Annales de la Fondation Louis de Broglie,
Vol. 6, n° 4, 1981

CAUSAL ASPECTS OF DIFFRACTION

par Georges N. CRAWFORD

Larmor Research, P.O. Box 12124
Seattle, Washington
98102 U.S.A.

(manuscrit reçu le 30 Janvier 1981)

Abstract : The analysis is directed at a causal description of photon diffraction, which is explained in terms of a wave exerting real forces and providing actual guidance to each quantum of energy. An undulatory ψ wave is associated with each photon, and this wave is assumed to imply more than an informative probability function, so that it actually carries real energy, in much the same way as does an electro-magnetic wave. Whether or not it may be in some way related to the electromagnetic wave is left as a matter of on-going concern.

A novel application of the concept of a minimum energy configuration is utilized ; that is, a system of energy quanta seeks out relative positions and orientations of least mutual energy, much as an electron seeks its Bohr radius as a position of least mutual *energy. Thus the concept implies more a guiding interaction of the ψ waves than an interfering cancellation of these waves. Similar concepts have been suggested by L. de Broglie and D. Bohm.*

Résumé : L'analyse suivante se rapporte à une interprétation causale du phénomène de diffraction des photons. Une onde ψ est associée à chaque photon, et cette onde est supposée être davantage qu'une fonction de probabilité, de telle sorte qu'elle transporterait réellement de l'énergie, similaire en cela à une onde électromagnétique.

Une nouvelle application du concept d'énergie minimum est invoquée, pour montrer comment un système de quanta, recherchant les positions et les orientations tendant à minimiser l'énergie mutuelle, obéira par cela même aux lois de la diffraction. De cette manière, ce concept donne aux ondes ψ davantage un rôle de guide, que d'ondes se détruisant par interférences. La relation exacte qui existerait entre ces ondes et le champ électromagnétique est laissée comme sujet d'études à venir. Des concepts similaires, quoique moins explicites, furent suggérés par L. de Broglie, D. Bohm et d'autres.

It is attempted in this paper to present a new interpretation of the diffraction phenomenon which will predict the behavior and the appropriate redistribution of photons according to the known experimental results.

The analysis presented here is directed at a causal description of photon diffraction, which is explained in terms of a wave exerting real forces and providing actual guidance to each quantum of energy. Thus, the concept implies more a guiding interaction of the ψ waves, than an interfering cancellation of these waves. Such concepts have been pioneered by L. de Broglie(1) (2).

We will adopt a program similar to that outlined by D. Bohm(3) in that an undulatory ψ wave will be associated with each photon, and we assume this wave to imply more than an informative probability function, so that it actually carries real energy, in much the same way as does an electro-magnetic wave. Whether or not it may be related to the electro-magnetic wave is left as a matter of on-going concern.

We shall utilize the concept of a minimum energy configuration ; that is, a system of energy quanta will seek out relative positions and orientations of least mutual energy, much as an electron seeks its Bohr radius as a position of least mutual energy.

This application of minimum energy requirements constitutes a subtle addition to the program of D. Bohm in that the concept DOES provide the "precise character of the quantum mechanical force exerted by the field" (4).

Although we shall hereafter refer to these quanta as photons, it will be understood that the analysis is intended to apply equally well to pairs of subparticles thereof. Therefore, let us introduce or refer to a photon-like subparticle, so that each photon may be visualized as being composed of two or more such phase coherent subparticles. Even though the present analysis will, for brevity, specify only a pair of interacting photons, the sub-photon concept allows the theory to apply either to many quanta or to a single quantum composed of several subquanta, the interactions being governed by the same laws in both cases.[1]

---

[1] The author perceives that the minimum energy concept will also support bosonian behavior and thus a need for the related studies and analysis is indicated.

Although the photon is not a single wavelength entity, the major portion of its energy lies within a very narrow band over which the present analysis is valid. Thus, we assume a central λ associated with the fundamental frequency of the photon. The remaining frequencies therefore merely serve to broaden the fringes.

Presume two parallel photon trajectories of identical wavelength travelling in the z direction and separated by the distance a (see Figure 1)[1]. Points of equal phase are joined by the line z_1z_2. Two perpendiculars to z_1z_2 are z_1q_1 and z_2q_2 which make an angle γ with the z axis. The associated undulating ψ wave will be taken as a mathematical representation of a real force field similar to the electro-magnetic field(5). Thus, assuming the wave to be transverse, then in a cylindrical system of coordinates (r,θ,z) the guidance field has ψ always in the r_1 or r_2 direction[2]. All other components are taken to be zero. Let A_1 and A_2 represent field functions whose strengths vary inversely as powers of r_1 or r_2, the transverse radial distances from their respective photon trajectory centres.

