A Comprehensive Treatise on the Applications of de Broglie Wavelengths for Macroscopic Objects

Ara Giaquinto[1], Naman Raina[2], Varun Seshadri[3],

September 5, 2022

[1]School of Physics, Georgia Institute of Technology, Georgia Tech
[2]Department of Theoretical Mathematics, ISKL
[3]Department of Relativistic Mechanics, ISKL

Abstract The application of de Broglie wavelengths to macroscopic objects seems impossible, however by optimizing for a slow enough velocity, a passage of time with a new unit may be established regarding the time taken for an object to diffract through an opening comparable to its original size. The purpose of this research paper is to challenge institutional norms, and to analyze the implications of macroscopic/multiparticulate diffraction.

1 Introduction

1.1 Background

It is well known that the conditions for diffraction are such that a wave's wavelength must be comparable in size to the slit in which it is diffracting through. Such phenomena are commonly visualized through photon diffraction, as observed in Young's double slit experiment. However, contrary to belief at the time of Young, photons were not the only particles capable of undergoing diffraction. Louis de Broglie theorized that every particle with a certain momentum p is able to exert properties of a wave, such as diffraction and interference. Hence, its wavelength can be represented with λ in terms of meters. This is demonstrated as follows in the de Broglie equation:

$$\lambda = \frac{6.63 \times 10^{-34} J \cdot s}{p} \quad (1)$$

Although it is quite explicitly stated that such an equation only applies to quantum point-particles, and certainly not towards large macroscopic structures, let alone groupings of particles, this groundbreaking new research states otherwise.

1.2 Alpha Particle Diffraction

During the Rutherford gold foil experiment, alpha particles are sent to bombard a thin grid of evenly-spaced gold atoms. The key observation, however, is that these alpha particles $\left({}^4_2\text{He}^{2+}\right)$ diffracted through the makeshift slits created by the spacing within the atomic lattice structure, measured as 'diffraction scattering' (Ableev et al.). This fascinating experiment (although less interestingly proved the existence of atomic nuclei) proves that a group of at least 4 baryons, composing of at least 12 quarks, may undergo diffraction. From this bare minimum research, a lower threshold for the maximum object size in order to induce diffraction may be set to 12 quantum particles. This is a significant improvement from the single photon or lepton ($e^{\pm}$) from Young and de Broglie. A similar effect was achieved by Estermann, by directing a beam of monochromatic helium onto a particular sample from which the ${}^4_2$He atoms could diffract onto. The condition was such that the de Broglie wavelength of the ${}^4_2$He atoms had to be comparable to the interatomic spacing of the sample which it was incident on, hence essentially formulating a series of makeshift slits as seen with the alpha particle diffraction experiments (Estermann, and Stern). Through the successful diffraction of an entire ${}^4_2$He atom, it can be stated that the new lower threshold for the maximum object size is 14 quantum particles. This, however, is just the beginning.

1.3 Macroscopic Application

A more rudimentary macroscopic approach to diffraction may bring to mind the examples of waves traveling through the ocean, and diffracting between rocks. Although an interference pattern may be observed, assuming the source is coherent, such diffraction does not occur via the laws of quantum mechanics. The de Broglie approach may at first seem to only apply to subatomic particles, however this is simply not true, as proven later on in Section 3 of the paper. With the understanding that the wavelength is proportional to the reciprocal of the velocity, via '$p = mv$', and assuming all else remains equal, then it would theoretically be possible to diffract macroscopic objects at substantially low velocities.

2 Theoretical Approach

2.1 Scenario One: Naman Raina

The studied object throughout this particular scenario within the investigation will be none other than Naman Raina, esteemed mathematician at the prestigious International School of Kuala Lumpur. Naman Raina is allegedy a macroscopic object, classified as the species 'H. sapiens', under the genus 'Homo'. Raina is indeed a multiparticulate object, experimentally greater in sheer quantum particle number than an entire alpha particle. Hence, a certain velocity will be deduced for which Raina will have to travel at in order to undergo diffraction. Subsequently, the time taken to diffract through this theoretical aperture will be calculated.

