Another Role for Corpuscles in the Double-Slit Experiment?

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The classic double-slit experiment, first performed by Young in 1801, is often cited as proving the dual wave-particle nature of light, with an emphasis on the wave aspect. In fact, when first conducted, the conclusion refuted newton's postulate of a corpuscular nature to light in favor of light being purely a wave. Not until the discovery of the photoelectric effect did light's potential behavior as a particle become rejuvenated. This paper examines a possibly enhanced role for light's corpuscular nature beyond what is currently assigned as a result of the double-slit experimental results in hope of opening yet another avenue of exploration into the still mysterious nature of light.

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1. Introduction

The double-slit experiment suggests the alleged wave-particle duality of light. First performed by Young in 1801, this experiment splits a light wave into two that later combine via a phase shift to create an interference pattern. Reputedly it is the wave nature of light that causes the interference, producing bright and dark bands on a screen - a result that would not be expected if light consisted of particles. However, the light is always absorbed at discrete points as individual particles (not waves). Furthermore, detectors at the slits find that each detected photon passes through one slit (as would a classical particle), and not through both slits (as would a wave), suggesting wave–particle duality. Electrons also exhibit the same behavior when fired toward a double slit. [1]

When the "single-slit experiment" is conducted, the pattern is a diffraction pattern in which the light is spread out rather than one corresponding to the size and shape of the slit, expanding as the slit width decreases. When Young first demonstrated this phenomenon, it indicated that light consists of waves vs. Newton's corpuscular theory, later rejuvenated via the photoelectric effect. Today the double-slit experiment is used to support light having both wave and corpuscular properties, the former usually being easier to comprehend from the results than the latter. This paper attempts to offer one possible avenue of exploration to support the latter.

2. Light as Corpuscles

Assume that a photon can be represented by a ball bearing (incompressible), but that its collision with an impenetrable barrier in which there is a slit wide enough for the ball to pass through cleanly will be less than totally elastic. If the ball hits the barrier head-on (impact angle α of 0), it is stopped completely, implying that the 'reaction' vector is exactly equal to the 'impact' vector (assumed, for convenience, to have a magnitude [length] of unity). For less than head-on impacts (up to a 'just miss' at $\alpha = 90^o$), the reaction vector will have length < 1 at angle α, deflecting the ball while still allowing it to pass through the slit at an angle $\theta = 90^o - \alpha$). This is illustrated in Figures 1 and 2. The impact vector will always have length 1 downward vertically. The reaction vector will have length = $\cos \alpha$ with vertical and horizontal components of $(\cos \alpha)^2$ and $(\sin \alpha)(\cos \alpha)$. Therefore, the 'deflection' vector will be the vector sum of the impact and reaction vectors, with length = $([1 - \{\cos \alpha\}^2]^2 + [\sin \alpha]^2[\cos \alpha]^2)^{1/2}$ and direction $\theta = 90^o - \alpha$ relative to vertically downward.

Passing through a single slit, a symmetric pattern peaked at the center will result on a screen placed parallel to the barrier. As the balls travel pass the screen (some deflected, most not), the will strike the screen at a horizontal location of $\cos \theta$. If we make a leap of faith and assume the intensity at each screen position is proportional to the length of the deflection vector, the pattern shown in Figure 3 results, based on the calculations from Table 1. This leap of faith represents the assumption that most balls pass through the slit without deflection, leading to peak intensity toward the center, which is represented by the length of the deflection vector as shown in Table 1 (deflection angle = 90^o).

To expedite subsequent calculations using the screen pattern, a regression fit to the data in Table 1 (representing the 'right side' of the curve in Figure 3, i.e., for horizontal position ≥ 0) yielded the following, also shown in Figure 3: [2]

$$y = 1.701/(x + 1.524),\ x \geq 0$$

where y = length (of deflection vector) and x = horizontal position. The 'left side' of Figure 3 is just a mirror image of the right. The result somewhat resembles the typical pattern exhibited by single slit diffraction (Figure 4), albeit with a sharper peak.

Now consider the double slit counterpart where the ball bearings are shot through two slits a distance of 0.5 unit apart (relative to the horizontal scale on the screen). If there is no interaction among the balls after passing through the slits, the expected screen pattern would just be the summation of two single-slit patterns with center peaks 0.5 unit apart, as shown in Figure 5.

