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What are the physical processes behind the evolution of spatial coherence out of incoherent light and particle beams?

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Abstract

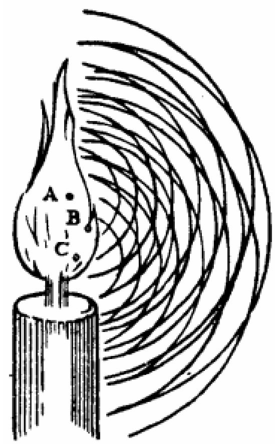
- Van Cittert-Zernike theorem, using Huygens-Fresnel diffraction model, provides us with an excellent physical-process behind the ***emergence of increased spatial coherence*** (phase-correlation) out of incoherent spontaneous emissions due to propagation of Huygens wavelets. ***Its prediction of π-phase shift in the correlation function has also been experimentally verified by Thompson and Wolf.*** We re-visit this experiment to underscore its significance.
- Then, we propose that similar experiments be carried out with Rb-beam to explore the similarities and differences between light and particle beam diffraction properties.
- This re-visiting is needed because we believe that the wave-particle duality continues to represent our deeper ignorance. The duality concept has not given us any new knowledge towards unifying waves and particles.

Foundation of optical Diffraction: Huygens Postulates & Non-Interaction of Waves (NIW)

Christiaan Huygens

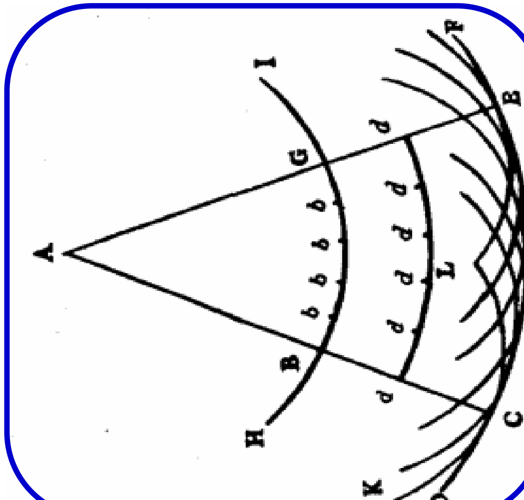
Promoter of interaction process driven thinking.

1629–1695



1. Secondary Wavelets emerge out of every point of the wavefronts.
2. "Unhindered propagation" means Non-Interaction of Waves (*NIW*).
There is no "interference between" different light beams in the absence of interaction with frequency-resonant materials.

".......how visible rays, coming from an infinitude of diverse places, cross one another without hindering one another in any way." From p.2 in "Treatise on Light" by Huygens (1678). Free download: http://www.gutenberg.org/ebooks/14725



Recognition of the physical reality of NIW is of critical importance in diffraction theory and optical engineering

Secondary wavelets, or overlapping light beams, while propagating unperturbed, in intermediate planes, do not re-organize their energies in the absence of optically interacting materials, with polarizability χ.

Generalized SP on a detector:

$$\Psi_{total} = \sum_n \chi_n(\nu_n) E_n(\nu) \equiv \sum_n \chi_n(\nu_n) a_n(t) \exp(i 2\pi \nu_n t)$$

H-F Integral on a detector:

$$\Psi(P_0) = \frac{-i}{\lambda} \iint_\Sigma \chi(\nu) U(P_1) \frac{\exp(ikr_{01})}{r_{01}} \cos\theta \; ds$$

On a specific detector plane, the Superposition Principle (SP), or the H-F integral should be presented as the sum-total dipolar stimulation induced by all the *LOCAL* fields $\sum_n \chi_n(\nu_n) E_n(\nu)$. *This linear SP is unobservable!* The detecting dipole executes the non-linear square modulus operation and absorbs the necessary quantum of energy $h\nu \sim \left| \sum_n \chi_n(\nu_n) E_n(\nu) \right|^2$. This non-linear *Superposition Effect (SE) is observable* through released photoelectrons or some molecular transformation. So, the miniscule size of the quantum entities indicate that SE is a CAUSAL & LOCAL effect.

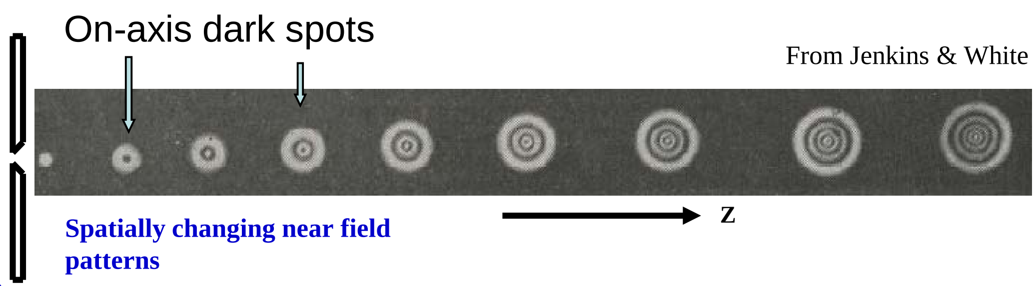
What is the origin of dark fringes in optical diffraction?

Physics: Zero E-vector stimulation of local detector as per H-F integral.

Dark fringe is non-absorption of energy by the detecting dipole; not due to “non-arrival of “photons”. E-field is present over the entire detecting plane. When the resultant dipolar stimulation is zero, it cannot absorb energy out of the stimulating fields.

