BOLETIN DEL INSTITUTO DE TONANTZINTLA, Vol. 2, No. 1, Junio 1976.

SOME INTERFERENCE EXPERIMENTS AND QUANTUM CONCEPTS II

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SUMARIO

Continuamos con nuestro intento de demostrar las razones de nuestra inconformidad con las interpretaciones de Mecánica Cuántica sobre los fenómenos de interferencia y difracción dadas por las Escuelas de "Copenhagen" y "Statistical". En este artículo proponemos que el principio de superposición se acepte como una realidad física, no como una construcción matemática proyectada para obtener resultados y se debe escudriñar hasta el último para averiguar sus límites en el reino Cuántico.

ABSTRACT

We continue our attempt to demonstrate the reasons for our disagreement with Quantum Mechanical interpretations of basic interference and diffraction phenomena given by both Copenhagen and Statistical Interpretation Schools. And we are proposing that the principle of superposition be understood as a physical reality rather than as a mathematical construction devised to arrive at results and should be pursued to the extreme to ascertain its limits in the Quantum realm.

I. *Introduction*

In a previous article (Roychoudhuri 1975a) we discussed a few two-beam interference experiments from the view point of an experimentalist to show "that there exist conceptual conflicts behind the usual text-book assumptions to explain the so-called wave-particle duality". In this follow-up paper we present some simple classical experimental results that are routinely produced in laboratories in some form or another with explanations direct from classical wave theory. But these results, as we shall see later, can be interpreted as the demonstration of the reality of the principle of superposition (interference). To put it differently, the effect of redistribution (or redirection in the propagation) of energy due to interference arises only when at least two similar physical entities carrying different physical information (phase, amplitude, etc.) are simultaneously present. Thus, when an interferometer or a grating is irradiated (i) with a single pulse of width narrower than its characteristic path-delay, or (ii) with a series of coherent narrow pulses of separation larger than the said path-delay, one does not observe customary stationary interference patterns (Roychoudhuri 1975b, c). All these are understood from simple classical real physical superposition (or classical causality).

Let us then define our methodology of thinking for this paper. We assume that the method of accumulation of knowledge is never direct. Every piece of our information is gathered in two stages of interaction or scattering between a minimum of three physical entities; the first stage of interaction is between the entities under study and the chosen "standard" (at least partially known), and the final stage of interaction is between the observing or detecting entity and one of the entities of the initial interaction. Thus any observation whatsoever forces all the three entities involved into new states and hence a complete description of past, present and future requires a complete knowledge of all the states in every detail correlated by an objective physical theory attempting to model nature. Until we can ascertain all the details, we can repeat similarly prepared experiments and then apply that knowledge to predict the future behavior of another similarly prepared system. Further, when the entities involved in a multistage interaction during an observation have space and time extension and are compound in the sense that they can carry more than one quantity of the same physical property (like phases), then the final information must constitute a superposition of all the similar information. Here we should emphasize that such superposition is real, physical and causal, i. e., the entities carrying the different information must be present in the same local region and must be present simultaneously for physical communication of information. We note in passing that an elementary particle to be elementary should not be able to carry more than one quantity of the same physical property at the same instant.

II. *Holographic Double-slit*

One of the most discussed problems in the explanation of phenomena of interference and diffraction by Quantum concepts is the double-slit pattern. [The very acceptance of the wave-concept for light was strongly established first by Young's (1802) principle of interference demonstrated by his famous double-slit pattern. For an accurate and lucid demonstration of double-slit patterns with light see Hecht and Zajac (1974).] From published books and literature, it appears that the majority of the Quantum physicists explain the origin of the double-slit pattern in one of the following two ways. First, the constituent "particle" of the wave (electron, photon, etc.) has extension and "interacts" with the extended periodic "potential" of the double-slit in some "mysterious" way (Feynman 1966) to produce the observed pattern. This is, probably, to "explain" the still controversial claim that even a single photon can produce interference (Mandel 1968, Dontsov and Baz 1967). This group also accepts that "the condition under which the interference pattern is produced forbids a determination of the slit through which the particle passes" (Merzbacher 1970) and the adherence of this group is generally to the Copenhagen Interpretation School (Stapp 1972). The second group generally belongs to Statistical Interpretation School (Ballentine 1970). Their explanation of the double-slit or grating pattern is that the grating "knows" its periodicity and acts "as a whole" to exchange momenta with the constituent "particles" of the wave and that diffraction is a process of scattering (Landé 1975). Before criticizing these interpretations we should like to mention that there are other Quantum physicists who are trying to develop a different mechanics (de la Peña and Cetto 1975, Phipps 1975, Boyer 1975) instead of just stretching the interpretation of the existing Quantum Mechanics.