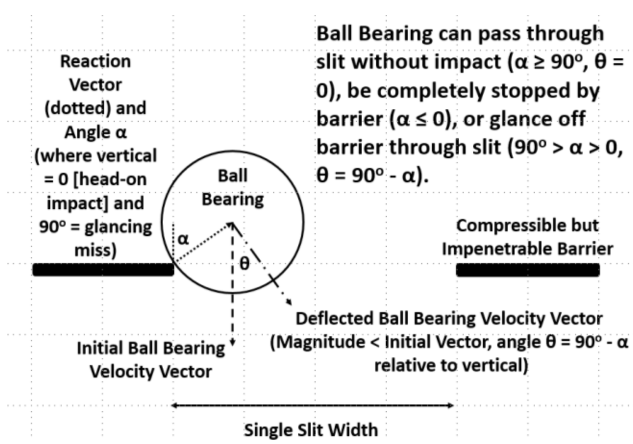

Figure 1. Geometry of Ball Bearing Impact with Slit Barrier

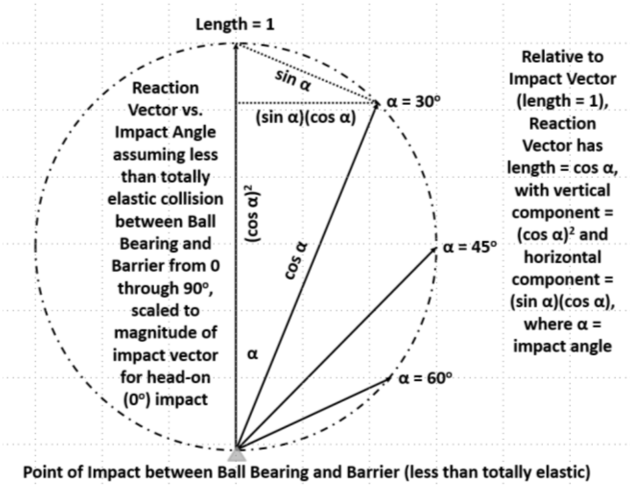

Figure 2. Schematic for Reaction Vector

Table 1. Data for Single Slit Screen Pattern

Impact Angle		Reaction Vector			Deflection Vector		
°	Rad	Vertical	Horizontal	Net	Length	Angle	Horizontal Location
0	**0.0000**	1.0000	0.0000	1.0000	0.0000	1.5708	
5	**0.0873**	0.9924	0.0868	0.9962	0.0872	1.4835	11.4301
10	**0.1745**	0.9698	0.1710	0.9848	0.1736	1.3963	5.6713
15	**0.2618**	0.9330	0.2500	0.9659	0.2588	1.3090	3.7321
20	**0.3491**	0.8830	0.3214	0.9397	0.3420	1.2217	2.7475
25	**0.4363**	0.8214	0.3830	0.9063	0.4226	1.1345	2.1445
30	**0.5236**	0.7500	0.4330	0.8660	0.5000	1.0472	1.7321
35	**0.6109**	0.6710	0.4698	0.8192	0.5736	0.9599	1.4281
40	**0.6981**	0.5868	0.4924	0.7660	0.6428	0.8727	1.1918
45	**0.7854**	0.5000	0.5000	0.7071	0.7071	0.7854	1.0000
50	**0.8727**	0.4132	0.4924	0.6428	0.7660	0.6981	0.8391
55	**0.9599**	0.3290	0.4698	0.5736	0.8192	0.6109	0.7002
60	**1.0472**	0.2500	0.4330	0.5000	0.8660	0.5236	0.5774
65	**1.1345**	0.1786	0.3830	0.4226	0.9063	0.4363	0.4663
70	**1.2217**	0.1170	0.3214	0.3420	0.9397	0.3491	0.3640
75	**1.3090**	0.0670	0.2500	0.2588	0.9659	0.2618	0.2679
80	**1.3963**	0.0302	0.1710	0.1736	0.9848	0.1745	0.1763
85	**1.4835**	0.0076	0.0868	0.0872	0.9962	0.0873	0.0875
90	**1.5708**	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000

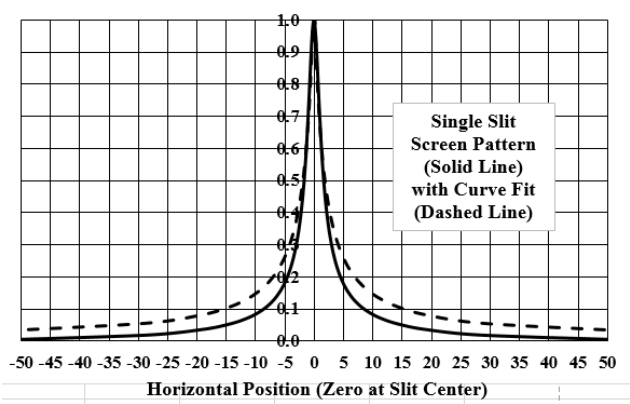

Figure 3. Single Slit Screen Pattern (Scaled)

