PHYS2110 – Quantum Physics and Laboratory

PRACTICAL EXAMINATION

Weeks 12 and 13

Session 1, 2014

Your task will be to measure the acceleration due to gravity g as accurately as possible, using the supplied Kater's pendulum. Notes on the experiment are attached and can be taken along to the exam. No other notes or written material can be accessed at the time of the exam.

The apparatus is available for inspection in the lab from Week 11.

You have been rostered into a particular group as indicated on the 2nd Year Lab notice board. You should assemble in the corridor outside 2nd Year Laboratory shortly before the time indicated for your group.

When you first enter the laboratory, your group will have 30 minutes to take all of the necessary measurements. You will be supplied with a stopwatch, a steel ruler and a knife edge for balancing the pendulum to find its centre of mass. The stopwatch will have an identification number on it and this <u>must</u> be clearly noted in your report.

You will then go to the back of the laboratory and write your report. The entire exercise should take 2 hours at most.

The groups will contain 2 – 3 students. You can make the measurements as a group, but each student must do the calculations and write the report individually. You can speak with your group members at the time of the measurement period, but not once you start on your report.

THE REPORT

Your report should contain:

- Your name and student number (do not forget this; there's always someone who does).
- A brief description of how you measured the various quantities used in the calculation.
- A calculated value of g with error.
- An explanation of how you estimated your error values starting from the primary error values for your measurements.
- Suggestions on how accuracy of the experiment might realistically be improved.

Some additional advice regarding this experiment

A significant number of marks will be awarded on the accuracy of your answer and a realistic and detailed estimation of your errors. For example, while the answer $g = 10 \pm 5$ ms^{-2} does include the expected value of g, it will not receive many marks. Note that this also isn't a bargaining game on errors; $g = 10 \pm 0.00001$ ms^{-2} is not likely to receive many marks either unless you can make a convincing argument that you can measure that accurately.

What counts is that your error estimate is realistic.

Note also that the stopwatches are inaccurate – they were abducted recently by aliens who have tampered with their inner workings as part of their own experimentations. This means that you may be unlikely to get a g of 9.8 ms^{-2}, but, we can't guarantee you won't get $g = 9.8$ ms^{-2} either as the 'tampering' may simply have been to wipe the dust off the screen, we don't know what the aliens did to them. This is the reason why you haven't been asked to include a comparison of your value with the accepted value for g in your report above.

A side-effect of this tampering is that you should be completely honest and unbiased with your data. In particular, it would be very unwise to 'fudge' aiming to get what you might believe is the correct value. That said, if your final value is off by more than one order of magnitude, you may wish to be suspicious about an error your own calculations.

Finally, you should spend some time preparing for this exam – this will involve thinking carefully about what you need to measure, about how to measure it most accurately and about how to correctly estimate the resulting errors. The experiment is easy if you prepare well; it is hard if you don't.

The Physics of Kater's Pendulum

Consider a "physical pendulum" with unspecified distribution of mass m.

The centre of mass is located at A. The pendulum is to be suspended from two different points of suspension defined as O_1 and O_2.

We define:

h_1 = distance between O_1 and A

h_2 = distance between O_2 and A

Consider the pendulum suspended from O_1. The equation of motion is:

$$I_1 \frac{d^2\theta}{dt^2} = -mgh_1 \sin\theta \approx -mgh_1\theta \qquad \text{if } \theta \text{ is small.}$$

where I_1 is the moment of inertia about O_1, g is acceleration due to gravity and θ is the angle of swing.

We can rearrange this to:

$$\frac{d^2\theta}{dt^2} + \frac{mgh_1}{I_1}\theta = 0 \qquad \text{if } \theta \text{ is small.}$$

This is the equation for simple harmonic motion and so the period of oscillation T_1 will be given by:

$$T_1 = 2\pi\sqrt{\frac{I_1}{mgh_1}} \tag{1}$$

The pendulum is now suspended from point O_2 to get period of oscillation T_2

$$T_2 = 2\pi\sqrt{\frac{I_2}{mgh_2}} \tag{2}$$

where I_2 is the moment of inertia about O_2.

If I_0 is the moment of inertia about the centre of mass, then the parallel axis theorem gives:

$$I_1 = I_0 + mh_1^2 \tag{3}$$
$$I_2 = I_0 + mh_2^2 \tag{4}$$

If we square Equations 1 & 2, combine with Equations 3 & 4, then write each in terms of $4\pi^2 I_0/mg$ and equate, we get:

$$\frac{4\pi^2}{g} = \frac{h_1T_1^2 - h_2T_2^2}{h_1^2 - h_2^2} = \frac{h_1T_1^2 - h_2T_2^2}{(h_1 - h_2)(h_1 + h_2)} = \frac{2h_1T_1^2 - 2h_2T_2^2}{2(h_1 - h_2)(h_1 + h_2)} \tag{5}$$

$$\frac{4\pi^2}{g} = \frac{h_1T_1^2 - h_2T_1^2 + h_1T_2^2 - h_2T_2^2 + h_1T_1^2 + h_2T_1^2 - h_1T_2^2 - h_2T_2^2}{2(h_1 + h_2)(h_1 - h_2)} = \frac{T_2^2 + T_1^2}{2(h_2 + h_1)} + \frac{T_2^2 - T_1^2}{2(h_2 - h_1)} \tag{6}$$

$$g = 8\pi^2\left[\frac{T_2^2 + T_1^2}{h_2 + h_1} + \frac{T_2^2 - T_1^2}{h_2 - h_1}\right]^{-1} \tag{7}$$

You will want to use Equation 7 to get g.