2.2 Example Calculation

The first trivial variable that must be deduced is Raina's mass. This has been provided to be approximately $68kg$, from Raina himself. Primary sources tend to be the most reliable, hence this value was accepted by the team. Using a height of $1.8m$, Raina's **alleged** height, we can understand that the slit through which he will need to diffract through must have a comparable height to him. Otherwise, the wavelength resulting from the de Broglie equation will present a wavelength which is significantly smaller than him, by approximately 30 orders of magnitude; he will not be able to physically fit through the slit. Hence, it is necessary to work in reverse from the $1.8m$ value, using that as his ideal de Broglie wavelength (λ_i). With the relation from line 1, we know that:

$$\because \lambda_i = \frac{h}{p} \tag{2}$$

$$\therefore \lambda_i = \frac{h}{mv} \tag{3}$$

$$\implies v = \frac{h}{m\lambda_i} \tag{4}$$

Hence, by substituting the respective values into the right-hand-side, we find that:

$$v = \frac{6.63 \times 10^{-34} J \cdot s}{68kg \times 1.8m} \tag{5}$$

$$\therefore v = 5.416666667 \times 10^{-36} m \cdot s^{-1} \tag{6}$$

$$\approx 5.42 \times 10^{-36} m \cdot s^{-1} \tag{7}$$

The unit conversions between lines 5 and 6 are trivial and left as an exercise to the reader. Thus, from the result in line 7, it is seen that it is actually possible for Naman Raina to exhibit wave-like properties, assuming he can be treated as a single particle, traveling at a mere $5.42 \times 10^{-36} m \cdot s^{-1}$. This, however, requires a velocity which covers a distance smaller than the Planck length every second $\left(1.616255 \times 10^{-35} m \cdot s^{-1}\right)$, which will be referred to the newly defined variable of 'Planck speed' (ℓ_{Ps}), thus making it physically impossible for such an object to undergo diffraction. However, if Raina were to employ the fetal position and reduce his height down to approximately 33.3%, thus effectively taking a third of the wavelength requirement, bringing λ_i down to only $6.0 \times 10^{-1} m$, then the resulting velocity is a meager $1.63 \times 10^{-35} m \cdot s^{-1}$. This, extraordinarily, is ever-so-slightly larger than the Planck speed, rendering it theoretically feasible that Raina may undergo de Broglie diffraction.

2.3 Defining the Raina Limit

With this new understanding that there is a minimum velocity requirement as per the laws of quantum physics, such that no particle/object may travel slower than ℓ_{Ps}, a constant may be derived based on the Planck length (ℓ_P) and Planck's constant (h). This is to be done in order to simplify and streamline the calculations, based on the result from line 4. Such a number would represent the maximum value that one's mass (m) times its ideal de Broglie wavelength (λ_i) can possess in order to undergo diffraction, as it would allow for velocities faster than ℓ_{Ps}, hence being within the realm of physical possibility:

$$\ell_{Ps} = \frac{h}{m\lambda_i} \tag{8}$$

$$\therefore m\lambda_i = \frac{h}{\ell_{Ps}} \tag{9}$$

$$\implies m\lambda_i = \frac{6.63 \times 10^{-34} J \cdot s}{1.616255 \times 10^{-35} m \cdot s^{-1}} \tag{10}$$

$$\therefore m\lambda_i \approx 4.10 \times 10^{1} kg \cdot m \implies \Re \tag{11}$$

From this, it can be observed that an object's mass times its wavelength can be equated to a certain constant, which will be established as the Raina limit ($\Re$). Hence, we can establish two conditions:

$$m\lambda_i > \Re \implies \text{physically impossible} \tag{12}$$

$$m\lambda_i \leq \Re \implies \text{physically possible} \tag{13}$$

In this case, $m\lambda_i$ essentially refers to an object's mass, and its height; ideally, the object should be able to fit through the slit in which it is being diffracted through. At velocities observable on a human scale, such as $9.0 m \cdot s^{-1}$, the resulting de Broglie wavelength would be significantly smaller than the object's dimensions, and hence not being comparable in size to the aperture which the object is crossing through itself. Thus, as mentioned earlier, it is vital for λ_i to be equal to the object's height; a diffraction condition exists where slits must be comparable in size to the wavelength of the particle. Nevertheless, from the two conditions that were established in lines 12 and 13, the following statements regarding physical possibility may be devised:

Impossible: The product of an object's mass times its de Broglie wavelength yields a value greater than $\Re$, hence requiring motion at intervals smaller than one ℓ_P every second, rendering such motion theoretically impossible.

