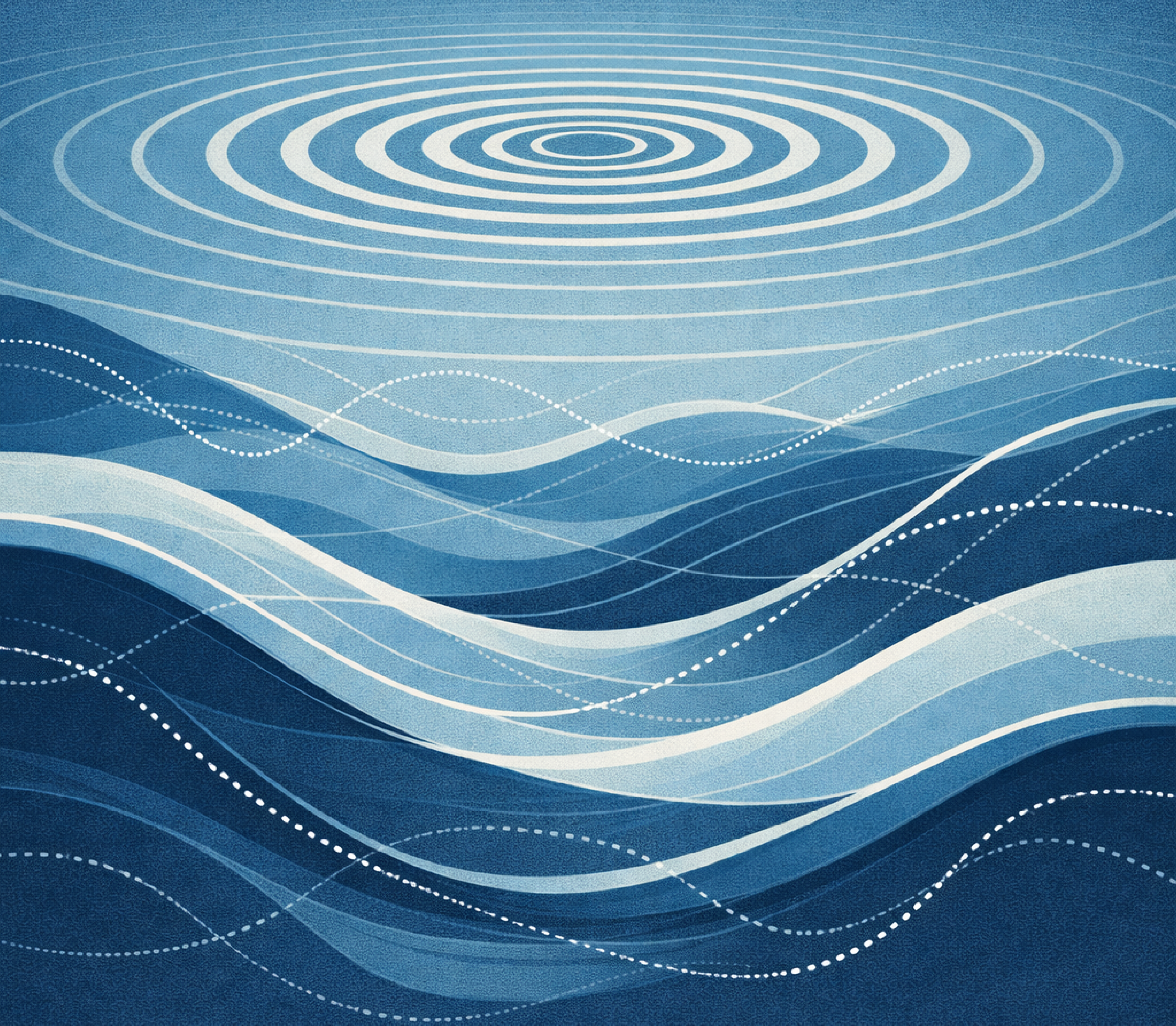
Making Waves
in Engineering

Ripple Tank Remote Laboratory



THE UNIVERSITY *of* EDINBURGH
School of Engineering

practable.io
non-traditional practical work

Measuring wave speed

Note: this activity should be performed with a 'single dipper' ripple tank, not the 'double dipper' tank which is used for the Interference activity instead.