The angular distribution of energy is different in the near-field (Fresnel) and the far-field (Fraunhofer) patterns. Neither of the above schools can explain how the trajectories of particles after passing through the grating change without hypothesizing the existence of a new long-range force between the grating and "particles" (Feyerabend 1968, 1969; Roychoudhuri and Cornejo 1975). It is also an observed fact that a second screen isolated from the double-slit but placed immediately after it, just covering one of the slits, gives rise to a single-slit pattern instead of a double-slit pattern. But by either school of interpretation, one should still see a double-slit pattern, maybe with reduced irradiance, since neither the "photons" nor the double slit should have a priori knowledge of the existence of a screen beyond the double-slit.

We want to demonstrate that the double-slit pattern arises simply due to real physical superposition of two similar physical enties each passing through one of two slits. The lateral separation of the two parts corresponds to two different bits of phase information at the region of real physical superposition giving rise to a new distribution of detectable energy. Then one must be able to demonstrate that each slit allows a part of the incident wave to pass through carrying the corresponding phase information.

Here one must recognize the experimental limitation of our detection devices for very high frequency electromagnetic radiation or "particles". They are without exception square-law detectors. They detect the square of the modulus of the incident complex amplitude and thus destroy our capability of ever recording the absolute phase. But, even so, we know that the relative phase can be recorded through interferometry that constitutes superposition of more than one wave. Further, using holographic interferometry (Gabor 1948, Smith 1969), one can even reproduce the complex amplitude information of any wavefront. If the complex amplitudes from the two slits are recorded separately but holographically with the help of the same reference beam, one can reproduce the two-slit pattern even after recording one slit at a time. Thus, the reality that a physical entity is passing through each slit can be demonstrated.

The conventional double-slit experimental set up is shown in Fig. 1a; Fig. 1b is a sketch of the resultant irradiance. The complex amplitudes at the plane of observation due to slits 1 and 2 are represented by

$$\psi_1 = a\, e^{i\phi_1} \text{ and } \psi_2 = a\, e^{i\phi_2} \qquad (1)$$

Then the resultant irradiance is,

$$|\psi_1 + \psi_2|^2 = 2a^2\,[1 + \cos\,(\phi_2 - \phi_1)]. \qquad (2)$$

The relative phase difference, $\phi_1 - \phi_2$, is the essential characteristc of the double-slit pattern. The central region of such a pattern is shown in Fig. 2a. But, if one records the square modulus of each of ψ_1 and ψ_2 the resultant pattern will be completely devoid of the double-slit characteristics,

$$|\psi_1|^2 + |\psi_2|^2 \neq |\psi_1 + \psi_2|^2. \qquad (3)$$

So, let us now introduce the holographic recording with a reference beam (Fig. 3) so that we can record and reconstruct the phase information. The steps are as follows (Smith 1969):

(a) Holographic recording.

$$|\psi_R + \psi_1|^2 = |\psi_R|^2 + |\psi_1|^2 + \psi_R^*\,\psi_1 + \psi_R\,\psi_1^* \qquad (4)$$

(b) Holographic development.

