

Discrete Screen

Add up sines or cosines to make waves of different shapes. Discover how changing the amplitudes of different harmonics changes the sound you hear.

ADD harmonics

GRAPH each harmonic

OBSERVE the superposition

SELECT type of waveform

HEAR the harmonics

DISPLAY the equation

MEASURE the wavelength or period

EXPAND sum

Game Screen

Combine harmonics to match the target waveform. Set the number of amplitude controls to adjust the difficulty of the level.

ADJUST amplitudes to match the pink waveform

COLLECT stars

SET difficulty by adjusting number amplitude controls

CHECK your answer

COMPARE your waveform to the target

TRY another challenge

Wave Packet Screen

Construct wave packets and explore the effects of changing the spacing between Fourier components and wave packet width.

HIDE the graphs

DISPLAY wave packet width

SET spacing between components

ADJUST wave packet center and width; **CLICK** on tick mark label to set exact value

EXPLORE functions of space or time

Customization Options

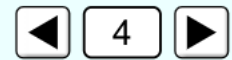
The following query parameters allow for customization of the simulation, and can be added by appending a '?' to the sim URL, and separating each query parameter with an '&'.

Query Parameter and Description	Examples
<code>gameLevels</code> - specifies which levels appear in the game.	<code>gameLevels=1,2,3</code>
<code>rewardScore</code> - sets the number of challenges that must be solved before being prompted to try another level (default is 5).	<code>rewardScore=3</code>
<code>screens</code> - specifies which screens are included in the sim and their order. Each screen should be separated by a comma. For more information, visit the Help Center .	<code>screens=1,2</code> <code>screens=3</code>
<code>audio</code> - if muted, audio is muted by default. If disabled, all audio is permanently turned off (this does not remove sound controls on the Discrete Screen).	<code>audio=muted</code> <code>audio=disabled</code>
<code>supportsPanAndZoom</code> - when true, enables panning and zooming of the simulation using pinch-to-zoom or browser zoom controls.	<code>supportsPanAndZoom=false</code>

Complex Controls

- The difficulty of the game can be adjusted by setting the number of Amplitude Controls. The minimum value is the number of non-zero harmonics. Increasing the value will randomly add amplitude sliders corresponding to harmonics that do not contribute to the pink waveform.
- Mousing over one of the amplitude sliders, the wavelength tool, or the period tool highlights the corresponding harmonic in the Harmonics graph.

Amplitude Controls:



Insight into Student Use

- Students with no background in Fourier analysis or quantum mechanics can learn a lot from the first two screens. The third screen usually requires more guidance.
- Students often confuse functions of space and time and use the terms “wavelength” and “period” interchangeably. Switching between the two (or both), and using the wavelength and period tools help them make the distinction clearer.
- Students often think that wavelength and period are properties of a specific location on the graph. Moving the wavelength and period tools can help them see that this is not the case.

Model Simplifications

- On the Discrete Screen, we refer to the terms in the Fourier series as “harmonics” because each term in the series has a frequency that is an integer multiple of the fundamental. However, on the Wave Packet screen, the terms displayed in the Components graph are not harmonics, so we use the more general term “component”.
- The Infinite Harmonics checkbox on the Discrete screen displays the waveform that results from an infinite number of harmonics. It is only enabled for the triangle, square, and sawtooth waveforms.
- The game requires exact answers to be considered correct.
- We use the convention for the wave number k normally used in Physics ($k = 2\pi/\lambda$) rather than the convention used in Spectroscopy ($k = 1/\lambda$).
- On the Wave Packet screen, σ_k and σ_x are the standard deviations of the Gaussian curves in Fourier and position space, respectively. They obey the uncertainty relation $\sigma_x\sigma_k = 1$. We use σ_k rather than Δk because students interpreted it as “the change in k ” in interviews. It is also easier to indicate the width on the graphs with the standard deviation than with the uncertainty.
- The Components on the Wave Packet screen are terms in the Fourier series. They appear at fixed locations and their amplitudes change as the center or width of the wave packet changes. The distribution may appear skewed if the spacing between components is large, the standard deviation is small, or the center does not align with the component spacing.
- Slider ranges on the Wave Packet screen were chosen to avoid the under-sampling that occurred in the Java version.
- Radians are dimensionless and omitted from the denominator for σ_x and σ_k .
- The y-axes on the Wave Packet screen are all auto-scaled. However, the y-axis scale for the Amplitudes and Components charts will not match. If the Wave Packet Center is not an integer multiple of the Component Spacing, the max component amplitude(s) will be less than the peak amplitude of the Continuous Waveform.

Suggestions for Use

Sample Challenge Prompts

- Predict what happens to a triangle, square, or sawtooth wave when the number of harmonics is increased or decreased.
- Determine which aspect of the Sum graph is described by each of the symbols in the equation.
- Describe the procedure you followed to match the pink waveform.
- Compare and contrast waves in space and waves in time.
- Explain the relationship between σ_k and σ_x .

See all published activities for Fourier: Making Waves [here](#).

For more tips on using PhET sims with your students, see [Tips for Using PhET](#).