Ripple tanks make waves controllable and visible. This gives us the opportunity to make direct measurements of wavelength for known wave frequencies and to investigate the relationship between wave speed (v), frequency (f) and wavelength (λ):

$$v = f\lambda \tag{1}$$

Non-dispersive waves have a constant speed, whereas waves that show dispersion are those where the speed of the wave changes depending on the wavelength. The splitting of white light into a spectrum by a prism is an example of dispersion, with different colours (wavelengths) of light travelling at different speeds through glass. Water waves are another example and we will investigate those with the ripple tank remote laboratory.

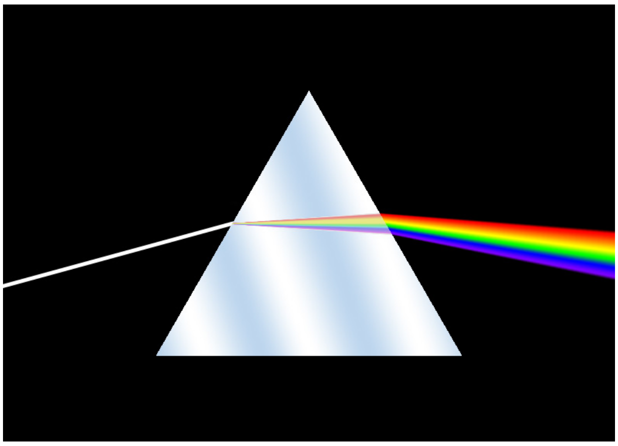


Figure 1: Dispersion of white light, containing a range of wavelengths, as it passes through glass. Image source: `https://commons.wikimedia.org/wiki/File:Dispersion_prism.jpg`

Surface water waves are driven by gravity and surface tension and these two forces contribute differently at different depths of water. In general, water waves are dispersive, with the speed of the wave depending on the wavelength of the wave, but in shallow water and with gravity dominating over surface tension, the wave speed is independent of the wavelength and defined by the depth of water (d) and the acceleration due to gravity ($g = 9.81m/s^2$):

$$v = \sqrt{gd} \tag{2}$$

These conditions are shown in Figure 2 as Region I, where v is constant with increasing wavelength. Region II shows the dispersion relation for deep water gravity-driven waves, while region III shows the relationship between speed and wavelength for water waves when surface tension is the dominant restoring force. For water waves, the minimum wave speed $v_{min} = 23cm/s$ at a wavelength $\lambda_0 = 1.7cm$, and this point is shown on Figure 2.

In this activity you will collect and analyse data to calculate the speed at which water waves travel in your ripple tank across a range of driving frequencies. You will compare your results to those expected for non-dispersive waves and identify the region in which your ripple tank is functioning.

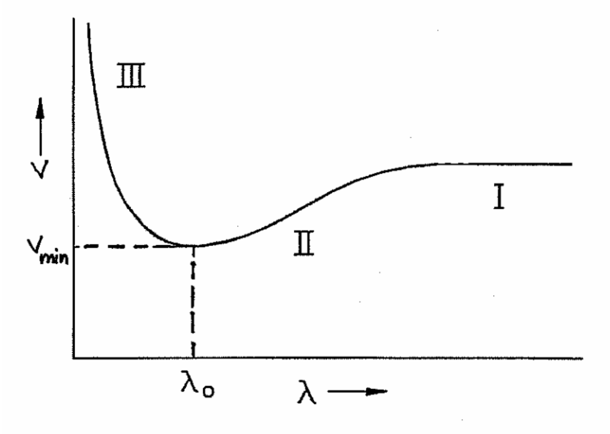


Figure 2: Dispersion curve for water waves showing three regions of behaviour. Image source, 2005 version of the wave phenomena activity available here: `https://www.physics.utoronto.ca/~phy224_324/LabManuals/WavePhenomena.pdf`

Controlling the ripple tank

Why do you think the default frequency of 24Hz looks like a stationary wave?