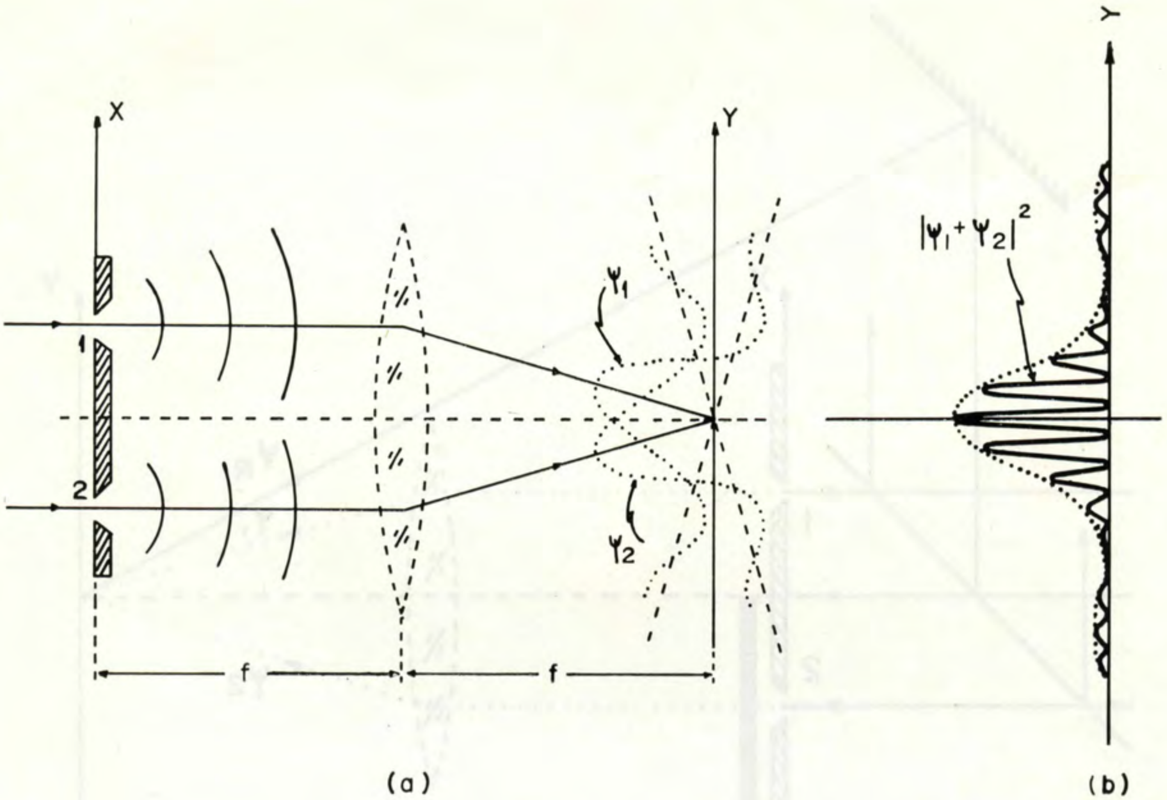

Fig. 1. *A conventional arrangement to obtain a Fraunhofer double-slit pattern.* (a) *X-double-slit plane: Y- Fraunhofer pattern plane; ψ_1 and ψ_2 are two single-slit patterns at the Y-plane due to slits 1 and 2.* (b) *The cosinusoidal double-slit patterns, $|\psi_1 + \psi_2|^2$.*

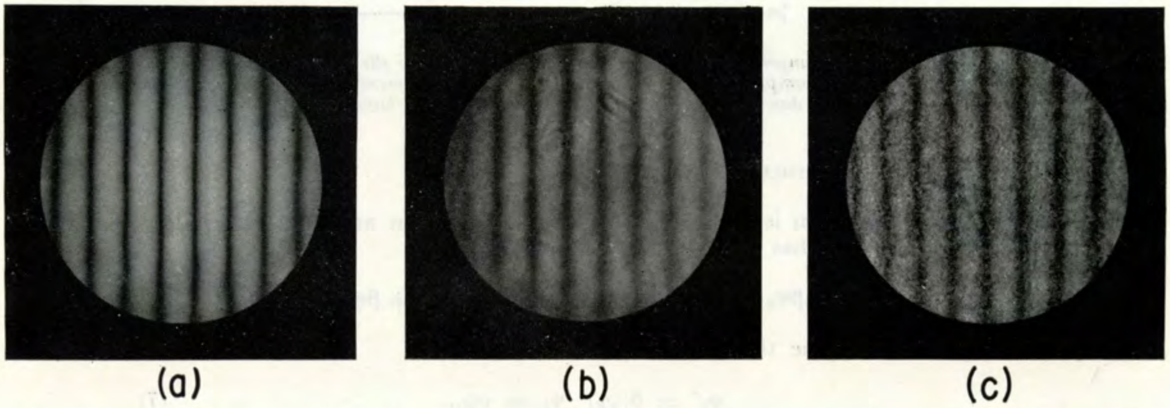

Fig. 2. *Photographs of the experimental cosinusoidal fringes of the central region of the Fraunhofer double-slit pattern.* (a) *Regular double-slit pattern recorded with the arrangement of Fig. 1.* (b) *Holographic double-slit pattern due to the same double-slit but after recording the single-slit patterns due to each slit separately.* (c) *Holographic double-slit pattern of the same double-slit where the single-slit pattern due to slit-1 was recorded and then reconstructed at the hologram plane (Y) while the other single-slit pattern due to slit-2 arrived at the Y-plane "live" from the X-plane (while slit-1 was closed). See text for details.*

This gives rise to a characteristic transmission of the hologram that is proportional to the recorded irradiance of Eq. (4),

$$t = \beta\,[|\psi_R|^2 + |\psi_1|^2 + \psi_R^*\,\psi_1 + \psi_R\,\psi_1^*], \tag{5}$$

where β is a constant.