Possible: The product of an object's mass times its ideal de Broglie wavelength yields a value less than or equal to $\Re$, placing motion within the realm of possibility. Ideally, to obtain the fastest possible velocity, both the mass and ideal de Broglie wavelength should be minimized.

2.4 Defining the Universe Time Unit

All seems to be well, however what is being blatantly ignored here is the time period requirement for which it would take Raina to diffract into. To complete the passage through a slit which is as thick as Raina's body (stomach-to-back), he would have to travel a distance of approximately $6.0 \times 10^{-1} m$, assuming that in the fetal position he makes a perfect circle with a radius equal to half his height. Via $v = \frac{d}{t}$, and hence the subsequent manipulation $t = \frac{d}{v}$, we can deduce the following time period:

$$t = \frac{6.0 \times 10^{-1} m}{1.63 \times 10^{-35} m \cdot s^{-1}} \tag{14}$$

$$\therefore t \approx 3.68 \times 10^{34} s \tag{15}$$

To convert this figure in terms of scalar multiples of a more manageable unit of time, such will be equal to scalar multiples of the estimated age of the observable universe, which according to various sources appears to be 13.77×10^{9} years, or $4.343 \times 10^{17} s$. This universe time unit will be expressed as a constant $\mho$, simply referred to as a 'universe', although it is indeed a variable value. Its variation, however, is negligible with respect to the human time period. The manipulation for the result in line 15 in terms of $\mho$ is as follows:

$$t = \frac{3.68 \times 10^{34} s}{4.343 \times 10^{17} s \cdot \mho^{-1}} \tag{16}$$

$$\approx 8.473 \times 10^{16} \mho \tag{17}$$

$$\implies t \approx 84.7 P\mho \tag{18}$$

Hence, the amount of time required for Naman Raina to diffract through a slit in the fetal position would require a time span equivalent to around 84.7 petauniverses. This is clearly impractical, and hence it can be stated with utmost confidence that Raina will likely not risk diffracting himself by passing through a comparable slit at the speed defined by his ideal de Broglie wavelength (λ_i). His particles would likely decompose prior to making any reasonable progress throughout this lengthy diffraction process. Furthermore, the vibration of his particles would far exceed the necessary velocity that Raina would need in order to produce a de Broglie wavelength equal to his height. Therefore, other scenarios involving smaller organic compounds must be investigated.

3 Further Investigation

3.1 Scenario Two: Red Blood Cells

This scenario involves the diffraction of a single red blood cell. With an estimated diameter of around $6.0 \times 10^{-6} m$ on the lower end according to multiple sources, this appears to be more feasible than Naman Raina's case. The estimated mass of the average red blood cell is approximately $27 \times 10^{-15} kg$ as well, meaning that we can test whether it satisfies the conditions for the Raina limit:

$$m\lambda_i = 27 \times 10^{-15}kg \times 6.0 \times 10^{-6}m \quad (19)$$
$$= 1.62 \times 10^{-19}kg \cdot m < 4.10 \times 10^{1}kg \cdot m \quad (20)$$
$$\implies m\lambda_i \leq \Re \quad (21)$$

The condition for the Raina limit has been met, and thus, red blood cells may be diffracted. By applying this to the result from line 4, we find that:

$$v = \frac{6.63 \times 10^{-34}J \cdot s}{1.62 \times 10^{-19}kg \cdot m} \quad (22)$$
$$\therefore v \approx 4.17 \times 10^{-16}m \cdot s^{-1} \quad (23)$$

Thus, the time taken for such an object to diffract, assuming a perfectly circular blood cell is passing through with the flat side's normal vector parallel to the surface of the slit, we find the following:

$$t = \frac{6.0 \times 10^{-6}m}{4.17 \times 10^{-16}m \cdot s^{-1}} \quad (24)$$
$$\therefore t \approx 1.439 \times 10^{10}s \quad (25)$$