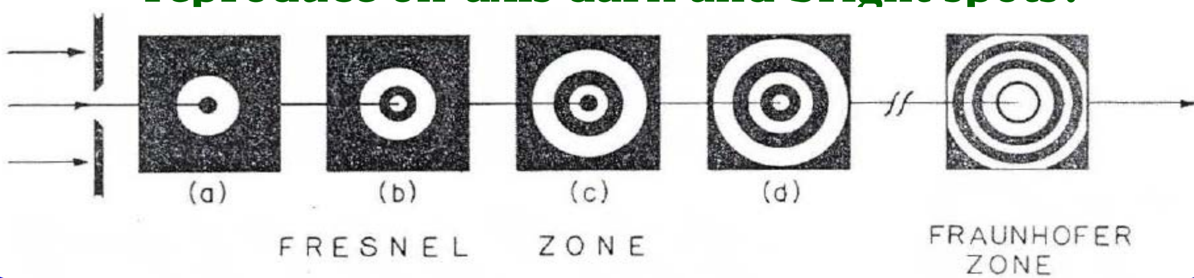
On-axis dipolar stimulation is zero at the dark spots.

$$I(P_n) = |\chi U(P_n)|^2 = \frac{1}{\lambda^2}\left|\iint_\Sigma \chi U(P_{screen}) \frac{\exp(ikr_n)}{r_n} \cos\theta \, ds\right|^2$$



Are the optical and particle diffraction phenomena fundamentally different?

Can near-filed particle scattering experiment reproduce on-axis dark and bright spots?

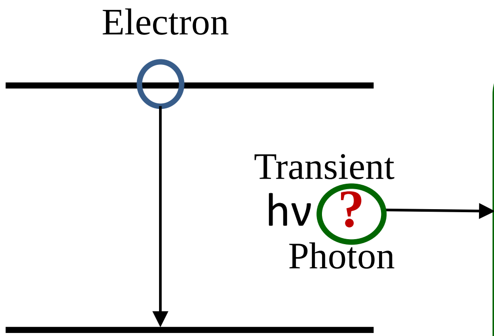


C. Roychoudhuri & A. Cornejo, Bol. Inst. Ton. Vol.1, No.4 , pp.245-6 (1975)

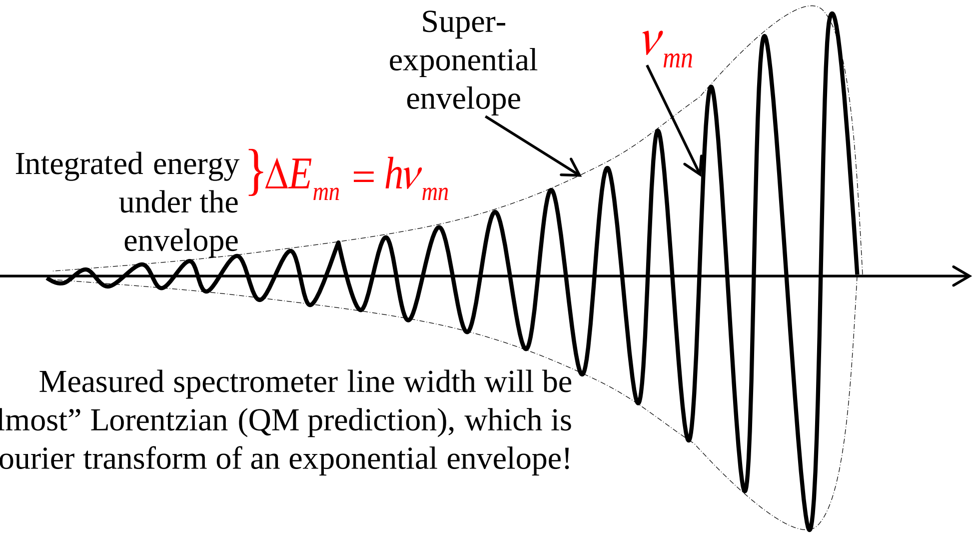
For EM waves, HYBRID PHOTON is a logical explanation

What could be the logical physical model for particle diffraction & phase evolution?

EMISSION:

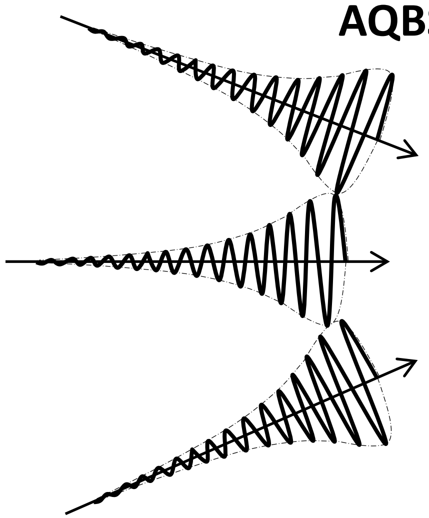


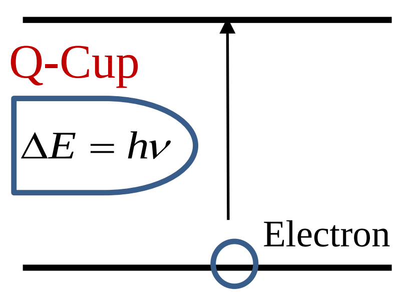
Evolves into a classical wave packet.