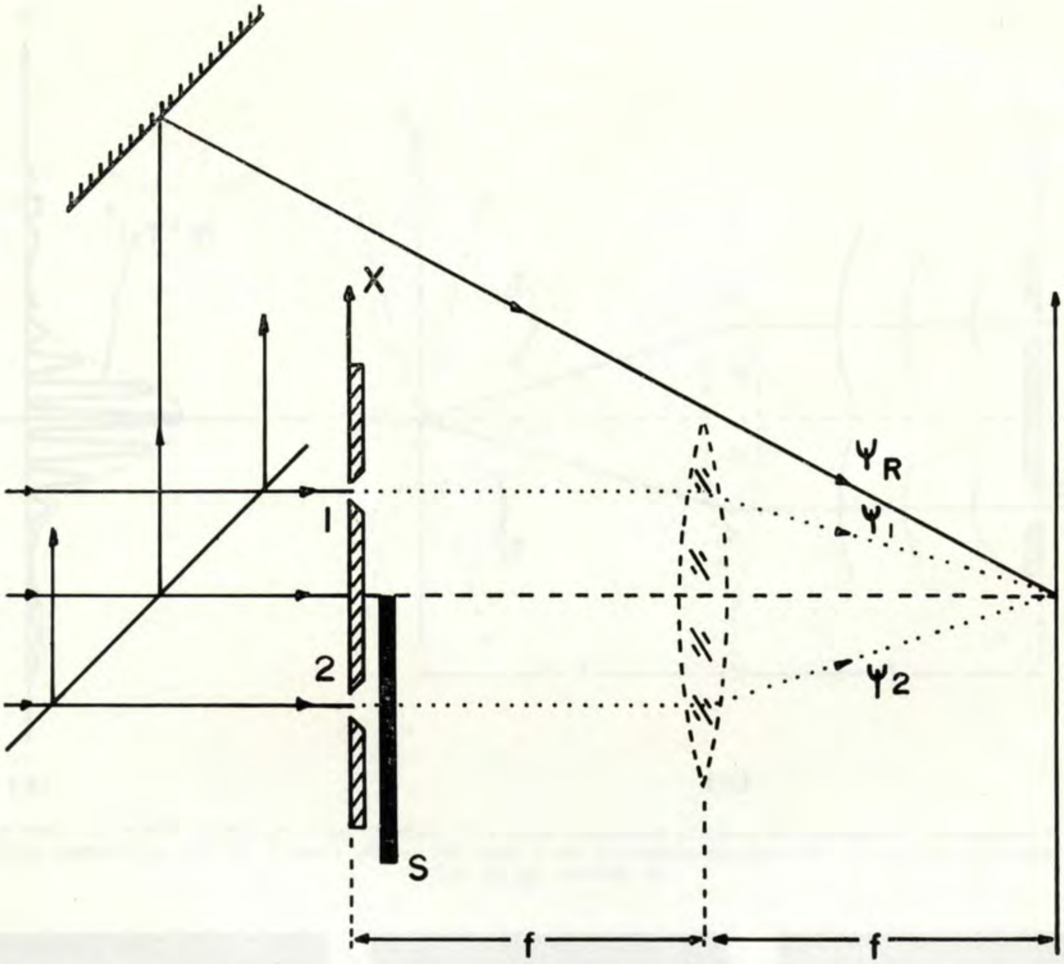

Fig. 3. *Holographic experimental arrangement to record the pattern due to one slit at a time and then to reproduce the conventional double-slit pattern in complete detail. ψ_R is the holographic reference beam and ψ_1 and ψ_2 are single-slit waves due to slits 1 and 2. Y is the plane of the hologram.*

(c) Holographic reconstruction.