And now to convert in terms of $\mho$:

$$t = \frac{1.439 \times 10^{10}s}{4.343 \times 10^{17}s \cdot \mho^{-1}} \quad (26)$$
$$\approx 3.313 \times 10^{-8}\mho \quad (27)$$
$$\implies t \approx 33.1n\mho \quad (28)$$

Hence, the time taken for a red blood cell to diffract through a comparable slit would only take 33.1 nanouniverses, which is equal to approximately 456 years. This works on a human scale, in terms of timing, thus making red blood cell diffraction slightly more feasible. However, it is highly unlikely that red blood cells may be preserved for 456 years. Hence, a smaller object with a relatively faster time period for the diffraction process will be investigated.

3.2 Scenario Three: Generic Enzymes

This scenario involves the diffraction of a generic enzyme. With an estimated diameter of around $3.0 \times 10^{-9}m$ on the lower end, this may be more feasible than the red blood cell case. The estimated mass of a generic enzyme is approximately $20kDa$ (kilodaltons) on the lower end as well, with the conversion to kilograms being as follows:

$$\because 1kDa \approx 1.661 \times 10^{-24}kg \quad (29)$$
$$\therefore 20kDa \approx 3.322 \times 10^{-23}kg \quad (30)$$

Hence, we can test whether the enzyme satisfies the conditions for the Raina limit:

$$m\lambda_i = 3.322 \times 10^{-23}kg \times 3.0 \times 10^{-9}m \quad (31)$$
$$= 9.966 \times 10^{-32}kg \cdot m < 4.10 \times 10^{1}kg \cdot m \quad (32)$$
$$\implies m\lambda_i \leq \Re \quad (33)$$

The condition for the Raina limit has been met, and thus the object may be diffracted. By applying this to the same relation derived in line 4, we find that:

$$v = \frac{6.63 \times 10^{-34}J \cdot s}{9.966 \times 10^{-32}kg \cdot m} \quad (34)$$
$$\therefore v \approx 6.784 \times 10^{-4}m \cdot s^{-1} \quad (35)$$

Thus, the time taken for such an object to diffract, assuming a perfectly circular enzyme is passing through the slit, we find the following:

$$t = \frac{3.0 \times 10^{-9}m}{6.784 \times 10^{-4}m \cdot s^{-1}} \quad (36)$$
$$\therefore t \approx 4.422 \times 10^{-6}s \quad (37)$$

And now to convert in terms of $\mho$:

$$t = \frac{4.422 \times 10^{-6}s}{4.343 \times 10^{17}s \cdot \mho^{-1}} \quad (38)$$
$$\approx 1.018 \times 10^{-23}\mho \quad (39)$$
$$\implies t \approx 10.2y\mho \quad (40)$$

Hence, the time taken for the smaller generic enzymes to diffract through a comparable slit would only take 10.2 yoctouniverses. This is an extremely small unit of time, however considering that the enzyme would only take about $4.42 \times 10^{-6}s$, it may actually be possible for such objects to undergo diffraction. This is only true theoretically, however. It would have to be experimentally deduced whether or not this is possible by consistently moving such an enzyme at $6.78 \times 10^{-4}m \cdot s^{-1}$, which may be possible with current human technology. Hence, one may attempt to accelerate an enzyme to 0.678 millimeters per second and observe the results.

