Experiment 1
Pendulum

SAFETY

Make sure that you have read the **General Safety Notes**, in the Introductory section of this manual, before you begin.

Do not, **under any circumstances,** attempt to repair or dismantle any of the equipment. If you suspect equipment to be faulty, turn it off at the power point and talk to your demonstrator.

Welcome to your first experiment in Physics 1. Before coming to the lab, ensure you have read the Safety Notes, the appendices and this experiment and attempted all of the pre-lab exercises, both in these notes AND online. You will also find other resources for each lab on the LMS. Throughout the experiment we have provided suggestions and questions for you to consider to help you learn to write up your experimental log, indicated by ✓. As you progress through the semester, it will be expected that you will need these prompts less and less and will become an independent and capable experimentalist. Your demonstrator is always available to assist you with the experimental method and physics discussion.

Outline of Experiment

Every physics student learns about falling bodies and g, the acceleration due to Earth's gravitational field. The Earth's gravitational acceleration, represented by lowercase g, is known to everyone through familiar and dependable effects that touch nearly all aspects of life. But have you ever tried to accurately measure 'g'?

In the lab when trying to make instruments that measure g work, gravity can sometimes seem rather arbitrary. In this lab, you will use two techniques to attempt to determine g, often referred to as the acceleration due to gravity, or 9.8 ms^{-2}. As you will see, the principles behind the experiments are quite simple, but require careful attention to detail. Part of the analysis will require additional thought to overcome perceived errors and assumptions, and hopefully through this you will gain some understanding of how important it is to make experimental tests of things that you have been asked to remember and apply.

equilibrium
平衡

One of the "easier" ways to determine 'g' is to study the motion of a pendulum. A simple pendulum is an idealised body consisting of a point mass, suspended by a light, inextensible cord. When pulled to one side of its equilibrium position and released, the pendulum swings in a vertical plane under the influence of gravity. The motion is both periodic and oscillatory.

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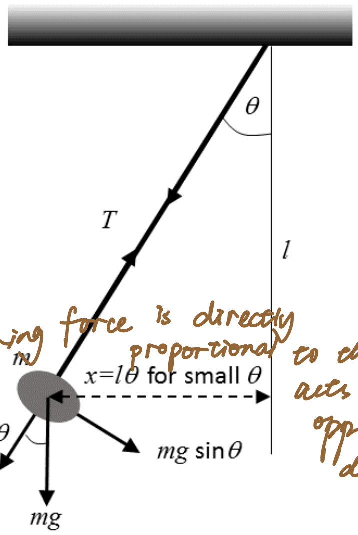
✓ ***Pre-lab exercises:*** *Read the laboratory exercise, complete the questions below, then submit the pre-lab task online (LMS or http://fyl.ph.unimelb.edu.au/prelabs) for this experiment. [Your marks for the pre-lab will be based on the answers to the online questions, which are taken from the pre-lab work in the manual]*

Learning Goals

- To become adept at using a digital oscilloscope
- To identify assumptions in theoretical models and the effects of these assumptions
- To determine the best mathematical model for fitting data
- To obtain an experimental value for the acceleration of gravity through analysing the motion of a pendulum

Introduction



In the figure to the right, the pendulum of length *l*, with an attached mass *m*, makes an angle θ, with the vertical.

the restoring force is directly proportional to the d and acts in direction opposite to that displacement.

The forces acting on m are *mg*, the gravitational force, and *T*, the tension in the cord. The tangential component of *mg* is the restoring force acting on *m*, tending to return it to the equilibrium position. Hence, the restoring force is given by:

$$F = -mg\sin\theta$$

Notice that the restoring force is NOT proportional to the angular displacement θ, but to $\sin\theta$ instead. The resulting motion is therefore not exactly Simple Harmonic Motion. ? However if the angle θ is small, we can use the small angle approximation $\sin\theta \approx \theta$ (expressed in radians).

Hence the displacement along the arc is $x=l\theta$ and for small angles, this is nearly straight-line motion.

$$F = -mg\sin\theta \approx -mg\theta = -mg\frac{x}{l}$$

For small displacements the restoring force is proportional to the displacement and is oppositely directed. The system is now behaving under Simple Harmonic Motion.

Using Newton's II Law; $\quad F = ma(t) = -m\frac{g}{l}x$

Which has a solution: $\quad x(t) = A\sin\left(t\sqrt{\frac{g}{l}}\right)$

Hence the period of a simple pendulum under the small angle approximation is: $\boxed{T = 2\pi\sqrt{\frac{l}{g}}}$

✓ **Pre-lab question 1**

What are the mathematical conditions for Simple Harmonic Motion (SHM)? Describe the motion of an object undergoing SHM.

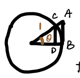
1. There must be a elastic restoring force acting on the system.
2. The acceleration is directly proportional to its displacement and always directed to its mean position.

the motion of an object undergoing SHM

The motion is periodic and oscillatory and like a sine wave.