The developed hologram is replaced in its original position and it is reilluminated with the same reference beam, ψ_R, that has a uniform amplitude,

$$t\psi_R = \beta\psi_R|\psi_R|^2 + \beta\psi_R|\psi_1|^2 + \beta|\psi_R|^2\,\psi_1 + \beta\psi_R{}^2\,\psi_1{}^*. \qquad (6)$$

β and $|\psi_R|^2$ being constants ,the third terms,

$$\psi_1' = \beta|\psi_R|^2\,\psi_1 \equiv c\psi_1, \qquad (7)$$

corresponds to the reconstruction of the original complex amplitude ψ_1. The wavefronts corresponding to other terms propagate in directions other than ψ_1 and hence can be physically separated from ψ_1.

Then a similar but separate recording of ψ_2 on the same hologram and corresponding reconstruction will produce

$$\psi_1' + \psi_2' = c\,(\psi_1 + \psi_2), \qquad (8)$$

that will give us the same pattern as that of Eq. (2), but with a multiplying constant. The proper experiment can be carried out as follows. One records ψ_1 using a screen S (Fig. 3) to cover slit-2. Then, changing the position of S, ψ_2 is recorded after covering slit-1. The reconstruction of the hologram, after covering both slits, gives rise to the same two-slit pattern (Fig. 2b) that one obtains directly from the two-slit system without any holography or screening (Fig. 2a). Thus the reality of ψ_1 and ψ_2 is established.

A variation of the above experiment goes as follows. First ψ_1 is stored in the hologram as in Fig. 3. Then slit-1 is kept closed and slit-2 is opened and simultaneously the hologram is reconstructed. If the hologram characteristic and illumination are so adjusted that the complex amplitude ψ_2 after passing through the hologram changes by a constant factor c to $c\psi_2$, then one has, because of holographic reconstruction,

$$c\psi_1 + c\psi_2 = c\,(\psi_1 + \psi_2). \tag{9}$$

This is the same as Eq. (8). Once again the two-beam pattern as shown in Fig. 2c is observed, which is similar to the patterns shown in Figs. 2a and 2b. Here we see that ψ_1 can be stored in one plane and ψ_2 can still be allowed to be generated from the original slit-2, again showing the real existence of both ψ_1 and ψ_2.

This holographic technique can be extended to prove the real existence of all the wavelets from every single slit of a grating using a suitable holographic material that can reconstruct many different wavefronts.

III. *Large Grating Illuminated by a Limited Wavefront*

The model of real physical superposition implies that interference phenomena are due to local "interaction". But this is categorically denied by both the schools we have mentioned. In fact d'Espagnat (1971) explicitly says, "the local effect of these waves is certainly not a correct hypothesis". Therefore, we are reviewing an elementary classical experiment of a large but finite size grating or a crystal illuminated by a wavefront of spatial size smaller than the diffractor (Fig. 4).

Let us take an ordinary grating of N slits each of width $2a$; the separation between the consecutive slits is $2b$,

$$g_N(x) = \left[\sum_{n=0}^{N-1} \delta(x - 2nb)\right] \oplus r(x/2a), \tag{10}$$

where $r(x/2a)$ is a rectangular function of width $2a$ representing each slit of the grating and $\oplus$ denotes convolution. The grating is illuminated by a plane wave, $w(x)$, of spatial width, say,

$$d \simeq m(2b), \tag{11}$$

where

$$m < N \tag{12}$$

So only a small area of the grating is illuminated (Fig. 4a). Mathematically, the combined effect of the grating and the illuminating wavefront is

$$t(x) = w(x) g_N(x). \tag{13}$$

Then the Fraunhofer pattern at the Y-plane is

$$T(y) = W(y) \oplus G_N(y), \tag{14}$$

where,

$$G_N(y) = e^{ikby\,(N-1)/f} \cdot \frac{\sin Nkby/f}{\sin kby/f} \cdot R(y) \tag{15}$$

where

$$R(y) = 2a\,\frac{\sin\,(kay/f)}{(kay/f)}\,. \tag{16}$$

If, as a particular example, we assume that $w(x)$ is a rectangular function of width $2a$ (that is, equal to the width of a single slit of the grating),