4 Implications of Macroscopic Diffraction

4.1 De Broglie Interference of Naman Raina

Producing a coherent source of identical, polarized Naman Rainas (meaning oriented in the same plane as the aperture in which he is passing through) upon two apertures, then assuming all particles collide with one another at the exact same interval (hence treating Raina as a single, large particle), with both Rainas being in-phase (path difference = $n\lambda$, where n is any positive integer and λ is the wavelength of the 'wave'), then they will superimpose with one another, forming constructive interference. The product would be the double of Naman Raina. If the Rainas intersect at a point out-of-phase by an interval of π, or in other words a path difference of $\left(n + \frac{1}{2}\right)\lambda$, every quark in Naman Raina's body would destructively interfere with itself. From this event, it could be expected according to Feynman diagrams that the annihilation will release a massive amount of energy from the possible gamma ray emissions. In more practical terms, however, the annihilation process would emit a significant number of gluons, and hence may potentially be a less costly alternative than kilometer-long particle accelerators for the production of glueballs; hypothetical composite particles consisting solely of gluons. Unfortunately, it would be an extremely difficult task to ensure that all particles annihilate one another at the exact same interval, hence calculating the energy released from this theoretical de Broglie interference would have no practical applications whatsoever, unlike the other sections of this research paper. Naman Raina may not be treated as a single particle with a radius of $0.3m$ in the fetal position, to the disappointment of many. If such interference were possible, however, then a coherent source of Naman Rainas traveling through two apertures would result in a particular interference pattern projected onto a screen. To determine the nature of this interference pattern, however, Naman Raina's theoretical angle of diffraction must be calculated; this is analogous to the occurrence of the first minima present in single slit diffraction. Nevertheless, in order to calculate Raina's angle of diffraction, assuming that his diameter b in the fetal position is equal to his height, and that his velocity is adjusted such that his height is equal to λ_i, then his diffraction angle may be calculated as follows:

$$\sin\theta \approx \frac{\lambda_i}{b} \tag{41}$$

$$\because \lambda_i = b \tag{42}$$

$$\therefore \sin\theta \approx \frac{\lambda_i}{\lambda_i} = \frac{1}{1} \tag{43}$$

$$\implies \theta \approx \frac{\pi}{2} = 90^\circ \tag{44}$$

Therefore, it can be stated that Raina would have a 90° diffraction angle under the aforementioned conditions, thus when unobserved, will undergo double slit diffraction and exhibit similar behaviors to a wave. Hence, the first minima will occur at this angle in a single slit. With the understanding on how double slit diffraction is modulated by the intensity curve of single slit diffraction as slit width is not negligible, due to the fact that the slit width is assumed to be equal to Raina's diameter in his spherical fetal position $\left(6.0 \times 10^{-1} m\right)$, then the following interference pattern, ranging from 0° to 135° on both sides, would demonstrate Raina's diffraction on the subsequent page, in Figure 1:

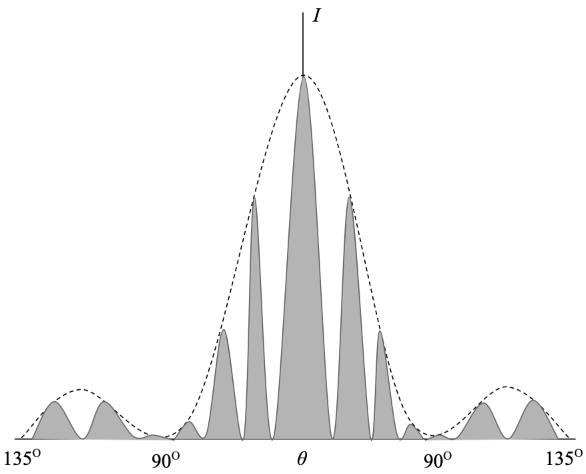

Fig. 1: Intensity Peaks for the Diffraction of Naman Rainas Through Two Slits

Again, due to the non-negligible slit width, it is possible to modulate the double slit intensity curve so long as the values for the first instance of diffraction minima are solved. In this case, doing so was relatively simple, as can be seen from line 44. Moreover, it is especially necessary to account for slit width with macroscopic/multiparticulate diffraction, since it not only renders the theory more applicable within the context of the real world, but also increases the plausibility of macroscopic diffraction as the objects crossing through the aperture are not point-particles themselves, and have a non-negligible size. Hence, with the new understanding from Figure 1 of how Naman Raina will diffract upon a slit comparable to his ideal de Broglie wavelength (λ_i), a simulation can be done demonstrating the probabilistic outcomes of diffracting a certain amount of Naman Rainas through two slits, employing the same range values as before. The results for the distribution of

