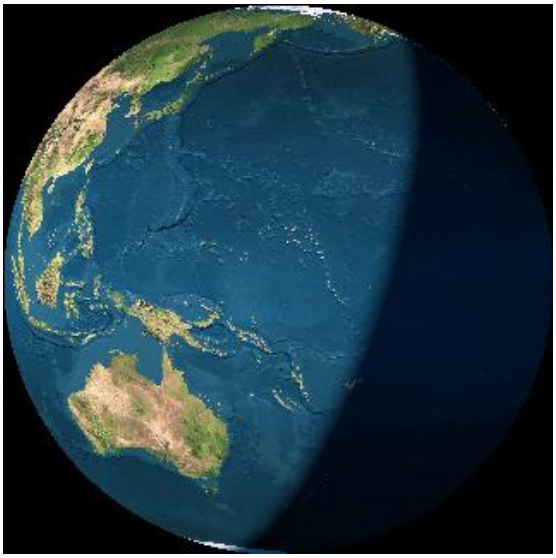
Area of study ENERGY AND CHANGE and WORKING SCIENTIFICALLY
Target **Level 6** or bright year 10 or 11 and 12 Physics and Maths students



How often is it in science that we take measurements by an indirect means? For example we measure force and mass by measuring the stretch of a spring that has been calibrated, we measure time by the swing of a pendulum, and even the mass of an electron by its curvature in a magnetic field.
Today we are going to measure the mass of the earth using a conical pendulum. **WOW** can we really do this.

Calculate the mass of the earth

The Foucault pendulum at Gingin that will be used to measure the mass of the earth.

This is a great exercise in demonstrating what indirect measurements are and how wide spread they are in science. The idea of ***measuring the mass*** of the earth using a conical pendulum Is the ***WOW*** factor that attracts both the teachers and students.

This is one of the activities that are designed for very able students in year10 or physics / maths students in year11 and year 12 to gain the most out of the exhibits at the Gravity Discovery Centre. The program is designed to offer a range of activities that are independent of each other and range in difficulty from the basics through to the sophisticated. The activities cover historical moments in science, cutting edge concepts and understanding of the scientific Process.
For the program to work, Students and teachers need to have carried out preliminary research and experimentation at school and have developed a good understanding of the tasks they will carry out at the gravity centre. The activities have all been trialled with a group of talented year 10 students who really enjoyed the challenge of quickly being accelerated to a level of conceptual understanding well beyond where their classroom normally operates.

The tasks are at a **level 6** and in some cases the very able students are able to demonstrate a **level 7**

SAFETY the bob has a large mass and when it is swinging back and forth or around then the energy it is caring is very large and enough to inflict serious injury. Therefore the following rules must always be followed.

RULES

1. A teacher or supervisor must be present.
2. Instruction must be given to all attending the session.
3. Only one person inside the fence when the bob is in motion.

Activity	Preliminary work at school	Activity at the Gravity Discovery Centre
Simple Pendulum Making a time piece	Simple harmonic motion and the pendulum. Rate of change (the % method) The one second pendulum	Extrapolation of school data to predict and measure and compare the Gravity Discovery Centre pendulums period.
The one second Pendulum	This module allows students to use % variation to establish the influence of a variable on the behaviour of the simple pendulum in a mathematical analysis of data gained in the Simple Pendulum module.	Use this knowledge to help with your GDC investigations
Conical Pendulum Measuring the mass of the earth	Preliminary theory and trigonometry	Use the Gravity Discovery Centre pendulum to measure the mass of the earth
Foucault Pendulum Measuring the rotation rate of the earth	Study the history of the Foucault pendulum and learn how to calculate the rate of the earths movement under the pendulum at the Gravity Discovery Centre.	Test the prediction at the Gravity Discovery Centre

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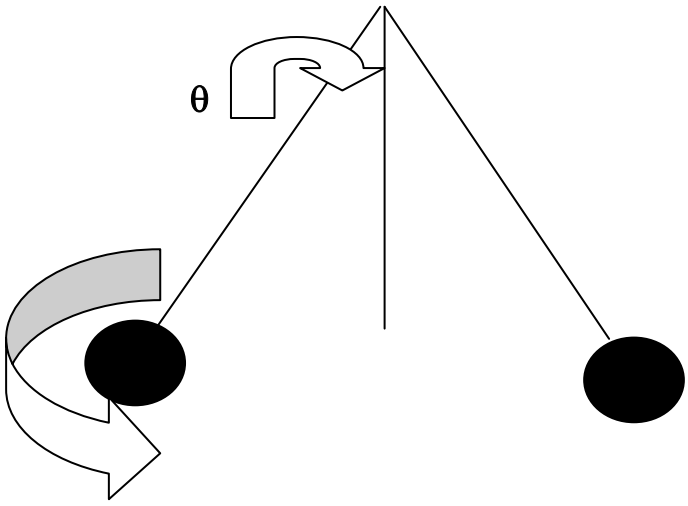
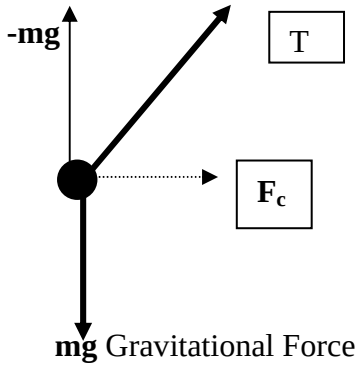
WHAT IS A CONICAL PENDULUM?

