ISSN: 2993-5377

Research Article

Open Access Journal of Applied Science and Technology

Alternative Approach to Copenhagen Interpretation

Pil-Jae Kim[1*]

Republic of Korea

[*]Corresponding Author
Pil-Jae Kim, Republic of Korea.

Submitted: 2024, Feb 02; **Accepted:** 2024, Feb 26; **Published:** 2024, Mar 05

Citation: Kim, P. J. (2024). Alternative Approach to Copenhagen Interpretation. *OA J Applied Sci Technol, 2*(1), 01-08.

Abstract

In this study, a double-slit experiment was simulated with only classical-mechanics assumptions to demonstrate that the phenomena associated with this experiment can be explained by classical mechanics. The experiment was conducted with the particle nature intact, by performing observations that did not affect the particle motion while recording the particle position at each simulation step. Only one experimental particle was assumed per session to prevent external effects. Nevertheless, wave patterns, which have previously been thought to occur only quantum-mechanically, were observed on the inspection plate. This study focused on proving that classical mechanics can explain the double-slit wave pattern.

Keywords: Double-Slit Experiment, Wave–Particle Duality, Simulation, Interference, Copenhagen Interpretation

1. Introduction

1.1 Copenhagen Interpretation

The Copenhagen interpretation is among the most widely accepted interpretations of quantum mechanics. It suggests that physical systems do not have definite properties prior to being measured and that the act of measurement affects the system. Consequently, the set of probabilities collapses to a single value [1]. This concept of wave function collapse is a fundamental aspect of quantum mechanics.

According to the Copenhagen interpretation, particles can exist as both waves and particles, with a wave function describing the probability of finding a particle at a given location. This wave–particle duality is a central feature of quantum mechanics and is often illustrated using the double-slit experiment.

1.1.1 Wavefunction Collapse

Wavefunction collapse is a fundamental concept in quantum mechanics that describes the collapse of the probability distribution of a particle into a single eigenstate upon measurement. This collapse is attributed to the interaction between the measuring device and the system being measured and is closely related to the Copenhagen interpretation of quantum mechanics. As Schrödinger stated, "The reason the function collapses at all and why the wave function chooses this alternative is that we have placed our measuring device in a position where only the former alternative could manifest itself." However, this interpretation has been subject to considerable debate [2]. Thus, a better understanding of wave function collapse and its relation to the Copenhagen interpretation is needed to clarify the fundamental principles of quantum mechanics.

According to the Copenhagen interpretation, a particle exists in the form of a wave while passing through the double slit; however, it collapses into a particle upon measurement. As noted by Schrödinger, this collapse is related to the interaction of the measuring device with the system. However, this explanation has been criticized as being counterintuitive and difficult to understand.

1.1.2. Doubts Regarding the Copenhagen Interpretation

Einstein did not accept the Copenhagen interpretation. One reason for this is that he believed it conflicted with the determinism of nature. According to the Copenhagen interpretation, without the intervention of an observer, quantum systems do not have a fixed state but only exist in a stochastic form. In contrast, Einstein said "God doesn't play dice" and preferred realistic and deterministic physical models [3].

1.2 Double-Slit Experiment

The double-slit experiment is the foundation of quantum mechanics, highlighting the wave–particle duality of matter. It involves shooting particles, such as electrons or photons, through a barrier containing two small parallel slits and observing the resulting interference pattern on a screen placed behind the barrier. Classical mechanics dictates that, for particles passing through a double slit, the observed pattern should comprise two distinct bands of particles aligned with the two slits. However, the actual pattern that emerges is a series of alternating bright and dark fringes, indicating wave-like behavior. This phenomenon has puzzled physicists for decades and is often used to illustrate the bizarre and counterintuitive nature of the quantum world. As Feynman famously said, "I think I can safely say that nobody understands quantum mechanics [4]."