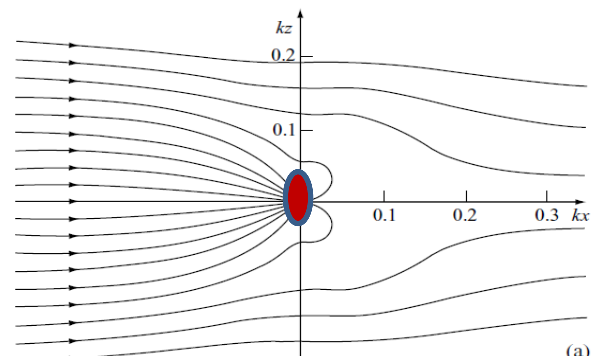
Measured spectrometer line width will be "almost" Lorentzian (QM prediction), which is a Fourier transform of an exponential envelope!

AQBSORPTION:





Diffractively spreading multiple wave packets fill up the Quantum Cup to help the upward transition.



A large effective cross-section of a quantum dipole while absorbing EM energy

See p.53 in *Introduction to Quantum Optics, by* H. Paul, Cambridge U. Press, 2004..

C. Roychoudhuri, See Ch.5 for theory of pulsed light spectrometry in:
"Causal Physics: Photon Modell by Non-Interaction of Waves; CRC, 20014.

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van Cittert-Zernike theorem

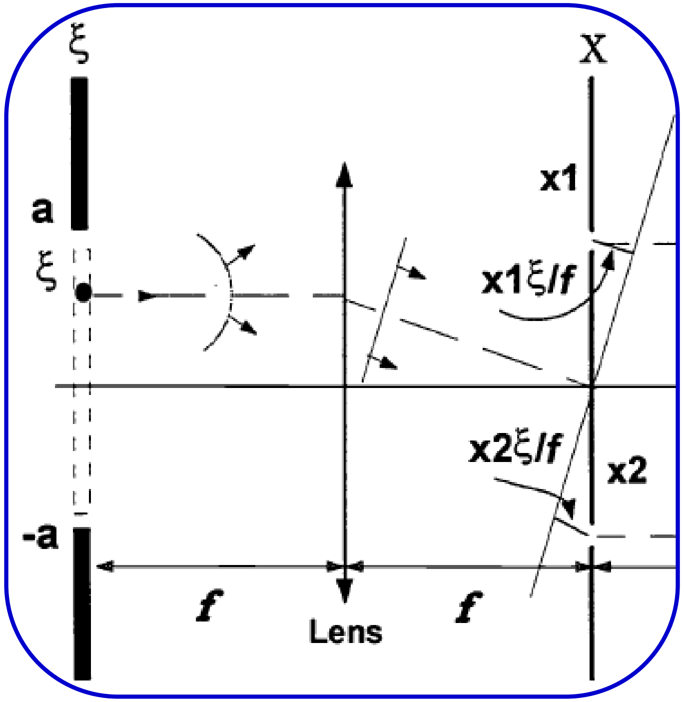
It provides a physical model for the emergence of phase-correlated signals in the far-field out of phase-random spontaneous emissions from an extended incoherent source.

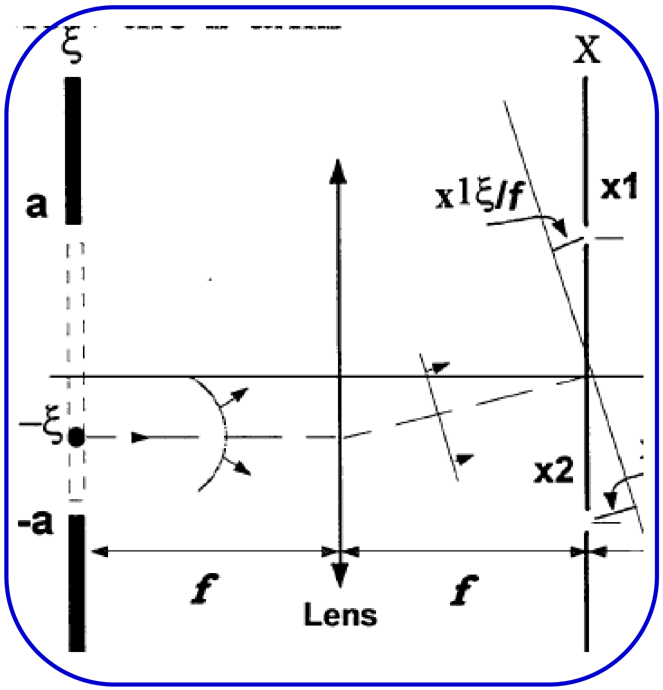
Normalized autocorrelation function for the optical field in the far-field of an incoherent source is the Fourier transform of the near-field incoherent source intensity distribution function.

The theory predicts that a fixed double-slit, placed in the far field of the incoherent source, will produce cosine fringes that will undergo π-phase shifts for specific values of the source diameter, when changed.

Thompson & Wolf had carried out an experiment to validate this property of the vC-Z theorem. Their experiment demonstrated the physical meaning of the π-phase reversal in the autocorrelation function.

