BPhO
British Physics Olympiad

2016 - 17 EXPERIMENTAL PROJECT

ROTATIONAL MOTION OF A RATTLEBACK

A. Introduction

Physics toys are very popular to show in class, but are often not well understood. Their interesting features often belie some subtle behaviour and they can be used to amuse, entertain, distract, or elicit some discussion of the physics that might be involved, without coming to a full understanding. The underlying physics may be quite deep and mathematically demanding, but the start is always by observation and measurement of the behaviour. Unless you find out what the toy does and how it behaves, you have nothing to pin down your ideas. This project is about **observation**, **measurement** and **determining the behaviour** of a toy, but without going as far as the mathematical analysis of a model version to test against your measurements.

This project concerns the rotational motion of a boat-like object, the *rattleback*. The clockwise and anticlockwise rotational motions differ despite its symmetrical appearance. (It can be purchased from toy shops or online: the purchase price of single rattleback is around £5.00, packets of ten cost around £15.00 online.)

To measure the rotational angles one requires a 360° paper protractor. This can be constructed by photocopying a 180° protractor twice, or obtaining a pdf one from a website (e.g. http://www.ossmann.com/protractor/). If required, the 360° paper protractor can be magnified on the copying machine. Many rotational angles in excess of 360° (one complete rotation), are to be measured. Beware of magnifying and distorting on a photocopier.

The rattleback is to be rotated about the centre of the paper protractor. The axis of its flat face rotates through a continuously varying angle, $\theta(t)$, in time t, with each experiment involving several complete rotations. The motion is to be filmed using a camera or smartphone.

[A firm called www.gyroscope.com in the UK is selling them at £2.48 + £4.19 + VAT. (The VAT may be removed on purchase if you are eligible).

If you are buying a reasonable number, contact them on support@gyroscope.com and tell them it is for the **BPhO Experimental Project**.]

B. Experiment

Film the rotational motions

(i) clockwise and
(ii) anticlockwise

as a function of time, until the rattleback comes to a complete rest, by giving the rattleback a suitable initial torque (an applied turning force). It is to be rotated about the centre of the paper protractor.

(iii) Tables of θ and t should be produced in order to draw up graphs.

C. Graphs

(1) Plot θ versus t graphs for both the clockwise and anticlockwise motions.

(2) Select a time for each graph, close to the initial time of rotation, when the angular velocities, ω, for both motions (the gradients of the θ vs t graphs) are equal - (this will be your new zero times for each set of results).

(3) Construct new tables and graphs (of θ vs t), in which the times, clockwise and anticlockwise, t_C and t_A, are measured from those respective times at which the angular velocities, ω, were chosen to be equal (the new zero times).

(4) Plot the addition of these two rotations in part (2), taking into account the sign of the rotation.

(5) Plot graphs, for both motions, of angular velocity, ω, against time, using these new time scales, from time zero, until the rattleback has come to a complete rest.

(6) Finally, draw a graph of the addition of the angular velocities, of clockwise and anticlockwise motions, taking into account the sign of the rotation.

D. Additional Data and Information

Measure the mass, length, width and depth of the rattleback.

At all stages of measurement give the accuracy and indicate the uncertainties.

E. Experimental Report

Prepare a written report with data, tables, graphs, diagrams, and photographs, plus a discussion of errors and accuracy.

This report should contain:

(i) A concise description of the experimental procedure, including diagrams/photographs and the labels for your setup.

(ii) A brief description of what you **observe** happening.

(iii) An outline of any experimental techniques used to improve accuracy or reduce uncertainty, and/or modifications to the procedure based on any trial experiments.

(iv) Precautions taken to consider safety.

(v) Tables of measurements with headings and units.

(vi) Errors and accuracy estimates and comments about them.

(vii) A concluding discussion of results, units and accuracy.

(viii) A photograph of the experimental arrangement.

(ix) Calculations.

Report Guidelines

Some examples of what makes up some of the elements of a good write-up will be placed on the BPhO website this summer www.BPhO.org.uk . There is no single style, but a contribution of pieces of information which guide the reader through the process of experimentation. Keeping a log book, a decent size A4 notebook from which pages cannot be ripped out, and pasting in tables, graphs, comments and ideas, is important. It helps you keep track of your progress and keeps the information in one place. All professional experimenters (and theorists) keep such a notebook.

You should give a full but concise description of the experimental procedure. Highlight any particular ideas you had to make the results more reliable, with results, tables, units, uncertainties, graphs, diagrams and images. This is elaborated below.
You do not want a long report, but one which describes your progress and results in a way that would explain clearly to the reader what happens in the experiment, what you did, and what your results were, in such a clear and simple way that he is persuaded that you knew pretty much what you were doing. You are trying to remove elements of doubt in the reader's mind that you might just be making random measurements. You should have an initial descriptive paragraph which describes how the rattleback moves when turned one way and then the other. This helps you observe what is happening in detail, and provides the reader with a picture in his mind of how the rattleback moves in different ways.

- You must include a plan of the experiment, such that a colleague could carry out the experiment from your instructions. You must also write about any additional points, the particular apparatus that you used, precautions you took and good ideas you had about reducing the uncertainties of your measurements and what were the difficult measurements to make and why. Do not write an essay but just a short comment about each good idea.

- Describe any trial measurements you made to see if the experiment was going to work, and what range of measurements you decided to take. Try out the apparatus to investigate what goes on; discuss it with a colleague to make sure that you see what there is to be seen.

- Say what changes or adjustments or range setting you made in the light of this experience.

- Take a **good range** of data, and **plot the graphs before you put the apparatus away**.

- Results tables should have the **original data** including any **repeated measurements**, with the **units** at the top of the column along with the **correct symbol** for the quantity. A column for the **average** can then be worked out. You might include a column with an **estimate of the uncertainty** on your average value.

- If you feel that the results are not right, then don't scribble them out or delete them; keep them and just point out what might be wrong with them or why you have no confidence in them. The purpose is to show that **you have investigated the apparatus** and given it a good try out so that you can convince the reader that **you know what you are talking about**. Things can go wrong and you need to show how you can overcome setbacks. If you delete everything that does not seem right to you, the reader might see a nice final table of results, but they do not know how much investigative effort you have put in to get that set of results. The reader might indeed wonder whether they are that good. Do **not** write an essay, just a few bullet point comments.

- Graphs should have labelled axes, units on the axes, with the plotted data taking up a significant proportion of the graph paper area, some gridlines if done in Excel so that the reader can get values off the graph, a scatter graph with a line of best fit (trendline in Excel) – definitely do not "join the points". Display the equation for the trendline on the graph. You do not have to use Excel. You can draw graphs by hand, which are just as valid.

- **Comment on the graph** i.e. look at it and state what you can see about the shape of the graph, the scattering of the points, does it go anywhere near the origin, is it a straight line or a curve (or is it hard to tell), is the data close enough to the line of best fit to agree with the uncertainties you wrote down in your table of results?

- The **conclusion** comes from the table of results and your graph. What **trends** are shown, or what **general comments** can you make to **summarise** your results. You should also make at least a **comment** about whether you yourself think that the results are reliable or not, and why.

Good Luck with the experiment!

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