Both small and large particles, such as electrons and C60, respectively, exhibit wave patterns in the double-slit experiment [5]. This demonstrates that quantum phenomena do not only affect subatomic particles, as evidenced by the observation of wave patterns from large particles.

2. Double-Slit Experiment Simulation

Simulation results cannot be used as definitive proof; however, from a computational engineering perspective, if the results of a simulation with limited conditions and assumptions agree with an observed phenomenon, they may provide a clue to the origin of the phenomenon. The simulations in this study were conducted using only the following assumptions, based on the laws of classical mechanics. The results indicate that the double-slit experiment can be explained by classical mechanics as well.

2.1 Simulation Assumptions

1. Particles move according to classical mechanics.
2. Particles move in a field space where the wave equations are applied.
3. For specific particles, circular waves are generated over time, and the source of the waves changes with a sine wave profile.
4. Waves generated by particles affect the motion of other particles in proportion to the intensity of the waves. When waves generated by the particles are returned to the particles through reflection and diffraction, they also affect the particles' motion.

The particles' positions were recorded and observed at every moment, and it was assumed that particles decayed because of their particle nature. These observations did not affect the particle motions.

2.2 Wave Equation

The wave equation can be easily derived from Hooke's law. The wave equation in two dimensions with a source-free region can be expressed as follows:

$$\frac{\partial^2 \delta}{\partial t^2} = c^2 \frac{\partial^2 \delta}{\partial x^2} + c^2 \frac{\partial^2 \delta}{\partial y^2},$$

Where c represents the speed of light. This equation can be discretized as

$$\frac{\delta_{i,j}^{(n+1)} - 2\delta_{i,j}^{(n)} + \delta_{i,j}^{(n-1)}}{\Delta t^2} = c^2 \frac{\delta_{i+1,j}^{(n)} - 2\delta_{i,j}^{(n)} + \delta_{i-1,j}^{(n)}}{\Delta x^2} + c^2 \frac{\delta_{i,j+1}^{(n)} - 2\delta_{i,j}^{(n)} + \delta_{i,j-1}^{(n)}}{\Delta y^2}.$$

Let $\Delta x = \Delta y$.

$$\delta_{i,j}^{(n+1)} = 2\delta_{i,j}^{(n)} - \delta_{i,j}^{(n-1)} + \left[c\frac{\Delta t}{\Delta x}\right]^2 (\delta_{i+1,j}^{(n)} + \delta_{i,j-1}^{(n)} - 4\delta_{i,j}^{(n)} + \delta_{i,j+1}^{(n)} + \delta_{i,j-1}^{(n)}$$

The above expression can be coded in MATLAB (version: R2022b, manufacturer: MathWorks, location: Natick, USA) as follows:

MATLAB code

```
wnp1(i, j) =
 2 * wn(i, j) - wnm1(i, j)
+ CFL2 * (wn(i + 1, j) + wn(i, j + 1) – 4 * wn(i, j) + wn(i - 1, j)
+ wn(i, j - 1));
```

where the Courant–Friedrichs–Lewy (CFL) condition is $\left[c\frac{\Delta t}{\Delta x}\right]$.

```
wnp1(i, j) =
 2 * wn(i, j) - wnm1(i, j)
+ CFL2 * (wn(i + 1, j) + wn(i, j + 1) – 4 * wn(i, j) + wn(i - 1, j)
+ wn(i, j - 1));
```

where the Courant–Friedrichs–Lewy (CFL) condition is [c Δt/Δx].

2.3 Initial demonstration

Figure 1 presents an example of the solution of the two-dimensional wave equation with a source-free region. The size of the ripple tank (with no units listed, as no actual experiments were conducted) was10 × 10, withdx=dy=0.1,dt=0.05 s, and c=1 (unit)/s. Four boundaries were considered with reflective boundary conditions. To develop the aforementioned MATLAB code, the code provided by Haroon was used [6].