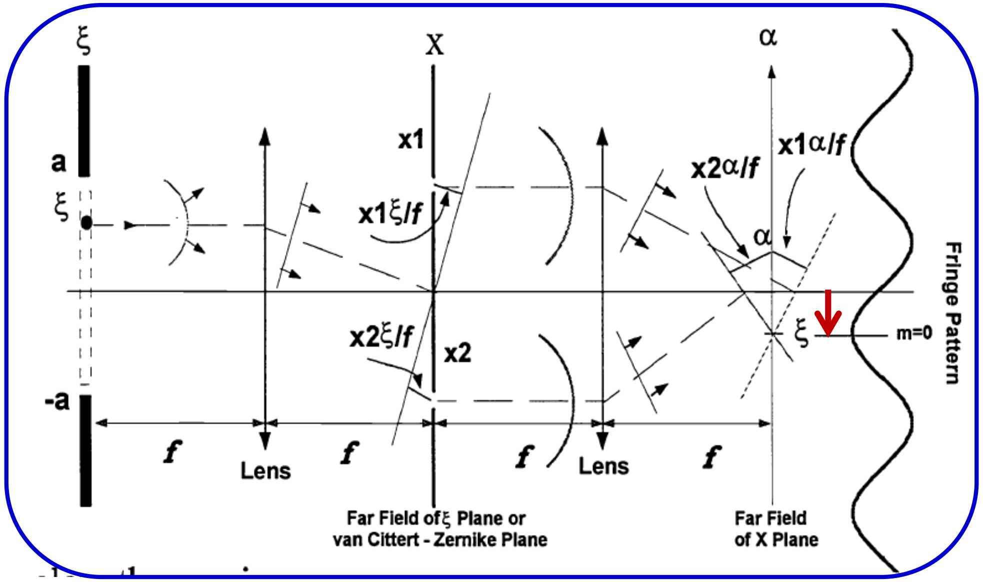
Can such phase-reversal be demonstrated for a phase-random particle beam?





Emergence of partially coherent signal out of fully incoherent signal!

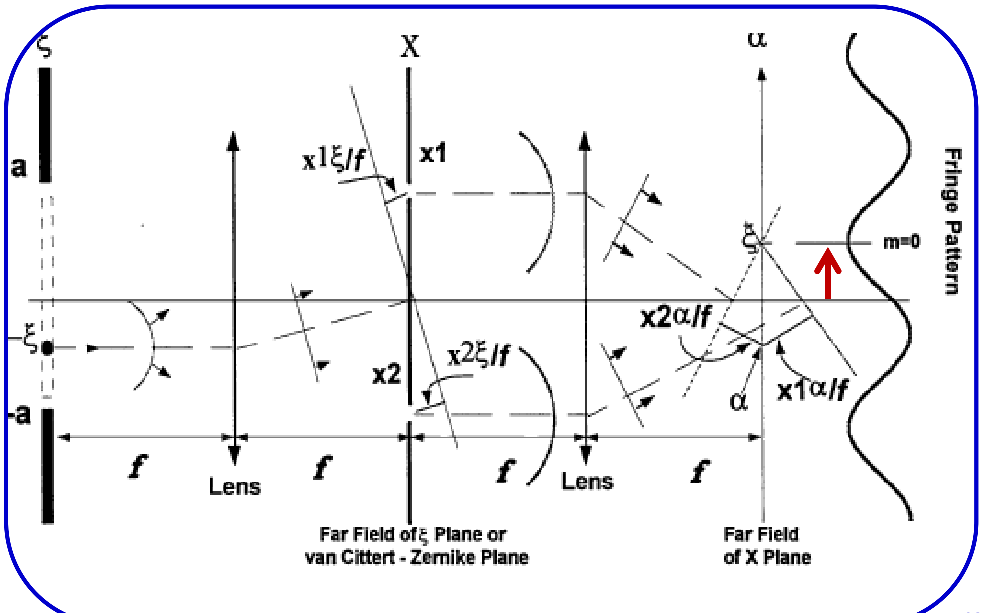
- Each spherically expanding Huygens wavelets, emanating from each point source, generates perfectly phase-correlated signal over an extended forward field. [?What is the equivalent **physical process** by which an indivisible individual particle can project itself as a spatially expanding phase-coherent wave? Does the "Pilot Wave" follow H-F Principle?]
- For light beams, overlapping of multiple phase un-correlated fields, arriving from different source points, degrade the relative phase correlation between any pair of points in the far field. [?Do the Pilot Waves first sum and then collapse at the detector plane?
- **Thus, Huygens' postulate of secondary wavelets, as the mechanism of wave propagation, is at the core of emergence of increasing spatial coherence, as one moves further from the incoherent source plane. [?What would be the model for particles?]**



Thompson-Wolf measurement approach to vC-Z theorem

> A double-slit is placed in the far-field of the source-plane and the fringes are recorded at the far-field of the slit-plane.

vC-Z theorem: The far-field degree of spatial coherence is the the Fourier transform of the source intensity function.