1) Set the frequency to 24Hz and start the vibrations by clicking the **on/off** toggle button. You should see a wave pattern in the video feed.
2) Capture an image of the waves by clicking the **Capture** button or by pressing the **'c'** key on your keyboard. This will store an image that you can perform measurements on later.
3) Increase the frequency of vibrations by 10Hz using the +10 button. Check that the waves in the video change appropriately when you update the frequency.
4) Capture an image of the waves at this updated frequency.
5) Repeat 3 and 4 up to 94Hz, capturing an image at each frequency.
6) Switch off the vibration generator by clicking the toggle to 'off'.

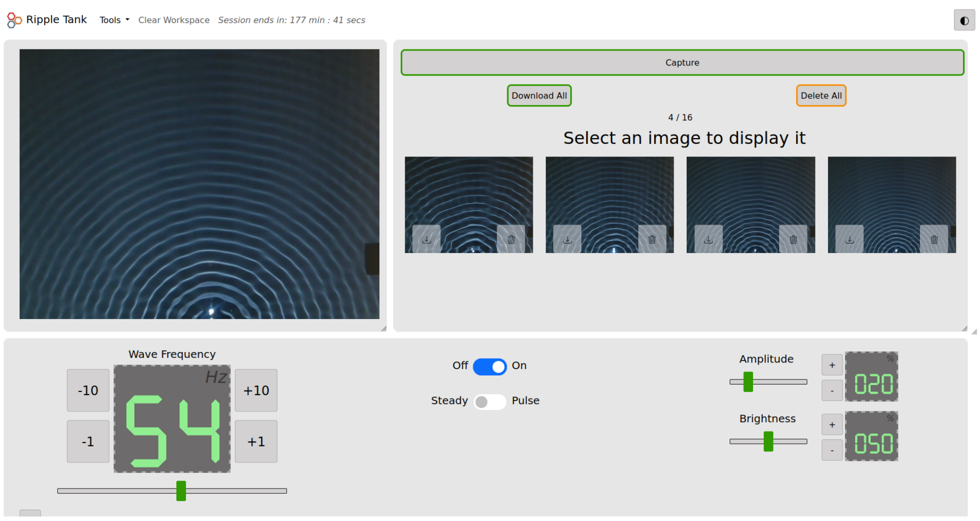


Figure 3: Screenshot of UI with captured images

If you do change the window or component size then you need to re-calibrate the ruler.

Measuring wavelength

1) Select one of your images, by clicking it in the image capture component.
2) You can resize each component on the user interface by clicking and dragging in the bottom right corner of the component. You may wish to increase the size of the image capture component for making measurements - for an example, see Figure 4.
3) Click on the **Tools** menu in the bar at the top and select **Ruler**.
4) Using the buttons that appear on the user interface (see Figure 4), calibrate your ruler tool by **rotating** it and **changing its size** until the ruler measures the black calibration strip as 1.5cm (see Figure 4).
5) Without changing the size of your ruler or window, measure the distance across 10 wavelengths (i.e. starting at a bright line, measure the distance to the tenth bright line from that). Calculate the wavelength of the waves by dividing your measured distance by 10.
6) Your measured wavelength will depend on the set frequency for your captured image, but should be within the approximate range of 0.2 - 1.5 cm. Confirm this.

You may want to note your results on paper too, just in case you close or refresh the interface and lose your data.

7) In the UI table, input the set frequency for the selected image (see Figure 5).
8) In the UI table, input your measured wavelength for the selected image.
9) Click **Record Snapshot** to record that data point.
10) Repeat 5-9 for at least 5 more images of increasing frequency.
11) Download your data. This ensures that you can recover your measurements if you accidentally close the interface.

