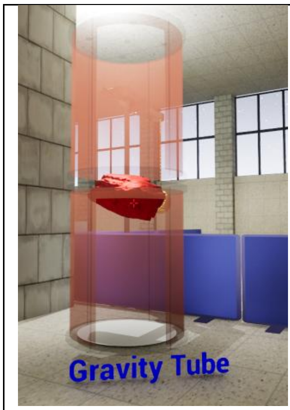
Chapter F
Gravity Tube

F.1 Summary of the Physics

Input from Teachers here



F.2 PhysLab Experiments

ROADMAP

Overview of chapter - maybe

DEMONSTRATION

F1 Observation of the Oscillator and its Time-Trace

We wish to see how the oscillator behaves, both by direct observation and also through inspection of its time-traces. The physics is clearly very different from the physics of harmonic oscillators, so we expect some pleasant surprises. One important feature of the physics is the *discontinuity* between the applied force when the rock moves from the top field (gravity down) to the bottom field (gravity up).

Here's the steps you will need to do for this demonstration.

a) Select the apparatus then press **F** and choose **Demo1**.
b) Press **F1** then **T** and observe the time traces and also the movement of the rock. Do either the time trace *z-t* or *v-t* show evidence of non-harmonic oscillation? Explain what and how.
c) Press **Ctrl-Z** to bring up the phase plane. Explain how the trajectory differs from harmonic motion.
d) Press **P** to bring up the parameter menu and set **damping** to 0.25. Observe the oscillations and the phase plot
    a. What happens to the period of oscillation as the amplitude becomes smaller
    b. Does the phase plane trajectory behave as you expect?
e) Press **X** to disengage the apparatus.
f) Can you explain what the rock is doing at the max and min values of the velocity time-trace (perhaps run another experiment) ?

EXPERIMENT

F2 Dependence of Period on Amplitude

We know that the oscillations are non-harmonic, and therefore they may not share one important property of harmonic oscillators; oscillation frequency is independent of amplitude. So here we shall test this by measuring the oscillation period as the initial rock displacement is changed.

(a) Data collection. Follow these steps to successfully collect some data.

a) Select the apparatus and press **F** and choose **Expt1** where nudgeHeight has been set to 0.1m.
b) Press **F1** and **T** and note down the **period** from the HUD together with the **nudgeHeight** value.
c) Press **P** and set the **nudgeHeight** to 0.2.

d) Press **F2** to reset, then **F1** then **T.** Make a note of nudgeHeight and period.
e) Repeat c) – d) for nudgeHeight values at intervals up to 2.0m.
f) Press **X** to disengage the apparatus.

(b) Data plotting and analysis

Theory shows us that the period should be proportional to the square root of the initial displacement

$$T = 4\sqrt{\frac{2z_{init}}{g}}$$

(a) To test any relationship, it's best to plot a straight line. How would you do this using your experimental results for T and z_{init}?
(b) Make such a plot using the Octave script **Gravity_Tube_Plotit_1.m** or the Excel file **Gravity_Tube_Plotit_1.xlsx.**
(c) Can you confirm from your plot that the above relationship is correct?
(d) If you plotted a straight line, find the gradient of this line and compare with the above expression for *T*.
(e) What does this tell you about the nature of the gravity tube oscillator – is it harmonic or non-harmonic? Explain!

INVESTIGATION

F3 Dependence of period on Initial Velocity.

The oscillators we have been studying are described by 2nd -order ODEs. This means that we must specify two independent initial conditions; one is initial displacement, the second is initial velocity. In the work above we have specified displacement, here we shall specify velocity. You will investigate the relationship between initial velocity and period.

(a) Investigation Planning. The independent variable is the initial rock velocity, and the dependent variable is the oscillation period. All the rest is up to you. How many data points to collect? Which values of independent variable to choose? How on earth do you answer such questions? One approach is to *play with the apparatus* try out some values of independent variable and see what happens. Use what you experience to plan your investigation.

(b) Data collection. The initial conditions are entered in a menu brought up by pressing **I.** Here we shall use this, and not **T** as our input. Here is a suggested protocol.

a) Press **F** and select **Invest1**
b) Choose the phase-plane display, press **Ctrl-Z**.
c) Press **F1** to start the simulation
d) Press **I** to bring up the initial conditions menu and set **initial Vely** to 1.0 m/s.
e) Observe the rock and the phase plot and note down both initial velocity, and period from the HUD.
f) Repeat e) and f) increasing the initial velocity but always keep the rock inside the double cylinder.
g) Press **X** to disengage the apparatus

(c) Data plotting and analysis. Since this is an *investigation*, you must work all of this out for yourself. There is an Excel file **Gravity_Tube_Plotit_2.xls** to help you along.

Fit a curve to your data point and use this to suggest the relationship between initial velocity and period.

INVESTIGATION

F4 Effects of Damping on Period

Remember that for harmonic motion a moderate amount of damping hardly changes the period. Changes become prominent when the damping approaches a critical value at which point oscillations cease.

Here we shall investigate the effects of damping on the Gravity Tube period. There are two research questions: (i) Is there a noticeable effect for moderate amounts of damping, (ii) Is there a critical value of damping where all oscillation ceases?

(a) Investigation Planning. The independent variable is the system damping, and the dependent variable is the oscillation period. All the rest is up to you.

(b) Data collection and Analysis. The following protocol might be useful.

a) Press **F** to select the apparatus as usual and choose **Invest2**

b) Press **P** and set damping to something like 0.5
c) Press **Z** to start logging then **F1**. After a few cycles of oscillation, press **Z** to stop logging then **V** to write data.
d) If Octave is installed press **O,** then press **X** to disengage.
e) You may have a .csv file **Gravity_Tube0.csv**, so open this. If you do not have an Excel file, I suggest you create one and copy your Octave data here. Then do this following.
   a. Get the period of each cycle. I suggest you take zero-crossings of the *v-t* curve (don't use neighbouring crossings!).
   b. Plot a graph of period vs. cycle number and try to fit the best curve to this.
   c. Get a maths expression for the curve ('trendline').
   d. Does this maths expression look in any way familiar, reasonable, to be expected? And ideas welcome!

F.3 Roundup

Here's the main ideas you should take away.

- Not all oscillators are harmonic. (In fact most real-world oscillators are non-harmonic)
- You can recognize non-harmonic oscillators from their time traces and phase plots. Time traces will not be sinusoidal. Phase plots will not be ellipses. Both may show discontinuities.
- Harmonic oscillators have period independent of amplitude. This is not true for the gravity tube.
- It is not absolutely necessary for a system to start with an ODE model for a system to show oscillatory behaviour.

F.4 Questions

Input from Teachers here