Wave pulses in a magnetically active fluid (10 points)

Introduction

In this question you will investigate the properties of wave pulses in ferrofluids. The surface wave pulses which can be generated in the fluids are due to the interaction of the effects of gravity, surface tension and magnetic forces.

For wave pulses, there is no single wavelength or frequency of the pulse, however, it is known that the speed of propagation of a pulse in the absence of a magnetic field is

$$v(d) = \kappa\sqrt{d}, \tag{1}$$

where d is the depth of the fluid and α is a constant of proportionality. This relationship only applies for smaller wave amplitudes. When the wave amplitude is large the changed fluid depth due to the pulse causes changes in speed of propagation resulting in nonlinear effects. When the nonlinear effects are not significant, wave pulses approximately maintain their profiles as they propagate. However, when nonlinear effects are significant the pulses can change their profile as they propagate and often develop ripples either ahead or behind of the main pulse.

Part A: Plane pulses (1.3 points)

(a) (b) (c)

Photos of the required set up, (a) the glass dish with ferrofluid on the wooden base, (b) the glass dish on the wooden base, under the light shroud and stand, and (c) the camera on the light shroud and stand.

In order to generate plane waves in your ferrofluid, place the container with the ferrofluid on the wooden base, with a long side of the dish along the barrier at the edge of the base. The barrier is to ensure that your dish moves only in one direction when pushed. Ensure that the base is flat and level. To generate pulses, push the dish sharply with your hand a distance of around 2 cm. To ensure consistency in your pulse generation, you can use blu-tack and/or wooden spacers on the wooden base to mark starting and finishing positions for the ferrofluid container. It is recommended that you practice generating pulses at least a few times to be able to generate more consistent pulses.

The stand should then be set up over the dish. The lamp must be used to provide adequate lighting to be able to observe pulses in the fluid. Ensure that you can generate plane wave pulses and observe them by eye through the stand. Once you are able to do this, place the camera on the stand and make a video of a pulse. Note that the lighting and pulse amplitude may need to be adjusted to make a useful video. To adjust the lighting you can use blu-tack to place the light in an appropriate position, and may wish to use the aluminium foil to block or further direct the light.

When adjusting the lighting it is important to consider how to minimise light directly from the source into the camera, and also how to minimise reflections from the lid of the container. Reminder: you must NOT remove the lid from the container for safety reasons. Two options which can be useful in different situations are to have very diffuse light from all directions within the stand, or to direct light onto the fluid through the glass sides of the container.

See the description of the camera in Appendix A for how to make and playback videos. Note that the default automatic settings of the camera are suitable for making the required videos. If you are having difficulty clearly recording the observed effects, you need to adjust the lighting to be able to more clearly observe the wave pulses.

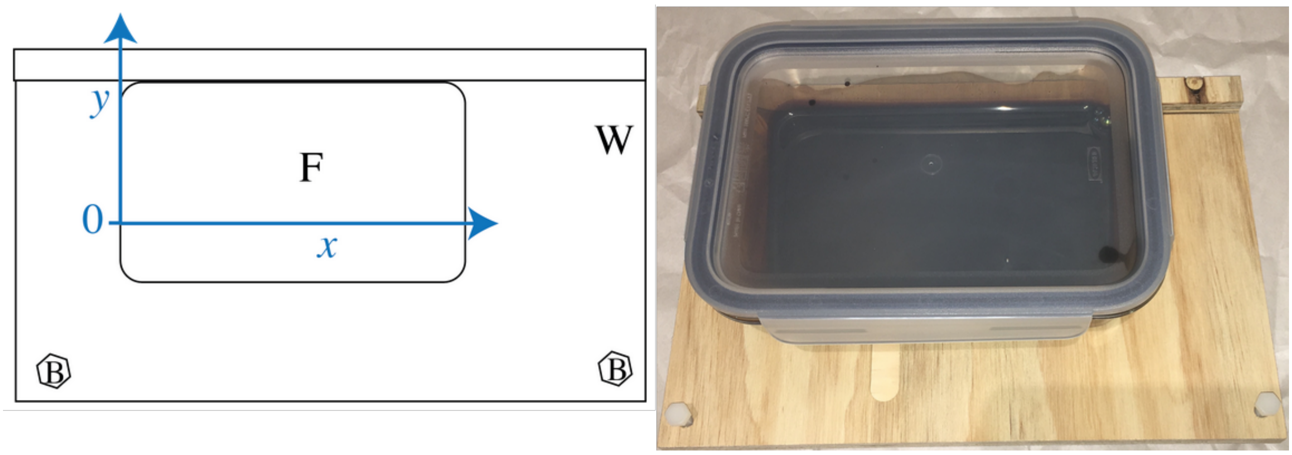
A.1	Draw a diagram of your set up, showing in particular how you positioned and directed the light.	0.3pt