Rainas is displayed in Figure 2

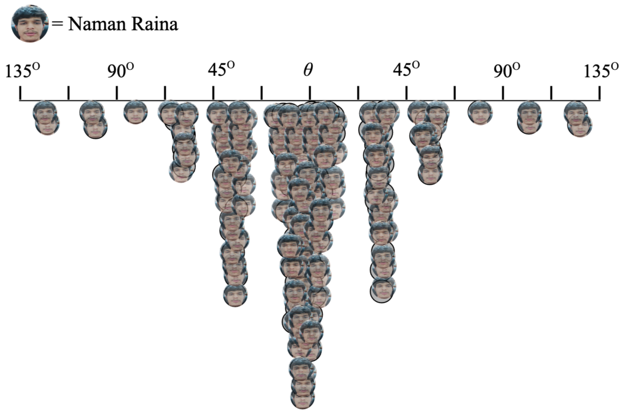

Fig. 2: Sample Distribution of Naman Rainas Through Double Slit Diffraction

Therefore, although a coherent source of Naman Rainas will most likely direct them straight towards the center of the screen, there is a probability that he may also be found at the other intensity maxima, where constructive interference occurs, and the Rainas essentially 'group' together. As this diffraction process assumes that Naman Raina may be treated as a particle, the biological implications of superpositioning two Naman Rainas onto one another are unknown, and could potentially be a further area of investigation. Furthermore, the seemingly empty regions between adjacent intensity maxima are the regions of destructive interference, where two out-of-phase Rainas by a factor of π (or 180○) will annihilate one another.

4.2 Feasibility of Enzyme Diffraction

Although a paper from the AMFEP titled "Why Enzyme Substances Are Not Nanomaterials" states that microscopic enzymes within this $1 - 100nm$ range can only exist in liquid form, and cannot be treated as particles, enzymes in granulate form "are particles with defined physical boundaries, however far bigger than the scales defined as nanomaterial" (Association of Manufacturers and Formulators of Enzyme Products). Hence, although enzymes with an $m\lambda_i$ of $9.966 \times 10^{-32} kg \cdot m$ may not be treated as a particle, slightly larger ones may very well be. Additionally, such particles would theoretically diffract at a speed slower than for the smaller liquid enzyme counterpart, and may occur under a slower time period than $4.42 \times 10^{-6} s$, facilitating the analysis pertaining to the multiparticulate diffraction process. At the moment, however, the laboratory conditions required to accomplish a successful diffraction of enzymes are unknown.

5 Conclusion

Thus, through our deep and insightful investigation, we can conclude that while somewhat unlikely, through pure physics it is absolutely possible for Naman Raina to diffract (among other macroscopic objects), as he meets the $\Re$ condition in the fetal position. However, due to our lack of financial backing and slight time constraints, this hypothesis remains untested. It remains to be seen whether or not the 'H. sapiens' specimen will be able to remain alive to witness their diffraction and what potential pattern they may give off upon diffraction, however that is a question our esteemed biologists may be able to answer. The importance of understanding how humans diffract and interfere plays into our health and safety goals, preventing humans from accidentally diffracting as we pass through ordinary everyday objects like doorways, entrances, et cetera. However with these findings, we can assure the public that so long as we never maintain a constant velocity equal to Planck's constant divided by our $m\lambda_i$, we have nothing to fear. One of our greatest mysteries may have been solved for good, though for now, it remains theoretical.

6 References

1. Ableev, V. G. et al. "Diffraction Scattering Of Alpha-Particles On Nuclei At 17.9 Gev/C". *Zeitschrift Für Physik A Hadrons And Nuclei*, vol 340, no. 2, 1991, pp. 191-197. *Springer Science And Business Media LLC*, doi:10.1007/bf01303832. Accessed 15 Apr 2021.

2. Association of Manufacturers and Formulators of Enzyme Products. "Why Enzyme Substances Are Not Nanomaterials". 2013, https://amfep.org/_ library/_ files/Why-enzymes-are-NOT-nanomaterials-Amfep-Statement.pdf. Accessed 15 Apr 2021.

3. Estermann, I., and O. Stern. "Beugung Von Molekularstrahlen". *Zeitschrift für Physik*, vol 61, no. 1-2, 1930, pp. 95-125. *Springer Science And Business Media LLC*, doi:10.1007/bf01340293. Accessed 16 Apr 2021.