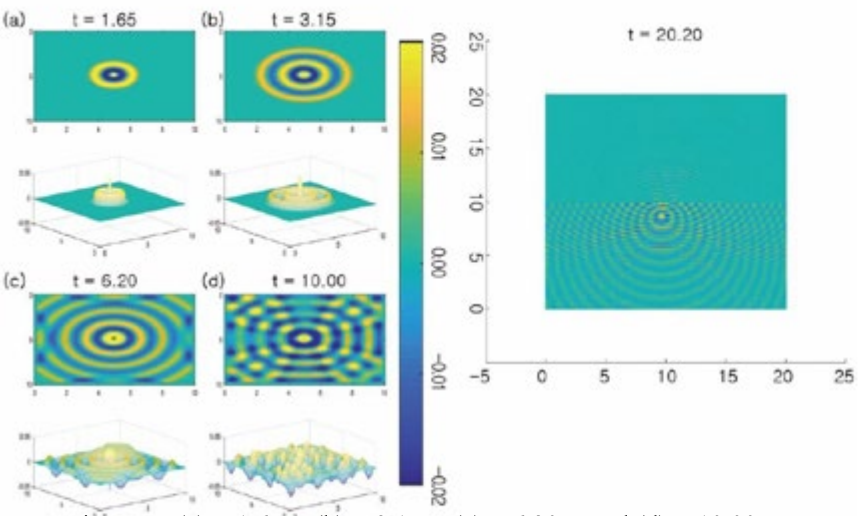

Figure 1: Left: results of the experiment at (a) t=1.65 s, (b) t=3.15 s, (c) t=6.20 s, and (d) t=10.00 s. Parameters: size of the ripple tank10×10 (unit^2),dx=dy=0.1 (unit), dt=0.05 s, and c=1 (unit)/s. Right: visualization of experimental conditions based on the Haroon code [6]

2.4 Self-Interference

It is obvious that the waves generated by particles influence the motions of other particles. However, waves are highly likely to return to their source because of diffraction and reflection. To obtain the correct result, waves returning to and changing the motion of the source must be considered.

Because there is no standing term to describe this phenomenon, I use the term "self-interference." This refers to a phenomenon in which a single particle creates a wave and the wave returns to the particle's position via reflection, diffraction, or a similar phenomenon, affecting the particle's motion.

2.5 Particle Position

According to the general interpretation of quantum mechanics, particles exist in a wave state before observation. In this experiment, to maintain the material state and show that only one side of the double-slit was transited, the position of the particle was recorded throughout the experiment. The URL of the corresponding file is provided in the Data and Code Availability section below.

2.6 Dynamic and Static Particles

The case in which the waves produced by the particle return to the particle via reflection and affect its motion was called the "dynamic particle" and the case where the wave does not influence the motion was called the "static particle."

3. Results

The position of a particle passing through the slit was recorded upon its arrival at the inspection plate on the far side of the experimental space. The y-axis in Figure 2 corresponds to the y-axis in the experimental space.

The two graphs on the left-hand side of Fig. 2 and the ratio presented below show the number of records indicating the specific slit that the particle passed through and the experimental results. In addition, the case in which no particle interference occurred was studied, as shown in the two plots on the right-hand side of Fig. 2. Subsequently, another computer simulation was performed without an applied force, owing to the difference in waves to the value of w_n ( ).

A wave pattern was observed on the inspection plate for dynamic particles. For static particles, the two-line pattern predicted by classical mechanics in the Copenhagen interpretation appeared.