A.2	Perform measurements and calculations from a video to find the speed of the waves in the ferrofluid. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	0.8pt

A.3	Make an estimate of the uncertainty of your measurement, showing any formulae you use to make the estimate.	0.2pt

Part B: Waves pulses in fluid of varying depth (3.4 points)

Insert the nylon bolts into the holes in the corner of the wooden base. By adjusting the bolts you can set up the platform so that the fluid depth in the container varies linearly with the distance from the lower edge (y-direction), and does not vary in the perpendicular direction (x-direction). We chose $y = 0$ to be where the depth of the fluid $d = 0$, so that the xy plane is the plane of the fluid's surface.



The set up of the glass dish with ferrofluid F on wooden base W so that the depth varies in the y-direction.

As the speed of waves in a fluid varies with depth, if a plane pulse is generated at one end of the container it will become curved as it propagates.

Set up your glass dish with ferrofluid on the wooden base so that you will best be able to characterise the variation of pulse speed with depth in the ferrofluid.

B.1	i. Draw a diagram of the container with ferrofluid as you set it up. Mark measurements, with uncertainties, of all distances which are important for you to know depth as a function of y in the container. ii. Write an expression for $d(y)$.	0.3pt

B.2	Generate plane wave pulses in your container, and qualitatively sketch a pulse you observe. Mark on your sketch the region where the pulse travels fastest with the letter A, and where it travels slowest with the letter B. Note: You will need to adjust the position of the light to clearly observe the pulses. To adjust the lighting you can use blu-tack to place the light in an appropriate position, and may wish to use the aluminium foil to make light blockers or light reflectors to further direct the light.	0.3pt

To a first approximation, we consider the pulse which is initially travelling in the x direction to remain travelling in the x direction only. Note: (x, y) are coordinates of points at time t are coordinates of points on the pulse at time t.

B.3	i. For a planar pulse which is at $x = 0$ when $t = 0$, find a relationship between x, y and t. ii. Mark on your diagram from B2, with the letter V, where within the glass dish with ferrofluid as you have it set up, this approximation is more valid?	0.3pt

B.4	Draw a diagram of your set up, showing in particular the position and direction of the light. Collect data to find κ and record in the table in the answer sheet. Include estimates of uncertainty for all data. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	1.2pt

B.5	i. Use a graphical method to calculate a value for κ. Include error bars for each measurement. Provide details of any formulae you use to calculate v, its estimated uncertainty Δv, d and its estimated uncertainty Δd. Record any additional calculated values for your graphs in the tables for B4. ii. From your data, state conditions on x, y and t for the relationship you developed in B3 to describe the observed wave pulses.	1.3pt

Part C: Wave and magnetic effects (1.8 points)

Warning: if the magnets collide they are likely to break. Broken magnets are dangerous, and yours will not be replaced if you break it.

As you observed in Question 1, in the presence of a magnetic field, the ferrofluid moves into the region of the strongest field. Your aim in this part is to investigate the interaction of wave a magnetic effects qualitatively.

Set up the ferrofluid container so that the ferrofluid has constant depth, as when you generated plane pulses. Next, place two small magnets underneath, as shown below. The magnets should have their poles aligned so that they repel each other when they are pushed together sideways in the channel on the wooden board. They should be positioned so that, with the ferrofluid in place, they are as close together as possible without repelling.

A safe way to put the magnets in place is to put **one** in the channel, then place the glass dish with ferrofluid over the track.You can use a wooden spacer in the track to position your magnet. The second magnet can then be slid into position, starting next to the dish, and using the spacer to push it along the channel under the ferrofluid.

Generate wave pulses using the following three methods:

- magnetically by rapidly withdrawing the large N42 magnet from near to the ferrofluid,
- mechanically by sliding the container on the wooden base, and
- mechanically by sliding the wooden base with the container fixed in place on top.