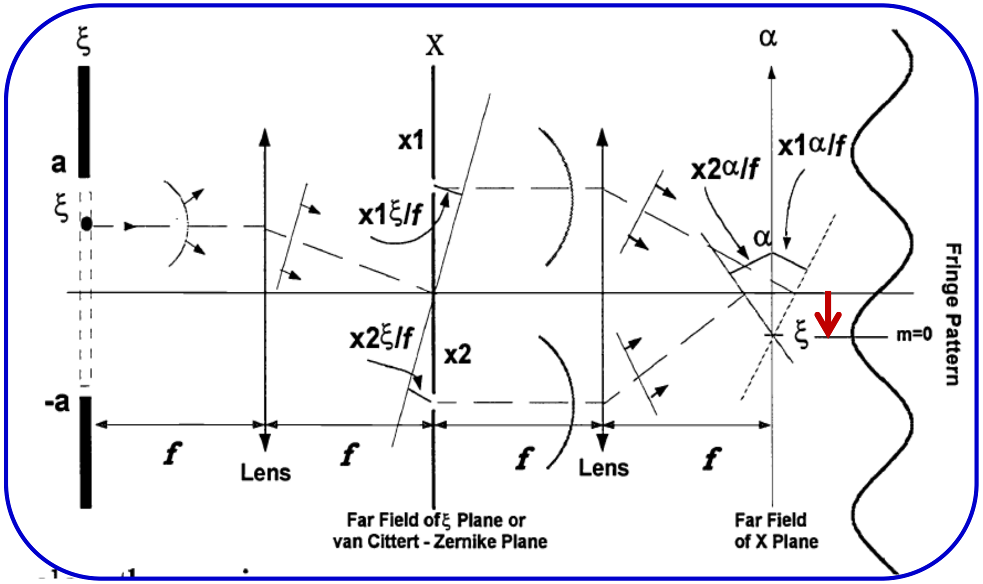


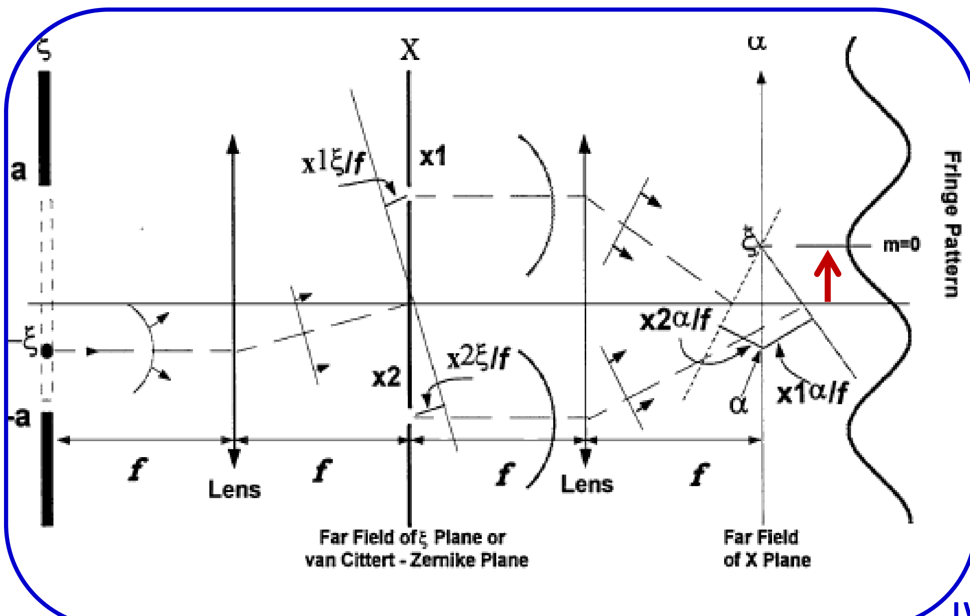
> The field due to each point source creates cosine fringes of perfect visibility.

> The location of the zero-order fringe for each point source is determined by the image of the point source (double Fourier transform; inverted image).

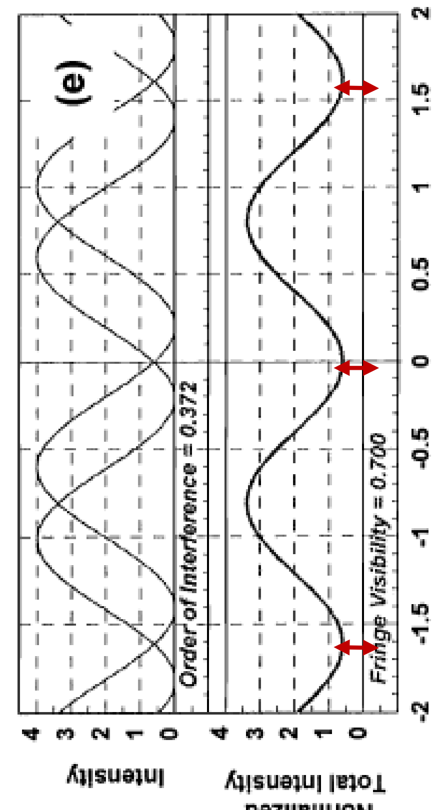
> The sum of the perfect, but spatially translated, cosine fringes reduces the fringe visibility.

Huygens' Principle explains increase in spatial coherence due to propagation of incoherent spontaneous emissions





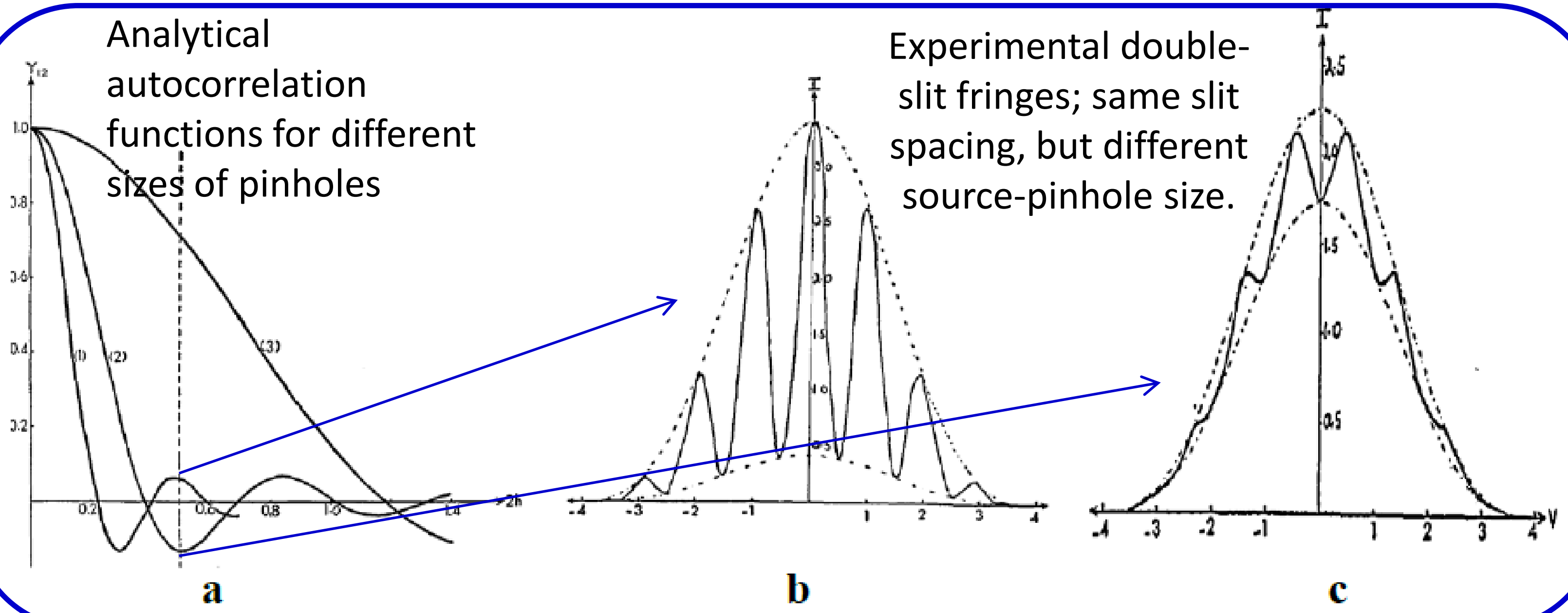
The sum of the perfect visibility but ***spatially translated*****, cosine fringes reduces the final fringe visibility.**