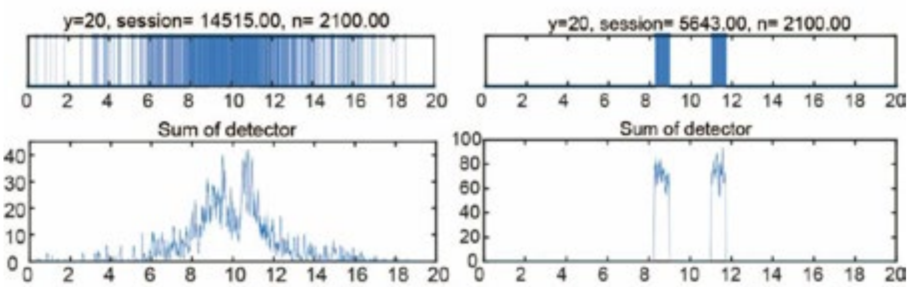

Figure 2: Visualization of the detector. For the upper left plot, y=20 (unit), number of sessions =14515, and the number of particles that hit the detector n=2100.A line was drawn at each position that a particle impacted the detector. The left lower plot was created using the five-array average to obtain the wave pattern. In the two plots on the right, the two-line patterns were obtained in the absence of field-induced movements

4. Discussion

According to the quantum mechanical assumption that observation affects outcome, no wave pattern can emerge from a particle's double slit, regardless of how the simulation is configured. However, as indicated by the results of this study, one extra assumption (that a particle's waves affect its motion) is sufficient to produce a significantly different outcome. Thus, we should consider the possibility that the results obtained with classical mechanics when the Copenhagen interpretation was formed were caused by the absence of this assumption.

It was possible to explain the double-slit phenomenon using classical mechanics because the simulation was configured with the above assumptions. Therefore, we should consider the possibility that the results of the double-slit experiment that led to quantum mechanics may not be caused by quantum effects but by properties of classical mechanics that have not yet been revealed.

Sometimes simulations show quantum effects because the experiment is configured with waves rather than particles. It is impossible to produce a wave pattern when the particle nature is maintained (because the position of the particle is recorded in memory at every moment) in a quantum mechanical description.

This is not to deny quantum mechanics, which has been extensively proven experimentally. However, at least the double-slit experiment can be explained with the assumptions of classical mechanics instead of quantum mechanical phenomena.

5. Conclusion

In this study, the double-slit experiment was simulated using only classical-mechanics assumptions. According to the general quantum mechanical interpretation, the particle's position was recorded in the computer's memory at every moment and observed. Hence, it was impossible to observe the wave pattern on the inspection plate, which is a quantum mechanical result, while maintaining the particle nature.

However, according to the experimental results, the particle passed through only one slit. By recording the position of the particle at each moment, wave patterns were observed that were previously thought to be impossible when the particle nature is maintained. This indicates that the phenomenon of wave pattern observation, which was controversial in the Copenhagen interpretation, was not considered in the assumptions of classical mechanics at that time.

This study only showed that classical mechanics can explain the results; it did not address the reason for the results or whether the experimental results match the simulation results.

In conclusion, the results of double-slit particle experiments can be explained by classical mechanics alone. Furthermore, this study demonstrated that the result reached by classical mechanics regarding the controversial result of the Copenhagen interpretation, was incorrect because there was something missing in the classical-mechanics assumptions.

This study was limited by a low resolution owing to computational complexity and the fact that the experiment was conducted in a two-dimensional space. More accurate results can be obtained if the experiment is scaled-up to overcome these limitations. We plan to do this in a follow-up study.

References

1. Bohr, N. (1928). *The quantum postulate and the recent development of atomic theory* (Vol. 3). Printed in Great Britain by R. & R. Clarke, Limited.
2. Schrödinger, E. (1935, October). Discussion of probability relations between separated systems. In *Mathematical Proceedings of the Cambridge Philosophical Society* (Vol. 31, No. 4, pp. 555-563). Cambridge University Press.
3. Einstein, A., Born, M., & Born, H. (1971). The Born-Einstein letters: correspondence between Albert Einstein and Max and Hedwig Born from 1916-1955, with commentaries by Max Born. (No Title).
4. Feynman, R. (1967). The character of physical law (1965). *Cox and Wyman Ltd., London.*
5. Nairz, O., Arndt, M., & Zeilinger, A. (2003). Quantum interference experiments with large molecules. *American Journal of Physics, 71*(4), 319-325.
6. Haroon, S. (2016). Lab12_2: Wave equation 2D. YouTube, Accessed 01 December 2023

Supplementary Materials
Materials and Methods
Initial Variables

This experiment did not consider the ratios of real-life experiments because the focus was on understanding the experimental possibility rather than replicating actual experiments.