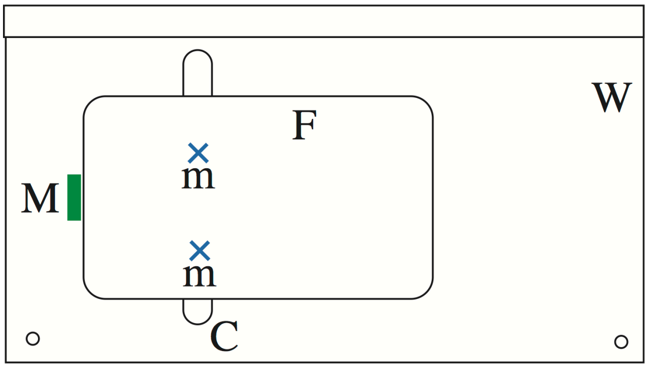


Diagram showing where to place the large magnet M, before rapidly removing it to generate a pulse travelling through the ferrofluid, where F is the glass dish with ferrofluid, m are the small magnets, W is the wooden base and C is the channel.

C.1	Sketch qualitative observations of the wave pulses for all three types of driving. Ensure that the diagrams clearly show how the presence of the magnets under the ferrofluid affects the wave front of the pulses. Identify all types of wave phenomena you observe. Mark with the corresponding number which effects cause which features of the observed pulse propagation. 1. reflection 2. refraction 3. doppler effect 4. beats 5. diffraction 6. interference (a) standing waves (b) from two slits or sources (c) from a diffraction grating (d) other	1.8pt

Part D: Internal properties of ferrofluid within a strong magnetic field (3.5 points)

In this part your aim is to quantify the effect of a magnet on pulse propagation in a ferrofluid.

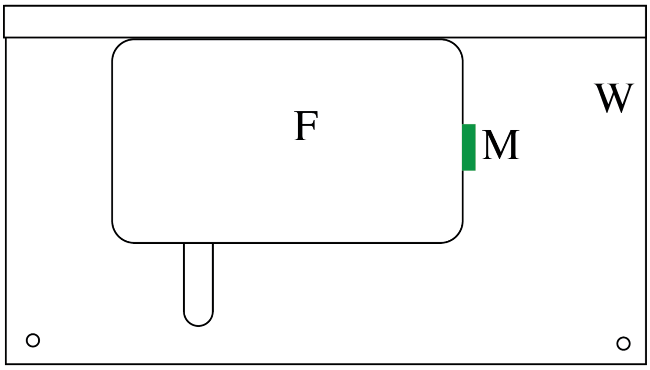


Diagram showing positioning of magnet in order to drive wave pulses in D1.

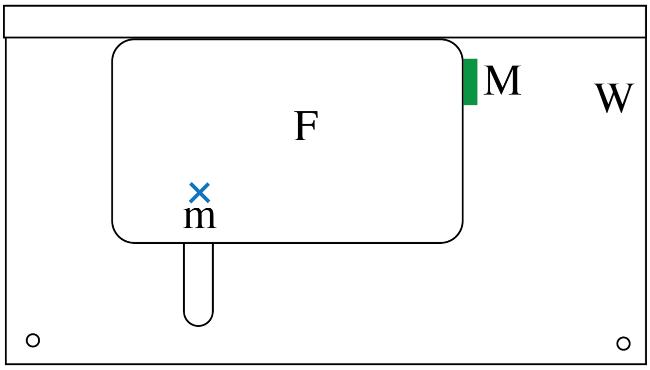
Set up the ferrofluid container so that the ferrofluid has constant depth, as when you generated plane pulses.

Generate pulses magnetically using the **large** N42 magnet, as in C1, and adjust the lighting to clearly observe the magnetically driven pulses.

D.1	Qualitative sketch a magnetically driven pulse in the ferrofluid.	0.2pt

D.2	Determine the speed of the pulse with its uncertainty. Sketch and diagram of your set up, including light position and direction, and record all data and formulae you use. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	0.8pt

Now place a single small magnet into the channel in the wooden base, and then place the dish and ferrofluid over the magnet. Its position can be adjusted using the wooden spacers, both in the track and to push the magnet around under the glass dish.