$$W(y) = 2a\,\frac{\sin\,(kay/f)}{(kay/f)} \equiv R(y), \tag{17}$$

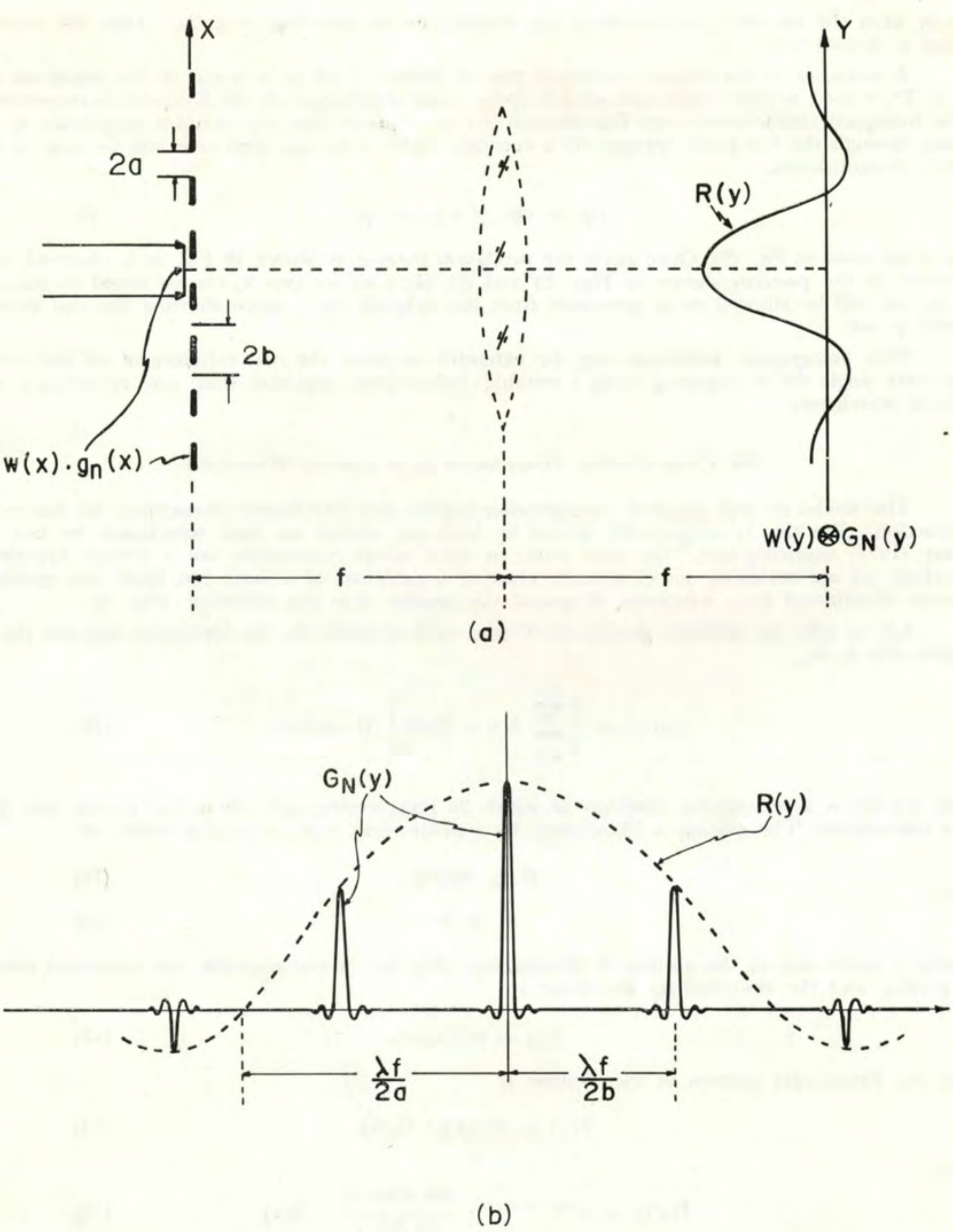

Fig. 4. *Diffraction experiment with a large grating illuminated by a space limited wave-front.* (a) *The large grating* $g_N(x)$ *is illuminated by a small wavefront* $w(x)$ *at the X-plane that encompasses only a single slit. Then the observed pattern* $R(y)$ *at the Y-plane is due to a single slit.* (b) *If the grating acts "as a whole", then the pattern should be a convolution of the single slit pattern* $R(y)$ *with the N-line grating pattern* $G_N(y)$.