Therefore, for convenience, the units are omitted. Nevertheless, a pixel can be defined as Therefore, for convenience, the units are omitted. Nevertheless, a pixel can be defined as (size of a pixel)× $\frac{1}{dx}$ ×*Lx*=20 (*Lx*=length of *x*-axis of ripple tank, *dx*=increment of *x*).

In the ripple tank, the lengths of the x- and y-axes were 20. For the tank size, the matrix (element size identical to the pixel size) was (200 × 200), where *nx*=200 and ny=200.

Table S1: The dimensions of the ripple tank, *Lx* and *Ly*, were set to 20 (unit) each, and *dx* and *dy* were set to 0.1 (unit) as differential coefficients. *nx* and *ny* represent the total number of pixels in the space. AorB was used to record the part of the slit that the wave passed through, and the detector resolution was 10 s *nx*. CFL is the Courant-Friedrichs-Lewy condition, where *c* is the speed of the wave and dt is the differential coefficient of *t*. T is the maximum time, and if it exceeds 100 *s*, the session is terminated.

```
%% Domain

% Space

Lx = 20;                    %x axis length of space
Ly = 20;                    %y axis length of space
dx = 0.1;                   %dx : differential coefficient
dy = dx;                    %dy is same to dx
nx = fix(Lx/dx);            %integer number of array(x)
ny = fix(Ly/dy);            %integer number of array(y)
S = 0;                      %Sum of lines

AorB = [uint32(0) uint32(0) uint32(0) uint32(0) int32(0)];

%recode numbers of which slit go through.
% 2 nd, 4 th number are left silt and right silt.
% Remain three numbers are hit the wall which wall(left, middle, right)

%Detectors

Sum_d = zeros(fix(10*nx),1);
detector_sub = zeros(fix(10*nx),1);
detector = false( fix(10*nx), 1);

% Parameters

CFL = 0.5;                  %CFL = c*dt/dx
c = 1;                      %c is propagation speed of wave
dt = CFL*dx/c;
T = 100;                    %max Time (Sec)
```

Moreover, in the above, variable S (variable considering the number of lines in the detector) represents the number of particles detected by the detector and *A* or *B* refer to the respective slits, thus indicating the passing or collision of particles. In addition, the size of the detectors was set to a (1,000×1) matrix and the CFL condition was $\left[c\frac{\Delta t}{\Delta x}\right]^2$ =0.5. *c*=1 And *dt*=0.05 were set to control the propagation velocity of the waves. The maximum time for the experiment in a session was set to *T*=100.

Table S2: The variables related to the initial velocity are defined, where v_x is 0.5 (unit)/s and v_y follows a uniform distribution within the range of -0.5–0.5 (unit) through a random function. The initial position is set as p_x = 10 (unit) and p_y = 0.3 (unit).

```
%% Time stepping loop
t = 0;
v_x = (0 + 0.1 * (rand() - 0.5));1
%initial velocity of particle

v_y = (0.5);        % initial velocity of y
p_x = fix(nx/2); % initial location of x
p_y = 0.3/dy;    % initial location of y
```

The initial velocities v_y and v_x were set to 0.5 and 0.8 × random (), respectively, and the initial locations p_x and p_y were set to 0.3 and 5.0, respectively.

Function w_n ( )

The function w_n ( ) is a height function of the wave at each location of the ripple tank at time t; in this experiment, it was defined by a 200 × 200 matrix.