Roychoudhuri & Lefebre, Proc. SPIE Vol.2525, p.148 (1995), "van Cittert-Zernike theorem for introductory optics course using the concept of fringe visibility".

Physical meaning of π-phase shift in the vC-Z ttheory

Thompson, JOSA, 48(2), p.95, (1958)

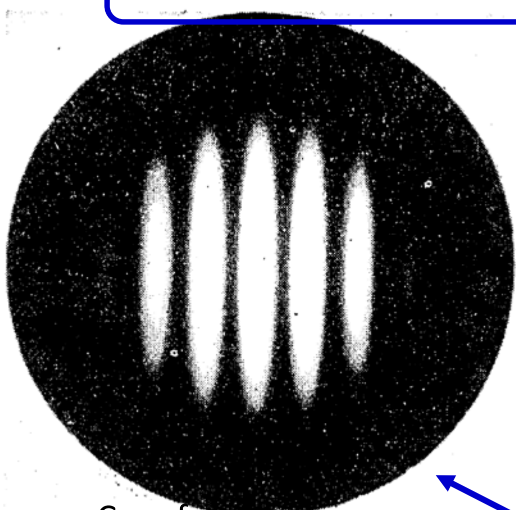


The plot of the complex degree of coherence, as in (a), for three different sizes of the incoherent source. The double-slit fringes show a central bright fringe, as in (b), for narrow source such (the curve "1" in "a"; note the dotted vertical line in a). But, the central fringe is dark and the visibility is poorer, as in (c), for a narrower source (curve "2" in "a"). The slit spacing now falls in the negative lobe as in (a); note the vertical line. This is the physical meaning of the negative degree of partial coherence [3,4].

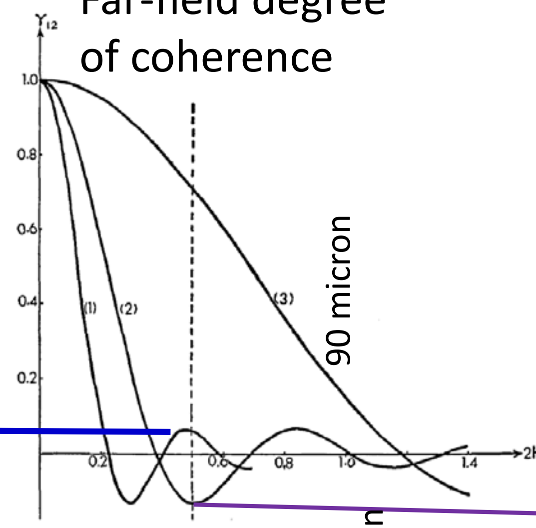
Experimental validation of the "Pi" phase shift in the central fringe – Vindication of Huygens Postulate

EM wave model explains all the intricate consequences of vC-Z theorem. "Indivisible light quanta" model fails to give us a physical process by which the entire cosine-fringe set moves by half-a-fringe simply due to minute change in the size of the incoherent source pinhole.

?Can such an experiment be re-produced using an incoherent particle beam?