The position of the small magnet under the glass dish with ferrofluid is marked with an x, and the position of the large magnet, which is held outside the dish and then rapidly removed to generate a wave pulse, is labelled M.

Generate wave pulses magnetically, by starting with the large magnet in the position marked in the diagram above, and observe them travelling through the ferrofluid, including the region with the strong magnetic field.

D.3	Sketch qualitative observations of the wave pulses. Ensure that the diagrams clearly show how the presence of the magnet under the fluid affects the wave front.	0.4pt

D.4	Draw a diagram of your set up to determine the effect of the presence of the magnet under the fluid on the propagation time for a wave pulse. Clearly mark the positions of the magnets and also the light.	0.3pt

D.5	Make and record measurements with uncertainty estimates to determine the travel time of a pulse across the region with the magnet. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	1.0pt

D.6	Does the additional depth of the ferrofluid over the magnet explain the difference in speed of the wave pulses? Show calculations to support your answer.	0.8pt

Appendix A: How to use Canon IXUS-185

To turn the camera on or off press the button (O) labeled "ON/OFF" at the top of the camera. Note that the camera automatically turns off after a time.

To focus the camera, press the button (S) on the top of the camera part way.

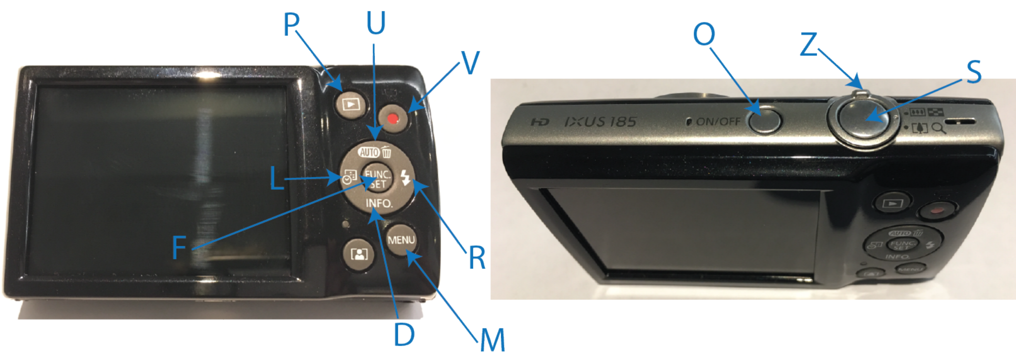
To take a photo press the button (S) on the top of the camera.

To take a video press the button marked with a red dot (V) to start recording. Press it again to stop recording. Note that the default HD videos record at 25 frames per second.

To view photos or videos you have taken, press the review button (P). Use the right (R) and left (L) buttons on the ring button on the back of the camera to navigate through your photos and videos.

- You can zoom in or out of photos using the ring (Z) on the top of the camera. Note: you cannot zoom after taking a video.
- To play a video press the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera twice.
- To pause a video, press the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera while the video is playing.
- When a video is paused you have options on the bottom of the screen. From left to right the options are: Exit, Play, Slow Motion, Skip Backwards, Previous Frame, Next Frame, Skip Forward. Use the right (R) and left (L) buttons on the ring button on the back of the camera to navigate through options, and the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera to change the volume of video playback.

To zoom in or out, push the ring (Z) to the left to zoom out and to the right to zoom in.



To enter the camera settings menu press the button (M) labeled "MENU", then use the right ring button (R) on the back of the camera to enter the camera settings menu. Note that the first option is to mute the camera sounds.

- Use the right (R), left (L), up (U) and down (D) buttons on the ring button on the back of the camera to navigate through the menu.
- Use the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera to select options.
- Use the "MENU" button (M) to exit the menu or to move back up through the menus.

To change the language of the camera, first enter the camera settings menu (see above). Press the down right button (D), labelled "INFO." on the back of the camera to scroll down the many page list to find "Language". Next press the right ring button (R) on the back of the camera to enter the list of language options. The the right (R), left (L), up (U) and down (D) buttons on the ring button on the back of the camera to navigate to the language of your choice. Use the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera to select the language.

Note: You are not expected to change any settings on the camera, except for optionally changing the language, as the default automatic settings are suitable for the videos are you are required to make. You will benefit more from adjusting the lighting of your set up.