Pixels

The field magnitude at each location for each pixel was quantified and color-coded for visualization purposes. The particle position was a real number (Z), and matter waves were assumed to be generated at the nearest-neighboring pixels. The particle position and response to w_n were as follows:

$$w_n(\lfloor p_x \rfloor, \lfloor p_y \rfloor),$$
$$\text{where } \lfloor x \rfloor = max\{\, m \in Z \mid m \leq x \,\}.$$

In the computer simulation, dx from the partial differential equation could not be set to zero. Thus, the points in the field were not continuous. The particle position was expressed by considering three digits, and the field size in the space was approximated by the pixels $\left(\left(\frac{1}{dx}\right) \cdot Lx\right.$ and $\left(\frac{1}{dy}\right) \cdot Ly)$ matrix. The experiment was designed such that the nearest pixel was affected by the wave generated by the particle.

Slits

Figure S1: shows the location of the slits

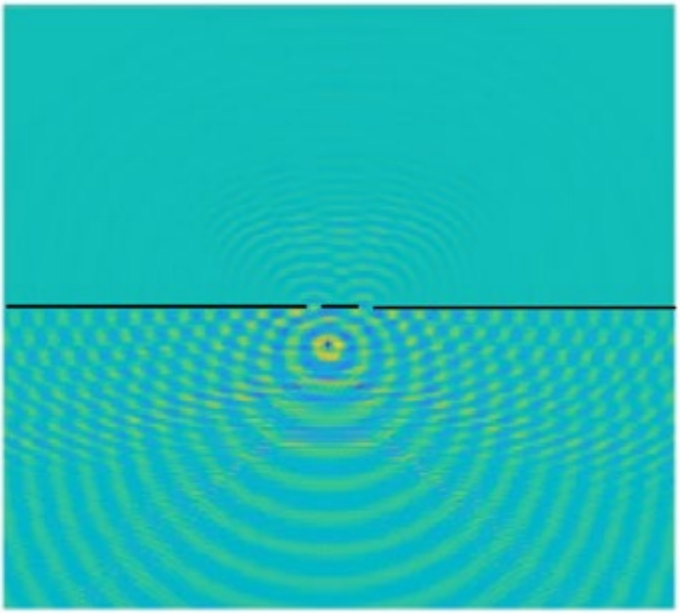

Figure S1: Location of the slits at $\boldsymbol{y} = \mathbf{10}$ (unit). The distance between the slits was 1.4 units, and the size of each slit was one unit. The session ends when a slit and pixel match. The wave equation was defined as $\frac{\partial^2 \delta}{\partial t^2} = c^2 \frac{\partial^2 \delta}{\partial x^2} + c^2 \frac{\partial^2 \delta}{\partial y^2}$. Reflecting boundary conditions were applied as the slit condition

Boundary Conditions

The absorbing boundary conditions were set and designed such that no reflections occurred at the experimental space boundary.

$$w_{n_{p1}}(1,:) = w_n(2,:) + ((CFL-1)/(CFL+1) \times (w_{n_{p1}}(2,:) - w_n(1,:)))^2$$
$$w_{n_{p1}}(end,:) = w_n(end-1,:) + ((CFL-1)/(CFL+1) \times (w_{n_{p1}}(end-1,:) - w_n(end,:)))$$

$$w_{n_{p1}}(:,1) = w_n(:,2) + ((CFL-1)/(CFL+1) \times (w_{n_{p1}}(:,2) - w_n(:,1)))$$
$$w_{n_{p1}}(:,end) = w_n(:,end-1) + ((CFL-1)/(CFL+1) \times (w_{n_{p1}}(:,end-1) - w_n(:,end)))$$

The absorbing boundary conditions were applied at the boundaries of each surface. When a pixel $W_n(\lfloor p_x \rfloor, \lfloor p_y \rfloor)$ reached the boundary, the corresponding session ended.

Velocity and Acceleration

The velocity of x and y is represented by v_x and v_y, respectively, and the location is represented by p_x and p_y, respectively. A moving pixel $W_n(\lfloor p_x \rfloor, \lfloor p_y \rfloor)$ was subject to a force in an opposite direction, depending on the height of a wave, as shown below.