NOTE: The ruler and protractor tools are displayed on a layer on top of the main interface, so if you need to interact with any part of the interface after opening the ruler or protractor then first click 'Toggle Workspace' (see top left of Figure 4). This will hide the ruler/protractor tool so that you can use the interface below, to show the ruler again click 'Toggle Workspace'. This is particularly important when using smaller screens or touchscreens where you may need to scroll the screen whilst using the ruler or protractor tool.

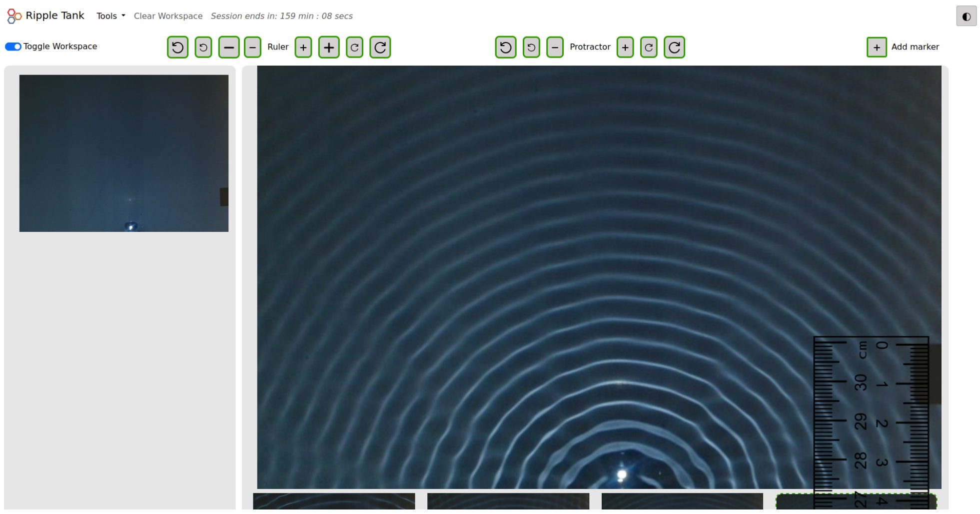


Figure 4: Screenshot of UI with ruler tool

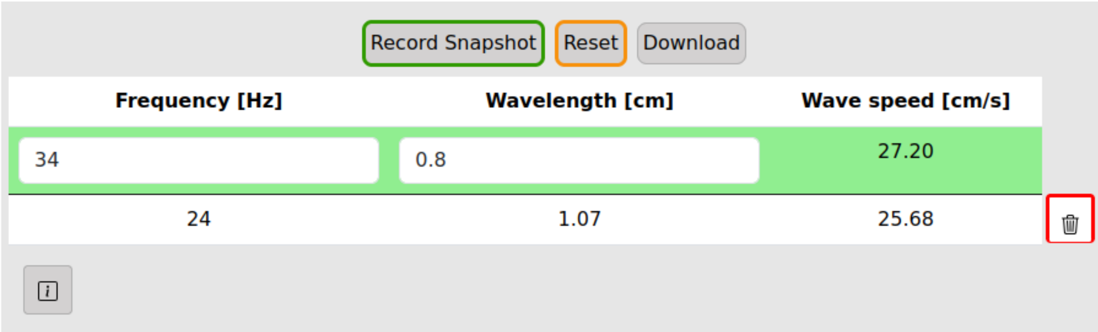


Figure 5: Screenshot of UI table tool for entering measurements.

Analysis

A graph is automatically plotted on the user interface that should help you.

1) Describe the relationship between measured wavelength and frequency?

2) Using Equation 2 calculate the expected wave speed given the depth of the ripple tank is $d = 10mm$. How does this compare to the wave speeds for your measured waves?

3) Is wave speed independent of wavelength? What is the relationship between wavelength and wave speed?

4) Are the waves in your ripple tank dispersive or non-dispersive? Which region of Figure 2 is your ripple tank functioning in?

Interference of waves

Note: this activity can only be run on a ripple tank setup with a double dipper to generate two sources of waves, so make sure you have selected a 'double dipper' ripple tank.