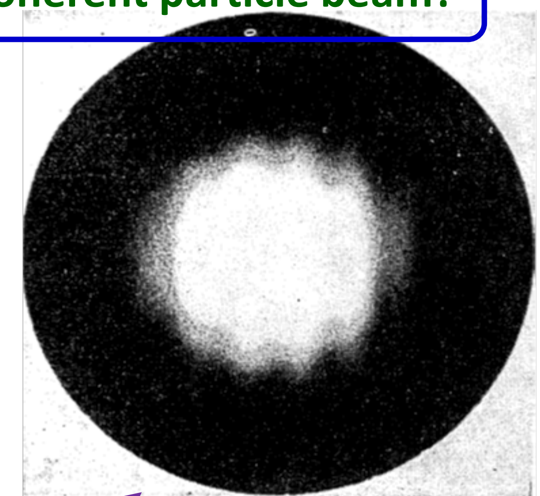
Far-field degree of coherence



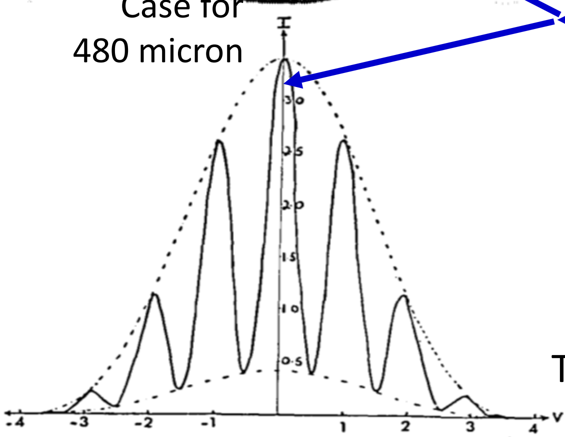
90 micron

480 micron

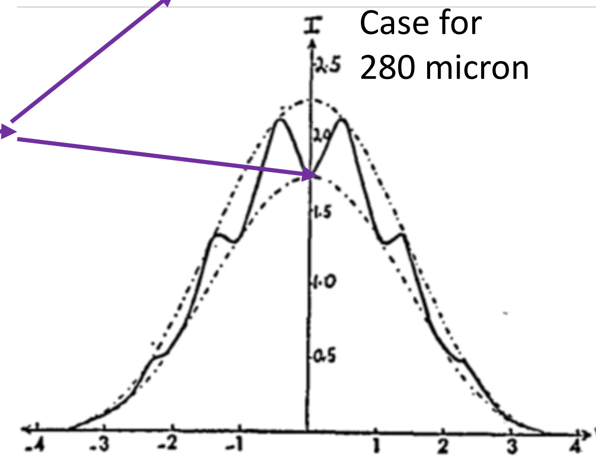
280 micron



Case for 480 micron



Case for 280 micron



Thompson, JOSA, 48(2), p.95, (1958)

The key un-resolved discrepancy between the models of "diffractive wavelets" and "indivisible photon"

Interaction process model for diffractive wavelets:

1. Bright fringes **– The sum total value of the electric vector stimulating the detecting molecule at these LOCATIONS is positive finite. The number of released photoelectrons is proportional to the square modulus of the total stimulation experienced by the LOCAL detecting dipole.**

2. *Dark fringes* - The sum total value of the electric vector stimulating the detecting molecule at these "darker" LOCATIONS is less than those for the bright-fringe locations. The waves with unabsorbed energy propagates through unperturbed.

3. *The Superposition effect* is LOCAL & CAUSAL dictated by the "local" resultant field value on a detecting molecule., which play a key roles in determining the out come.

4. Properties of detecting molecules determine the outcome of superposition: **A multi-mode He-Ne laser would be read as a CW signal by a slow detector. But a fast detector will generate time-varying heterodyne signal.**

Interaction process model for "indivisible photons":

1. Bright Fringes **– The arrival of the total number of "photons" on the detecting plane is dictated by the entire apparatus. Larger number comes to the "bright" locations. Detectors just pick up the arrived photons.**

2. Dark fringes **– Due to reduced or non-arrival of photons.**

3. The Superposition effect **is NON-LOCAL & NON-CAUSAL, dictated by the details of the ENTIRE apparatus.**

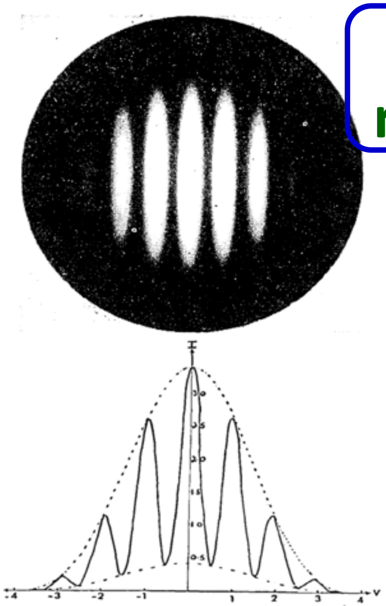
4. Detecting system simply counts the number of arrived photons. Had this model really represented real physics, heterodyne detection would have been impossible. **How do the stream of CW photons in the two beams re-organize their oscillatory arrival on the detector in a heterodyne experiment?**

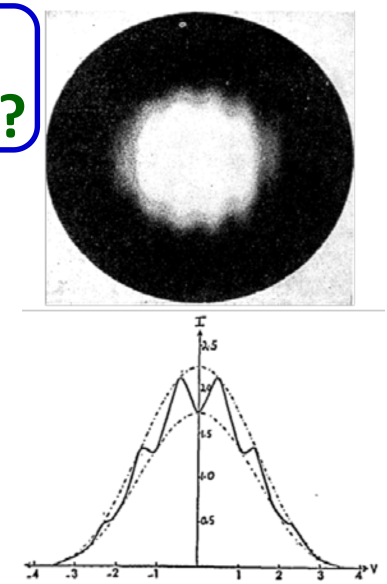
Proposals for three diffraction experiments using Rb-beam
What is so unique about Rb-beam?