Table S3: The design is based on the proportional relationship between the magnitude of *wn*() and the force, which represents the acceleration of speed. The variables k and l are used for discretization because *wn*() is discrete in space.

```
%velocity and acceleration
k = fix(p_x);
l = fix(p_y);
v_x = v_x - 3 * dx * (wn(k + 1, l) - wn(k - 1, l)) * dx/dt * 2;
v_y = v_y - 3 * dy * (wn(k, l + 1) - wn(k, l - 1)) * dy/dt * 2;
p_x = p_x + v_x * dt/dx; %p_x is the x-coordinate of the particle
p_y = p_y + v_y * dt/dy; %p_y is the y-coordinate of the particle
```

$$\frac{3((k+dx)-k+k-(k-dx))}{2}\frac{dx}{dt}\cdot 3\cdot dx, \frac{(k+dy)-k+k-(k-dy)}{2}\frac{dy}{dt}\cdot 3\cdot dy,$$

Where dx is a parameter denoting changes in the x-direction and "3" is an empirical value.

Observations

The observation code was developed to identify the slit that pixel $W_n(\lfloor p_x \rfloor, \lfloor p_y \rfloor)$ passed through. Moreover, a counter was recorded as the particle passed through the double slit to demonstrate that the particle did not collapse.

Table S4: Record of the particles that passed through the slits in MATLAB code. When a particle passed through the slit, its position was recorded as being on the left or right. AorB(2,1) and AorB(4,1) represent the left and right slits, respectively.

```
%passed through slit

 if fix(p_y) == fix(10.6/dx)
   if AorB(2, 1) + AorB(4, 1) <= S
     if p_x < nx/2
        AorB(2, 1) = AorB(2, 1) + 1;
     elseif p_x > nx/2
        AorB(4, 1) = AorB(4, 1) + 1;
     end
   end
end
```

Source

Initially, the experiment assumed that the particle was an electron; however, owing to the curved path, the particle was assumed to be a neutron that emitted a matter wave.

Table S5: Wave source in MATLAB code. The particle emits a sine wave over time.

```
wn(fix(p_x), fix(p_y)) = wn(fix(p_x), fix(p_y)) + ...
dt^2 * (2 * (1/dx)) * sin(50 * pi * (t) / 20) - dt^2 * (2 * (1/dx)) * sin(50 * pi * (t - dt) / 20);
```

A sine function was used as the source wave. In particular, a continuous sine wave was emitted from the particle. This wave propagated along the *x*- and *y*-axis space.

Detectors

A detector was located aty=20, and the matrix size was(1000×1).

Particle

For each session, the experiment assumed that only one particle was present. Moreover, no external effect was present except for the field changes owing to the transmission, reflection, and diffraction. After each session, the ripple tank was set to its initial conditions.

Computational Machine

Central processing unit: AMD Ryzen 9 3900X, 12-core processor operated at 3.79 GHz.
Memory: 32 GB (2666V).

Data S1-2. (Separate file)

This is the full MATLAB code comprising the separate code files for static and dynamic particles, each in a .m file (MATLAB). Data S1 represents the case of dynamic particles, and Data S2 represents the case of static particles.

Data S3-4. (Separate file)

The left graph represents the slit that the particle passed through. The three graphs show where the detector collides. The middle graph is the average of the five graphs, and the lower graph is the symmetric graph of the five-averaged graph. These graphs were collected when there were 50-2100 valid collisions. Data S3 represents the case of dynamic particles, and Data S4 represents the case of static particles, each in a .fig (MATLAB) file.

Data S5-6. (Separate file)

A file was created in CSV format for each session. The position of the particles at each time step was noted, with the time, p_x, and p_y being recorded. S5 represents the dynamic particles and S6 represents the static particles, each in a .csv file.