where f is the focal length of the lens used to obtain the Fraunhofer pattern. Then the resultant pattern, according to Eq. (14), should be given by the convolution of the dashed curve of Fig. 4b with the grating spectra denoted by the solid curve. But we know that the result will be a simple single slit pattern because the wavefront that passed through the grating encompassed only a single slit of the grating. Even though $G_N(y)$ exists mathematically, physically it does not, in spite of the fact that the Statisitcal Interpretation School claims that the grating exchanges momenta with the "particles" "as packet associated with a particle, irrespective of

a whole". What physically exists is $R(y)$ because the wave has passed through one $r(x)$ (single slit) and has brought oniy that information to the Y-plane. To predict this observed result, the Copenhagen Interpretation School would have to introduce a new hypothesis to the effect that the size of the wave ~~Figure 5 shows a Fraunhofer pattern that~~ its other physical properties, depends upon the particular instrument that produces it.

Figure 5 shows a Fraunhofer pattern that is characteristic of an 8-line grating (there are six secondary maxima) even though the grating used has 21 lines. This was produced by using a wavefront whose spatial extension was such that it could illuminate only 8 lines of the grating. We shall cite a somewhat similar experiment with a crystalline substance. A transparent solid body of CaF_2, roughly 1 cm^3, made of randomly oriented crystallites of average size 200 micron was illuminated with a focussed laser beam of 20 micron diameter. Brillouin spectra characteristic of a pure single crystal was obtained (Brody, Roychoudhuri and Hercher 1973). If the "photons" did exchange momenta with the entire solid block of crystallites, no Brillouin lines could have been clearly visible.

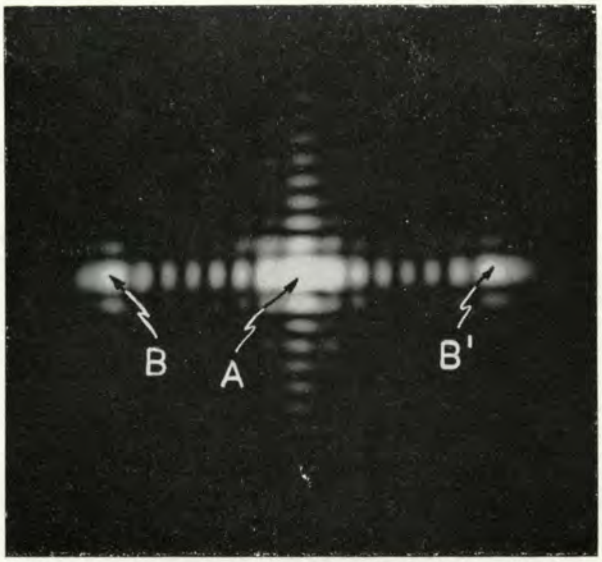

Fig. 5. *A photographic record of the central region of a 21-line grating illuminated by a space-limited wavefront that encompassed only 8 lines of the grating. The pattern shows 8-line, rather than 21-line, characteristics. There are 6 secondary maxima between two consecutive major maxima (AB or AB').*

IV. *Discussion*

We have attempted to emphasize that the "explanations" given by Quantum physicists for interference and diffraction phenomena are incomplete and also have built-in contradictions. The experiments with light we have presented are routinely carried out in laboratories in some form or another. But we are not aware whether anybody has done precisely similar experiments with particles like electrons. While we are eagerly looking forward to see experiments with electron beams in the hope that a very critical investigation might show some distinction between electromagnetic waves and particle waves in the realm of interference and diffraciton phenomena, we do believe that the essential results will be very similar to that due to electromagnetic waves. This is because in the basic single and multiple slit experiments with electron beams the electrons show very similar diffraction characteristics to those of light (Jönsson 1974, Merli et al. 1974).

The arguments we present here against the established interpretations of interference are based on elementary classical physics without any new theory. We are proposing that rejecting the classical principle of real physical superposition is premature; that a thorough investigation is necessary to ascertain if a limit exists beyond which this principle does not apply. We believe that this is directly related with the problem of reality that is extensively discussed in the literature of the philosophy of Quantum Mechanics (Bunge 1967, d'Espagnat 1971, Jammer 1974). A Quantum physical model should take into account the details of the observed classical interference effects mentioned here and in other papers (Roychoudhuri 1975a, Roychoudhuri and Cornejo 1975) and should be able to sucessfully explain them.

One of us (C. R.) would like to acknowledge some inspiring discussions with M. Bunge, L.

de la Peña, A. M. Cetto and T. A. Brody. Two of us (R. M. and M. C.) would like to acknowledge the scholarship support by CONACYT.

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