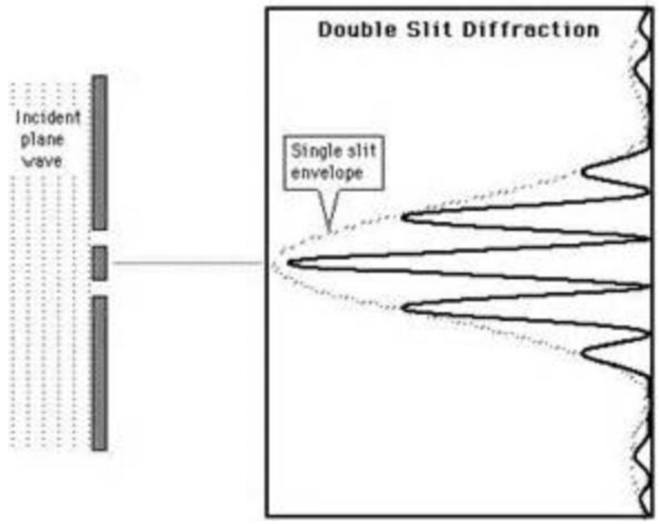

Figure 4. Diffraction Pattern for Single and Double Slit Experiment [3]

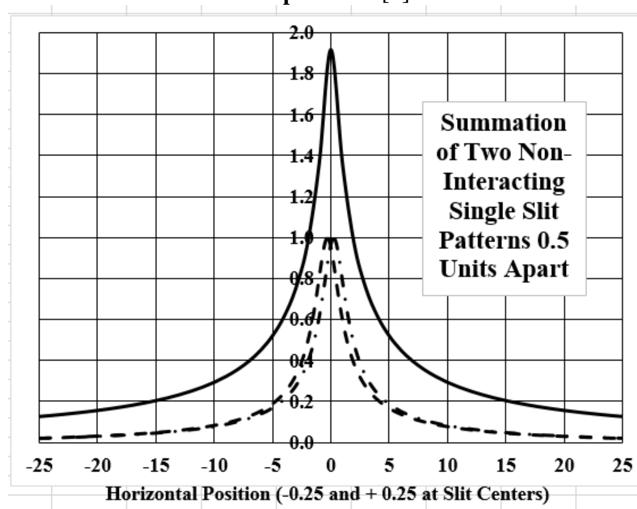

Figure 5. Non-Interacting Double Slit Screen Pattern (Scaled)

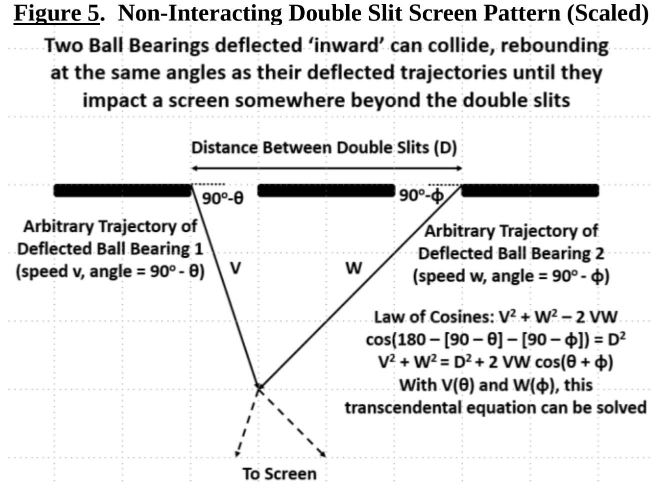

Figure 6. Assumed Geometry for Ball Bearing Collisions after Passing 'Inward' through Double Slits

What if the ball bearings collide with one another after passing through the slits? This, is not expected to occur for the single slit arrangement, since each ball bearing, representing a photon, retains its initial speed even after impacting the barrier; so any two passing even very close, but still ever so slightly offset, in time will never collide even if their trajectories intersect. With the double slit arrangement, multiple balls can pass, some deflected, such that intersecting trajectories, with just the right time offset, can result in (assumedly) totally elastic collisions between a pair. These would rebound off one another and continue at their pre-collisional speed and reverse deflection angle. Figure 6 illustrates the presumed geometry.

While 'outward' collisions are possible, I assume the propensity for these to be much less than that for 'inward' collisions, so outward collisions are ignored. From Figures 1 and 2, with the results from Table 1, the deflection vectors' length and direction, V(θ) and W(ϕ) in Figure 6, are known. Therefore, assuming D = 0.5 (distance between slits), the following transcendental equation can be solved to obtain the horizontal locations where the deflected balls strike the screen after collision:

$$V(\theta)^2 + W(\phi)^2 = (0.5)^2 + 2V(\theta)W(\phi)\cos(\theta + \phi)$$

Solutions to this equation are provided for the range of impact angles from 0 to 90° in Table 2.