The atomic and molecular structure of materials can be studied using waves. Since many of these structures are themselves smaller than visible light, shorter wavelength parts of the electromagnetic spectrum (and even the wave nature of particles like electrons) are used. This includes X-rays, which were used by Rosalind Franklin to study the structure of DNA. As X-rays pass through DNA strands, the waves diffract and interfere to generate a unique pattern that depends on the structure of the molecule. From images such as that shown in Figure 6 the size and spacing of atoms in the DNA double helix were calculated.

In this activity, you will measure the separation between two sources of waves (as a model of atomic spacing) by measuring the interference pattern generated by a double dipper in the ripple tank.

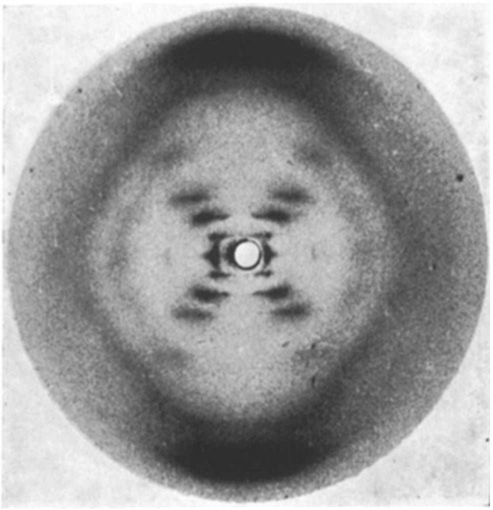


Figure 6: X-ray crystallography of DNA. Photo taken by Rosalind Franklin, 1952. Reproduced by Maria Evagorou, Sibel Erduran, Terhi Mäntylä `doi:10.1186/s40594-015-0024-x`

Theory

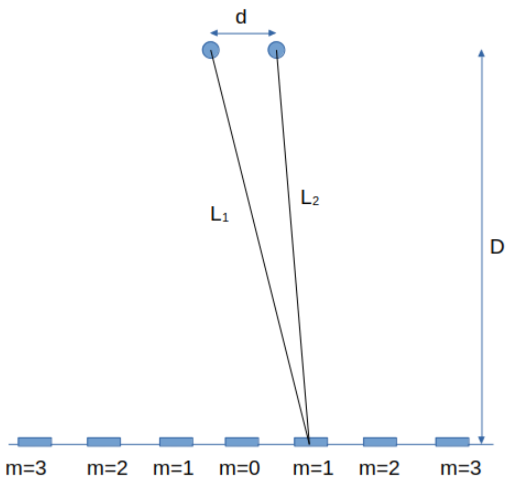
When waves from two sources meet they form a superposition, with the amplitude of each wave adding together. For coherent sources, there are positions where these two waves will always meet in phase and constructively interfere – visible as larger amplitude waves in the ripple tank (called maxima). Similarly, there will be positions where the waves meet completely out of phase (anti-phase) and destructively interfere – resulting in zero amplitude (minima).

Any position where waves from the two sources have a path difference equal to a whole number of wavelengths will meet in phase. Any position where waves from the two sources have a path difference that is half a wavelength different, will meet in anti-phase. In equation form:

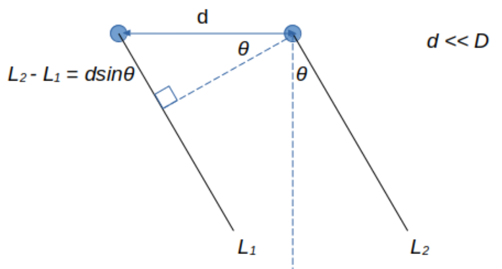
$$\Delta L = L_2 - L_1 = m\lambda \quad \text{for maxima} \tag{3}$$

$$\Delta L = L_2 - L_1 = (m + \frac{1}{2})\lambda \quad \text{for minima} \tag{4}$$

If we assume that the source separation d « D, the distance to the plane containing the maxima and minima, then the above equations, combined with the relationship shown in Figure 7b, results in:



(a) Interference maxima due to two coherent sources of waves.



(b) Relationship between path difference, angle and source separation.