Thus at some fixed time, say t=0, the space variation of the fields for each of the two photons may be expressed as follows (see Figure 2, noting that $z_1 = z_0 + \Delta z$ and $z_2 = z_0 - \Delta z$, and the frequency $\nu = c/\lambda$),

$$\begin{aligned}\psi_1 &= A_1\exp(i\theta_1)\,\cos(\beta\, z_1)\\ \psi_2 &= A_2\exp(i\theta_2)\,\cos(\beta\, z_2)\end{aligned}\qquad (1)$$

where $\beta = 2\pi/\lambda$ and λ and c are the wavelength and the velocity of light. Also equations (1) are defined over the effective length L of the photons and become zero elsewhere.

The total field is,

$$\psi = \psi_1 + \psi_2 \qquad (2)$$

The energy density due to the guidance field is taken to be proportional to $|\psi|^2$; thus if μ is the constant of proportionality,

$$e = \mu\ |\psi|^2 \qquad (3)$$

and the total energy stored in the surrounding space is,

$$E = \int_0^\infty \int_{-L/2}^{L/2} \int_0^{2\pi} e\ r\ dr\ dz\ d\theta \qquad (4)$$

The integral extends from 0 to 2π, a distance L along the z axis and radially to infinity (regions in which either r_1 or $r_2 < r_0$ are to be avoided since the integral is not valid, r_0 being the smallest of radii, e.g. $r_0 \sim 10^{-13}$cm). Putting $M = \cos(\beta\, z_1)$ and $N = \cos(\beta\, z_2)$ and using equations (1) and (2) we have for the total field at any point p in the $z = z_0$ plane,

$$\psi = M\ A_1\exp(i\theta_1) + N\ A_2\exp(i\theta_2) \qquad (5)$$

and

$$|\psi|^2 = M^2A_1^2 + N^2A_2^2 + 2MNA_1A_2\cos(\theta_2-\theta_1) \qquad (6)$$

---

[1] At this point the photons would have already emerged from the two slits of a diffraction grating. We proceed here in reverse sequence to the usual analysis in that initially we consider the photon to have already been perturbed. This, however, adds a degree of generality.

[2] ψ may in general have a component along the θ direction, but to simplify the presentation and because the result is not altered the θ component has been deleted herein.

Let S represent the infinite r, θ surface, substitute equations (3) and (6) into (4) and integrate over S. In so doing, for brevity, we put

$$I_1 = \frac{1}{2}\mu\int_S A_1^2 \, ds$$

$$I_2 = \frac{1}{2}\mu\int_S A_2^2 \, ds$$

$$I_{12} = \frac{1}{2}\mu\int_S A_1 A_2 \cos(\theta_2-\theta_1) \, ds \qquad (7)$$

Assuming the two photons to be very nearly (within a few λ) at the same position along the z axis and also that the energy hν of each is predominately concentrated near the frequency ν, we can express the total energy due to the guidance field and associated with the photon. Thus,

$$E = I_1\int_{-L/2}^{L/2} M^2 \, dz + I_2\int_{-L/2}^{L/2} N^2 \, dz + I_{12}\int_{-L/2}^{L/2} M\,N \, dz \qquad (8)$$

Using the equivalent cosine expressions for M and N and integrating, we obtain

$$E = I_1 L/2 + I_2 L/2 + I_{12}\left(\cos^2(\beta\,\Delta z) - \sin^2(\beta\,\Delta z)\right)L/2 \qquad (9)$$

Now to find the minimum energy configuration, differentiation gives the result

$$\frac{dE}{d\gamma} = -LI_{12}\; 2\cos(\beta\,\Delta z)\,\sin(\beta\,\Delta z)\,\frac{d\Delta z}{d\gamma} = 0 \qquad (10)$$

Using the identity $2\cos(\beta\,\Delta z)\sin(\beta\,\Delta z) = \sin(2\beta\,\Delta z)$ and also the relationship from Figure 1, $\Delta z = (d/2)\sin\gamma$, we can express the condition as follows,

$$\sin\left(\frac{2\pi\, d}{\lambda}\sin\gamma\right) = 0 \text{ and } \sin\gamma = \frac{K\lambda}{2d} \quad K=0,1,2... \qquad (11)$$

So long as the integral I_{12} is finite and positive then K yields minimum energy conditions when even and a maximum condition if odd. Since the system seeks naturally its minimum energy configuration we admit only K = 2n as the definition of the preferred energy states, thus

$$\sin\gamma = n\,\lambda/d \qquad (12)$$

It is to be observed as indicated by the foregoing, that when perturbed, monochromatic photons or their constituent sub-quanta travelling parallel trajectories (or nearly so) will influence each other, so as to cause a mutual rotation of their velocity vectors, in unison, to one of the angles which satisfy equation (12) and which thereby results in a minimum mutual energy within the space between and surrounding their trajectories.