1. We are extending the model of real physical superposition from optics to particle diffraction.
2. EM waves are classical and the detectors are quantized. Same basic assumption is true for particles. de Broglie's "Pilot Wave", $\lambda = h / p$, is not quantized. However, the detecting molecules are quantized.
3. The current model assumes that the "Pilot Wave" guides the classically scattered "localized" particles to preferentially arrive at the "in-phase" locations, which generate the fringes. This is an ad hoc non-causal assumption as there is no force involved.
4. We replace the un-quantized "Pilot Wave" hypothesis by another un-quantized postulate: To ***incorporate harmonic phase as a physical and causal parameter***, we postulate that all very small particles possess velocity dependent intrinsic harmonic oscillation, $a \exp[i2\pi ft]$, where the kinetic energy is $\mathrm{a}^2 \equiv (1/2)\mathrm{mv}^2 = hf$. Both a and f can assume continuous values. Phase sensitive quantum detectors succeed in extracting hν quantity of energy out of simultaneously arrived many in-phase-oscillating particles. Out-of-phase particles null their stimulation capability. ***This quantum property of quantum detector is at the root of quantumness we observe in registering superposition effects.***
5. Thus, if we can preserve the diffracted particles, like Rb atoms, on the detecting plate, then Rb-resonance florescence can give us their real physical arrival distribution.

Proposals for three diffraction experiments using Rb-beam Incoherent source. Validating vC-Z theorem. Expt.-1

?Can the Thompson-Wolf experiment be re-produced using an incoherent Rb-beam?





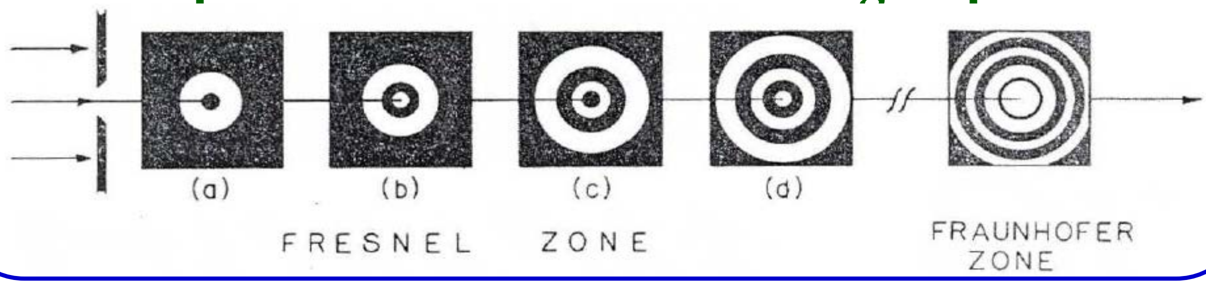
1. Set up the Thompson-Wolf experiment using an oven with adjustable small aperture for the emission of ***phase uncorrelated***, but mono-energetic beam of Rb-atomic beam.
2. Then, carry out a series of recording of diffraction patterns as given in Thompson's paper.

3. The detector plate has to be researched carefully. The plate should have molecules, like Ag-Halide that breaks down quantum mechanically to Ag-atoms, which would produce "blackened fringes" after chemically processed. However, some novel detecting material may be needed that would not remove the Rb-atoms from the locations they have arrived originally.
4. First, illuminate the exposed and developed plates with bluish-white light (filter out 780nm light). It should show the diffraction fringes. ***Is π-phase shift clearly observable?***
5. Then, illuminate the plates with Rb-resonance radiation, 780nm. They should show that the distribution density of Rb-atoms in all plates correspond approximately to Gaussian.

Proposals for three diffraction experiments using Rb-beam
What are the key discerning criteria? Expt.-2

***Are the optical and particle diffraction phenomena fundamentally different?*.**

Can near-filed particle scattering experiment reproduce on-axis dark and bright spots?



C. Roychoudhuri & A. Cornejo, Bol. Inst. Ton. Vol.1, No.4 , pp.245-6 (1975)

1. As before, research and use a detecting plate with embedded molecules (like Ag-Halide) that easily breakdown after in-phase Rb-atoms collide on them and “blackens” the locations of their arrival site after the plate is “developed”.
2. The experiment should be repeated for four to five times with fresh plates placed at different near-field locations, as shown in the above figure.
3. When the plates are illuminated with bluish-white light (filter out 780nm), they should display dark-bright fringes as shown in the above diagram. Fringes are produced due to quantum mechanical break-down response of the detecting molecules.
4. When the plates are illuminated with just 780nm light, the fluorescence would show the approximate Gaussian distribution of scattered Rb-atoms.

Proposals for three diffraction experiments using Rb-beam
What are the key discerning criteria? Expt.-3

1. Repeat the last two experiments after researching for a "detecting plate" material, whose molecules do not break down quantum mechanically under the impact of arrived Rb-atoms. The Rb-atoms should be just stopped and immobilized locally.
2. Then illuminate the "detector plate" with a bluish-white light (780nm filtered out). Our prediction is that the **scattered light will not show any diffraction fringes.**
3. Next, illuminate this "detector plate" with Rb-resonance 780nm light. It should show almost Gaussian like scattering distribution of Rb-atoms.

Conclusion & Question

1. Conclusion:

EM waves are classical and follow HF integral. Scattering of atoms and small particles are also classical – follow Gaussian scattering. The quantumness in the diffraction and interference fringes appear only when we *use phase-sensitive quantum detectors.*

2. Question:

If single indivisible particles, one at a time, can really generate all the interference and diffraction patterns; then why do we need phase correlation (or mutual coherence) between successive particles?

References

[1] M. Born and E. Wolf, see article 10.4.2 in *Principle of Optics*, Cambridge U. Press, 1999.

[2] B. J. Thompson, "Illustration of the Phase Change in Two-Beam Interference with Partially Coherent Light", J. Opt. Soc. Am.Vol.48 (2), pp. 95-97 (1958).

[3] C. Roychoudhuri, “Causal Physics: Photon by Non-Interaction of waves”, Taylor & Francis, 2014. See Ch.11 for particle diffraction.