An interesting property of the family of results is symmetry about impact angles for vector 1 of 15° and 75°, with no solution between 30° and 60°. For the lower range of impact angles, collisions satisfying the transcendental equation occur when the sum of the deflection angles (θ + ϕ) = 150°, with each angle constrained to the range from 60 to 90°. Over this range, the pair of ball bearings strike the screen between horizontal locations -23.4 to -11.6 and 11.6 to 23.4. For the upper range of impact angles, collisions satisfying the transcendental equation occur when the sum of the deflection angles (θ + ϕ) = 30°, with each angle constrained to the range from 0 to 30°. Over this range, the pair of ball bearings strike the screen between horizontal locations -0.20 to -0.08 and 0.08 to 0.20, essentially indistinguishable from the central peak and constrained within the distance between slits of 0.5 (-0.25 to 0.25).

Table 2. Solutions to Transcendental Equation for 'Inward" Collisions

Impact Angle (α), Vector 1	Deflection Angle (deg) Vector 1 (θ)	Vector 2 (ϕ)	Deflection Length Vector 1 (θ)	Vector 2 (ϕ)	Horizontal Location (+/-)
0°0'1"	89.9997	2.8E-04	4.8E-06	0.5000	11.58
1°	89.00	61.00	0.0175	0.4848	12.43
8°	82.00	68.00	0.1392	0.3746	19.27
15°	75.00	75.00	0.2588	0.2588	23.36
22°	71.00	79.00	0.3256	0.1908	21.86
29°	61.00	89.00	0.4848	0.0175	12.43
30°	60.00	No solution	0.5000	No Solution	
45°	45.00		0.7071		
60°	30.00		0.8660		
61°	29.00	1.00	0.8746	0.9998	0.0967
68°	22.00	8.00	0.9272	0.9903	0.1759
75°	15.00	15.00	0.9659	0.9659	0.2014
82°	8.00	22.00	0.9903	0.9272	0.1759
89°	1.00	29.00	0.9998	0.8746	0.0967
89°59'59"	2.8E-04	30.00	1.0000	0.8660	0.0806

To illustrate the possible effect of these 'preferred collisions' and their potential resultant 'buildup' at the horizontal locations on the screen, we arbitrarily double the length of the deflection vectors shown for the ranges of horizontal locations in Table 2 for the lower range of impact angles for vector 1 (i.e., -23.4 to -11.6 and 11.6 to 23.4 for impact angles from 0 to 30°) for the summation shown in Figure 5. The result is Figure 7.

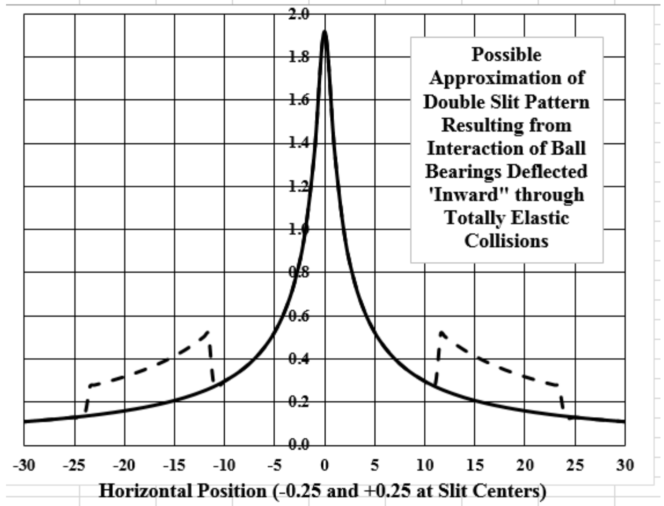

Figure 7. Interacting Double Slit Screen Pattern (Scaled)

While this only crudely approximates just one pair of secondary peaks for the double slit pattern shown in Figure 4, it nonetheless offers a potential avenue of investigation toward the possibility that at least part of the explanation for the unique diffraction pattern for light in the double slit experiment could arise from light's corpuscular nature. One might imagine that with better modeling of the potential for collisions between photon corpuscles after passage through the double slit, peaks other than just the central might result, perhaps approaching the pattern currently attributed exclusively to the wave nature of light.

3. Summary

The double-slit experiment is often cited as indicating the dual wave-particle nature of light, with the emphasis on the wave aspect, which is usually easier to comprehend. Any corpuscular behavior by light is limited to absorption at discrete points as individual particles and detectors at the slits suggesting that a photon passes through one slit (as would a classical particle), and not through both slits (as would a wave). This paper attempts to offer one possible avenue of exploration to support an enhanced role for the corpuscular nature of light than has previously been attributed.

4. References

1. *https://en.wikipedia.org/wiki/Double-slit_experiment.*
2. *http://www.xuru.org/rt/NLR.asp#CopyPaste.*
3. *http://www.bing.com/images/search?q=double+slit+diffraction&qpvt=double+slit+diffraction&qpvt=double+slit+diffraction&FORM=IGRE.*