By way of visualization, as photons penetrate a diffraction grating they do not experience complete disassociation of their constituent sub-parts, but only a degree of deformation occurs which is corrected when the photon is regrouped or reformed on the far side of the grating, in accordance with equation (12).

This new concept of diffraction appears to occupy a middle position between relativity and quantum theory. For example, it follows that any slight difference in path length (phase difference) which arises between two coherent neighboring photon trajectories always gives rise to a path curvature in order that they establish an existence of minimum mutual energy, whether those paths be passing closely to the sun or emerging from a diffraction grating. Both these examples could thus be regarded as diffraction phenomena which are causal in nature in that photons tend to seek paths to establish minimum mutual energy of their de Broglie waves.

REFERENCES

(1) L. de Broglie, The Revolution in Physics, Routledge & Kegan, London (1954).

(2) L. de Broglie, Non-Linear Wave Mechanics, A Causal Interpretation, Elsevier Co., (1960).

(3) D. Bohm, Causality and Chance in Modern Physics, Univ. of Penn. Press, pp. 111-116 (1971).

(4) Ibid. p. 112.

(5) D. Bohm, Phy. Rev. 85, 2, p. 173 (1952).

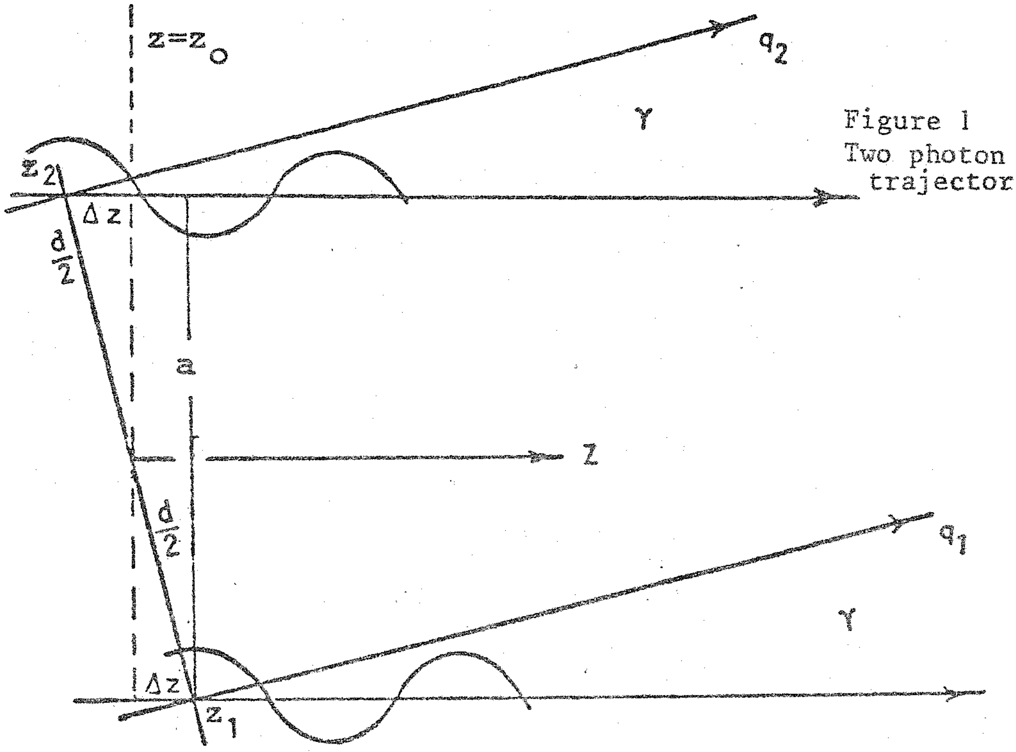

Figure 1
Two photon trajectories

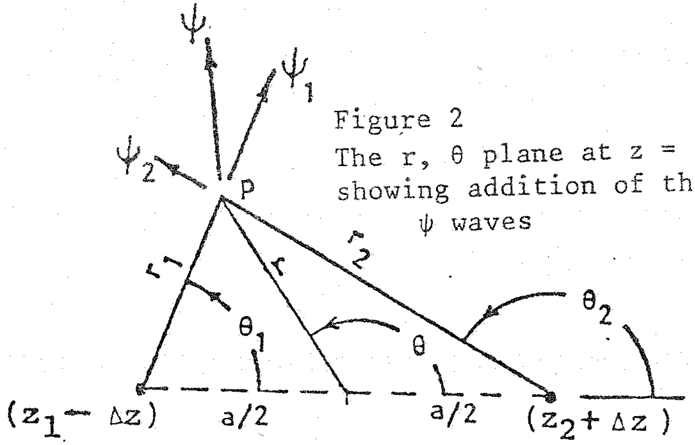

Figure 2
The r, θ plane at $z = z_0$ showing addition of the ψ waves