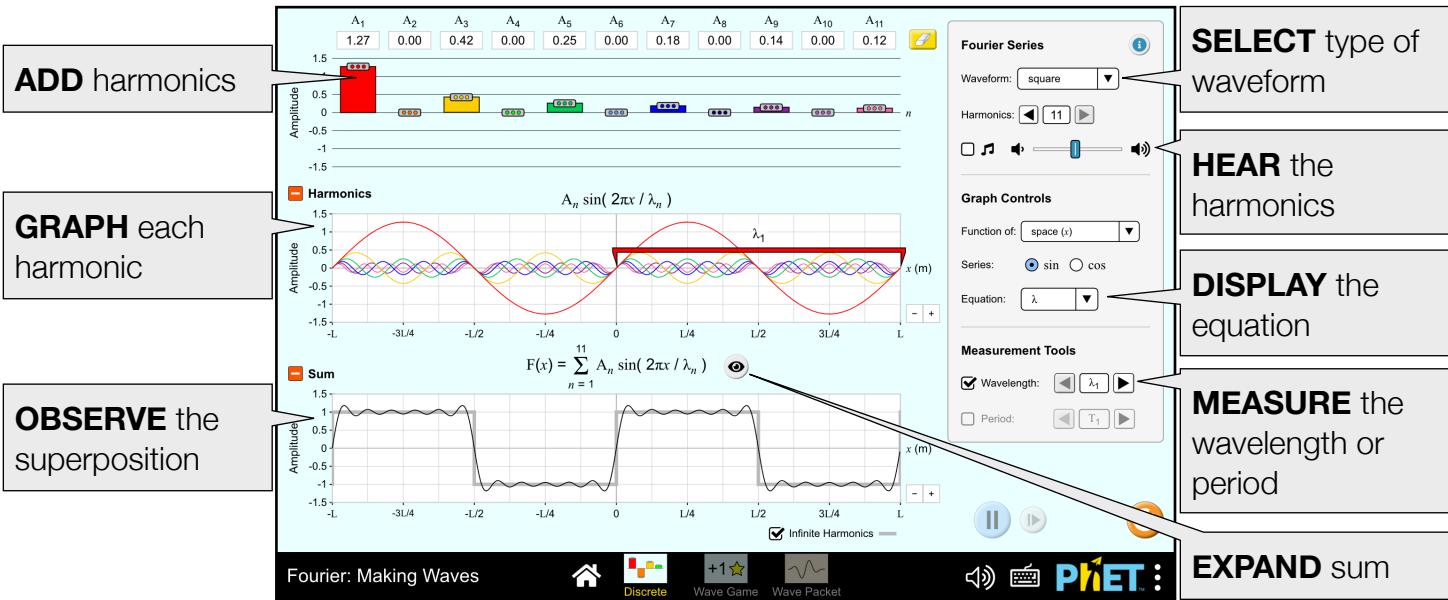


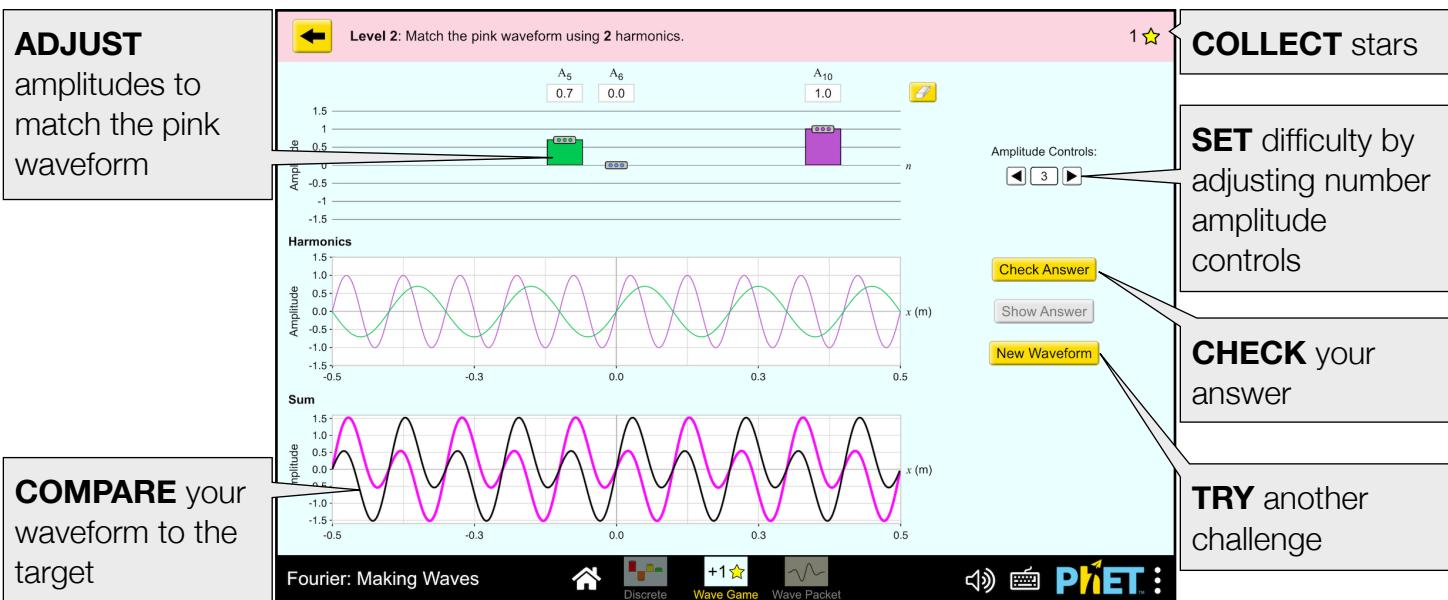
Discrete Screen

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



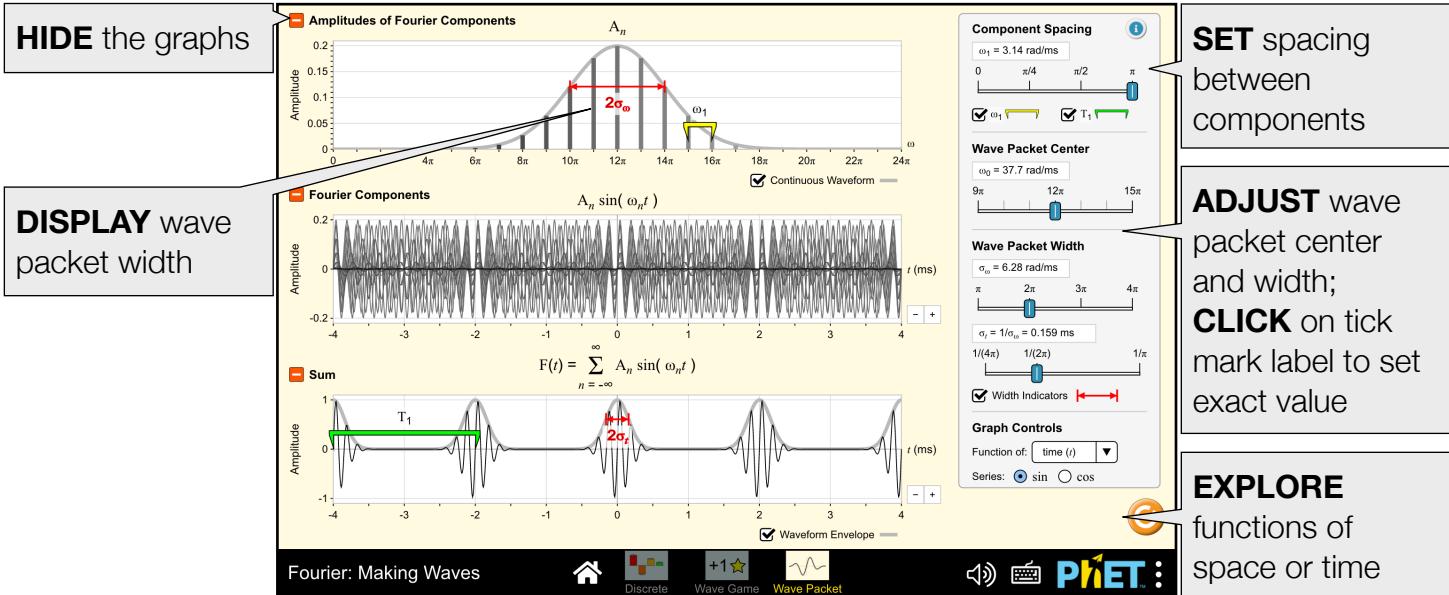
Game Screen

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



Wave Packet Screen

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



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.

Customization Options

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 a '&'. The general URL pattern is:

`...html?queryParameter1&queryParameter2&queryParameter3`

For example, in Fourier: Making Waves, if you only want to include the 1st and 2nd screens

(`screens=1,2`), with the 2nd screen open by default (`initialScreen=2`) use:

https://phet.colorado.edu/sims/html/fourier-making-waves/latest/fourier-making-waves_all.html?screens=1,2&initialScreen=2

To run this in Spanish (`locale=es`), the URL would become:

https://phet.colorado.edu/sims/html/fourier-making-waves/latest/fourier-making-waves_all.html?locale=es&screens=1,2&initialScreen=2

⊗ Indicates this customization can be accessed from the Preferences menu within the simulation.

Query Parameter and Description	Example Links
<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>initialScreen</code> - opens the sim directly to the specified screen, bypassing the home screen.	<code>initialScreen=1</code> <code>initialScreen=3</code>
⊗ <code>locale</code> - specify the language of the simulation using ISO 639-1 codes. Available locales can be found on the simulation page on the Translations tab . Note: this only works if the simulation URL ends in “_all.html”.	<code>locale=es</code> (Spanish) <code>locale=fr</code> (French)
<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>allowLinks</code> - when <code>false</code> , disables links that take students to an external URL. Default is <code>true</code> .	<code>allowLinks=false</code>
<code>supportsPanAndZoom</code> - when <code>false</code> , disables panning and zooming using pinch-to-zoom or browser zoom controls. Default is <code>true</code> .	<code>supportsPanAndZoom=false</code>

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_t .
- 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](#).