Figure 7

$$L_2 - L_1 = m\lambda = dsin\theta_m \quad \text{for maxima} \tag{5}$$

Where θ_m is the angle to maximum m.

Procedure

1) Before starting the vibration generator, capture an image of the tank for calibration.
2) Set the wave generator frequency to **64Hz** and capture an image. Can you identify positions where maxima and minima exist?
3) Set the frequency to a value much **lower** than 64Hz and capture an image.
4) Set the frequency to a value much **higher** than 64Hz and capture an image.
5) Select the first image you took (with no vibration) and scale the image component to a reasonable size.
6) Open up the **Ruler** from the **Tools** menu. Calibrate your ruler tool using this image. Remember not to change the size of your window or user interface elements after calibrating.
7) Select the image corresponding to the set frequency of 64Hz.
8) By clicking **Add marker** and then moving the markers to appropriate positions, add a marker above the position of each of the two sources - see Figure 8.
9) Now add markers to the maxima from $m = 1$ to the largest visible, placing them as vertically far from the sources as possible and in the same plane as each other - see Figure 8.
10) Measure the path difference, $L2 - L1$, using the **Ruler**, for the largest order maxima visible ($m = 4$ in Figure 8).
11) Calculate the wavelength using Equation 5

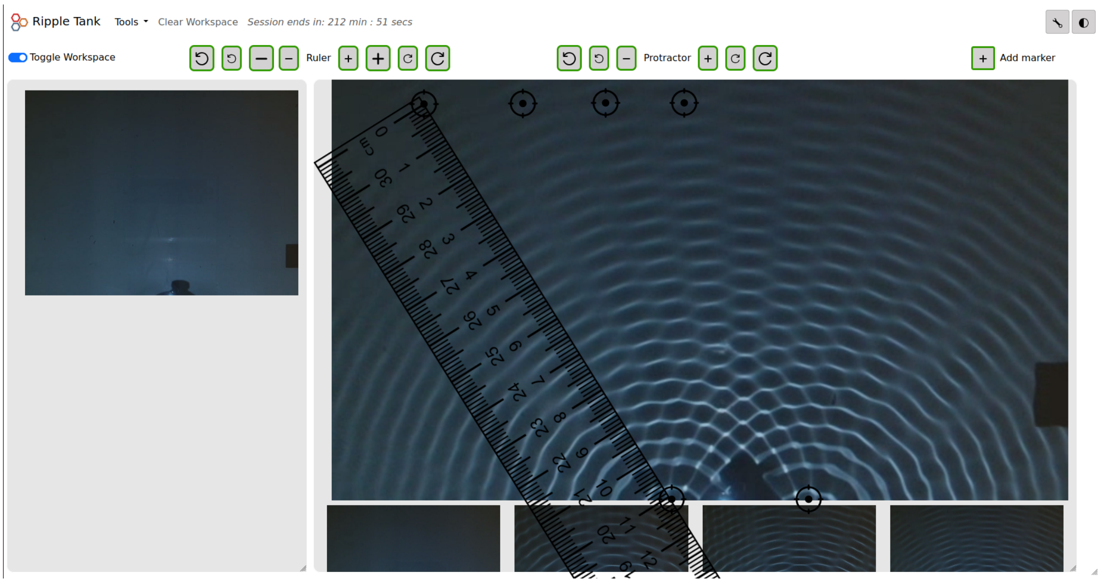


Figure 8: Screenshot of UI during a measurement of the path length from one source to the 4th order maximum.

Analysis and extensions

1) If you have already measured the wavelength for a frequency of 64Hz in an earlier activity, how do your measured values compare?
2) By measuring the angle to the largest order maximum and using Equation 5, calculate the separation between the two sources, d.
3) With the calibrated ruler, measure the separation between the two sources. How does it compare to your calculation above?

