration direction in the case of B2 and B3 (ab and cd in Figure 1(b)) is along the longitudinal direction OZ, no beam gets emitted in this direction. We therefore do not have a spectral line with the original frequency, ω, in this case.

10 Summary

We have endeavored to show that deduction from the postulates of the Reciprocal System leads one to the concept that the simple harmonic motion of the photon is really a birotation. In fact, the apparent mass of a photon is shown to arise from its angular momentum.

A complete theory of dispersion of light has been developed. Other phenomena considered to demonstrate the birotational nature of the photon were the Doppler shift, double refraction, rotatory polarization, circular polarization, and the Zeeman Effects.