✓ **Pre-lab question 2**

Test the small angle approximation mathematically (remember to use radians). At what angle to you consider it to break down and why?



radian = 1

$\overset{\frown}{CB} = \theta$

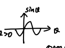
$AB = \tan\theta$

$CD = \sin\theta$

from the graph we can see

$CD < \overset{\frown}{CB} < AB$

$\sin\theta < \theta < \tan\theta$



since $\theta \in [0, \frac{\pi}{2}]$ $\sin\theta > 0$

so $1 < \frac{\theta}{\sin\theta} < \frac{1}{\cos\theta}$

$\cos\theta > \frac{\sin\theta}{\theta} > 1$

for $\theta \in [0, \frac{\pi}{2}]$ $\lim_{\theta\to 0}\cos\theta = 1$ $\lim_{\theta\to 0} 1 = 1$

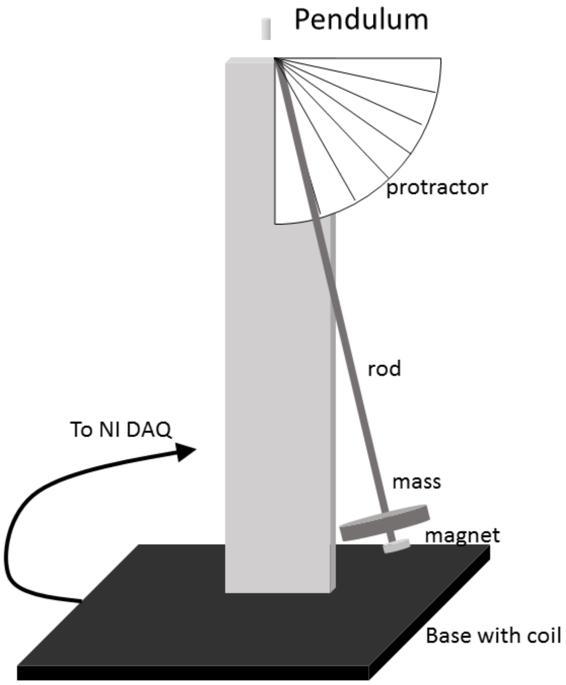
so $\lim_{\theta\to 0}\frac{\sin\theta}{\theta} = 1$

$\Rightarrow \sin\theta \approx \theta$ when θ is small

Section A: The approximation of sin θ=θ

Experimental Set-up

Set up the timing sensing equipment as shown in the diagram below. Your demonstrator will assist you in this key step. Note that as the magnet passes the sensing loop, a small voltage is induced in the coil, and a can be observed with the help of a digital oscilloscope.



Digital Oscilloscope

Set the pendulum swinging and adjust the voltage/trigger settings on the oscilloscope to record the induced voltage. By choosing a suitable length l and varying the angle θ, observe any resultant period variations.

HINT: You can use the “CURSOR” option to make accurate time measurements.

✓ What settings on your equipment will you use? How many measurements will you take? Note your experimental settings and why you chose them including all measurements to be taken and the settings on the oscilloscope. Include diagrams and a screen capture.

Data

✓ Record the period of the pendulum for each angle.

Analysis

✓ Graph the variation of the period T with the angle θ .

✓ Comment on the features of the graph and when the small angle approximation is no longer true. How did this compare with your first pre-lab question?

✓ How will this influence the rest of your experiment?

Section B: Determining a value for g

Experiment

In this experiment, you will study the variation of period with length of the pendulum to determine the value for g.

✓ Adjust the position of the mass to change the length of the pendulum. For a suitable range of lengths, determine how to calculate a value of g and write down how you went about your experiment. Comment on your sources of uncertainty.

Data

✓ Record the period of the pendulum for each length.

Analysis

✓ As you can see from the Introduction, $T \propto \sqrt{L}$.

In light of this, will you plot $T\ vs\ L$, $T\ vs\ \sqrt{L}$ or T^2 vs L? Which is likely to be the best mathematical model for this data and the easiest to determine a fit?

(hint: consider which variable is likely to have a systematic error in it, and consider the effect of a systematic error on your result…)

✓ Tabulate and plot your data. Use your plot to determine a value of 'g'. How does your value of g, with confidence limits or measurement uncertainties, compare to the known value of g = 9.80 ms^{-2} for Melbourne?

Section C(extension): Is the period really mass independent?

Experiment

In this part of the experiment, we would like to prove the statement that "the period of a pendulum is independent of the mass". A possible approach is to compare the periods by experimenting with the additional masses provided. (Do you need to know their actual weights?). In order to prove that the period is independent of the mass you will need to record your data with uncertainties.

Data

✓ Record any relevant measurements, including uncertainties.

Analysis

✓ When you changed the mass, did all of the other variables remain unchanged?

✓ Can you explain any discrepancy in your values of the period of the masses, with a possible variation in these other variables?

Conclusion

✓ Summarise your findings and how well they compare with the theory for all three sections.