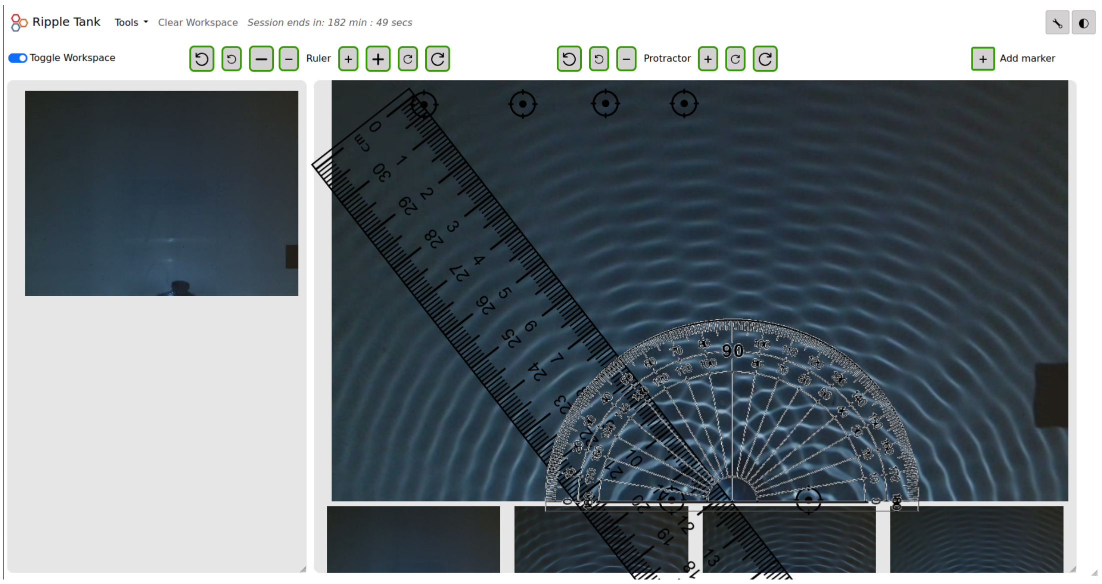


Figure 9: Screenshot of UI during a measurement of the angle to the 4th order maximum.

References

Ruxandra M. Serbanescu, 2020, Wave Phenomena, `https://www.physics.utoronto.ca/~phy224_324/LabManuals/WavePhenomena.pdf`

Troubleshooting

Different operating systems and browsers can result in different layouts and display. Below is a brief guide to some possible layout issues.

1 Everything looks too big or small on screen

If all components appear too big or small then you can zoom your browser page by pressing Ctrl and + (to zoom in) or Ctrl and - (to zoom out). If you are using the ruler or protractor tools during the zoom, then please click 'Clear workspace' and re-open the tool to ensure correct functioning of the tool after zooming.

2 I want to change the size of a single component

Each component can be individually sized using the small icon in the bottom right of each component - it should look like small, diagonal, parallel lines (but may differ on different browsers). Components in a row can be scaled horizontally. Each row can be scaled vertically using the same icon at the bottom right of a row.

3 I'm clicking the buttons but nothing is happening

If you have the ruler or protractor tool on display then you cannot interact with the hardware buttons until you click the 'Toggle Workspace' button. This will hide the ruler/protractor so that you can use the interface buttons. Click 'Toggle Workspace' again to return to using the measuring tools.

4 I have the generator switched off but I can see a wave pattern in my ripple tank

These remote lab experiments are stacked next to each other and, under certain conditions, the vibrations from one tank can create a visible pattern in another one next to it. This should be faint in comparison to the waves generated by your own tank and when you are generating waves it should have very little effect.

5 I'm trying to capture an image but things are changing too fast for me to respond

The keyboard can be used for some interactions. The 'p' key will start pulse mode and the 'c' key can be used to quickly capture images. Alternatively, there is a video recording component that can capture up to 3 seconds of video. Clicking 'r' will start the video recording and you can step through the video frame by frame.

6 I increased the size of the ruler tool but it has disappeared off screen

You will need to click 'Clear workspace' and then add the ruler again. Try to keep the ruler closer to the centre of the screen whilst you are zooming and don't zoom too quickly.