This is a pendulum that is placed in circular orbit. As it revolves around a central point there are only two forces on it the tension in the rope (**T**) and the force of gravity on the weight. (**mg**). When these are added together the resultant net force is towards the centre of the weights rotation, in other words it is also called the centripetal force. The bob does not move up or down.





mg Gravitational Force

$\mathbf{m_p}$ =mass of the pendulum $\mathbf{F_c}$ =force centripetal
$\mathbf{m_e}$ =mass of the earth $\mathbf{r_p}$ = radius of the conical pendulum
$\mathbf{v_p}$ = speed of the pendulum $\mathbf{r_e}$ = radius of the earth

Now from the diagrams above you can see that

Tan θ = F_c/ m_pg and $\mathbf{F_c = m_p v_p^2 / r_p}$

$\mathbf{F_c = \tan \theta\ m_p g}$ substitute this value for $\mathbf{F_c}$

$\mathbf{\tan \theta\ m_p\ g = m_p\ v^2 / r_p}$

$\mathbf{g = m v^2 / r_p \tan \theta}$ but $\mathbf{g = G\, m_e / r_e^2}$ by substituting $\mathbf{G m_e / r_e^2}$ for g in $\mathbf{g = m v^2 / r_p \tan \theta}$ and by rearranging you can get an expression for the earths mass.

DERIVE IT

THE CONICAL PENDULUMS PERIOD

The period of a pendulum is the time it takes the pendulum to complete one revolution around its centre. The symbol for the period is **T** and its units the second (s).
We can use this value together with the radius of the conical pendulum to calculate the instantaneous velocity of the bob. (its speed)

Speed = circumference / period

Speed = $2\pi r / T$ **this speed is the velocity of the bob**

Now substitute **$2\pi r / T$** into the equation you have derived on the previous page and write out your final equation

NOW ITS TIME TO FIND THE MASS OF THE EARTH

You will need to follow the instructions very carefully and be aware of safety at all times.

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METHOD

- Walk the bob around the PRE-DRAWN CIRCLE (this is the coloured tiles forming the circle) until the speed at which it is moving matches the circle drawn. Take care that you have it travelling in a circle.
- Time how long it takes to complete 10 revolutions.
- Stop the bob.
- Gather the following information that will enable to work out the mass of the earth

DATA

Time for 10 revolutions		Length of bob rope wire	
Period of the bob T		The angle θ	
Radius of the bob r_p		Universal gravitational constant G	
Radius of the earth r_e			

Remember that all your values must be in mksA units

MY CALCULATIONS

You now need to calculate the value of the earth's mass using the formula you have derived in your group.

WHAT WAS MY % ERROR FROM THE TRUE VALUE?

$$\% \text{ Error} = \frac{\text{True Value} - \text{Experimental Value}}{\text{True Value}}$$

WHY DO YOU THINK THE MASS OF THE BOB IS SO HEAVY

THIS METHOD OF MEASURING THE EARTHS MASS CONSIDERED INDIRECT. WHY?

These sheets are for teachers and students to help in the levelling of student work in this module.

Overarching Major Learning Outcomes

There are opportunities to assess students in the following outcomes when taking part in this program.

OLO 7: Students understand and appreciate the physical, biological and technological world and have the knowledge and skills to make decisions in relation to it.

OLO 5: Students describe and reason about patterns, structures and relationships in order to understand, interpret, justify and make predictions.

OLO 6: Students visualise consequences, think laterally, recognise potential patterns and are prepared to test options.

Science Major Learning Outcomes

Working Scientifically

1. Investigating skills
Students investigate and answer questions about the natural and technological world. They use the skills of scientific investigation, reflection and analysis to prepare a plan for their investigation; to collect, process and interpret data: to communicate their conclusions
2. Communicating Scientifically

Students communicate scientific understandings to different audiences for a range of purposes.
3. Applying Science in Daily Life
Students apply and evaluate scientific knowledge, skills and understanding across arrange of contexts.

Using Science in Society
Science understands that science is a human activity which influences all people as a part of their daily lives.

Understanding concepts

1. Earth and Beyond

Students understand the physical world around them and its impact on the way we live.

2. Energy and Change

Students understand the scientific concept of energy and explain that energy is vital to our existence and quality of life.

Student Outcome Statements

Students typically in years 8-10, will be performing at levels (3-6). The following examples demonstrate outcomes for levels 5 and 6

Investigating scientifically

Planning:

1. Identifies the variables to be changed, the variable to be measured and at least one variable to be controlled. In a descriptive study plans are made for the necessary types of observations.
2. Analyses problems, formulates a question or hypothesis for testing and plans an experiment in which several variables are controlled.

Conducting:

1. Takes care with data collection so that data is accurate, uses repeated trials and uses independent variables that are usually continuous.
2. Uses equipment that is appropriate for the task and uses preliminary trials of the investigative procedure to improve the procedure or measurement techniques.

Processing Data:

1. Calculates averages from repeated trials, plots data as line graphs where appropriate and makes conclusions, which both summarise and explain the patterns in the data.

2. Makes conclusions, which are consistent with the data and explains the patterns in the data in terms of scientific knowledge.

Evaluating:

1. Makes specific suggestions for improving the data
2. Suggests a specific change that would improve the techniques used or the design of the investigation.

Energy and Change

1. Understands that energy interacts differently with different substances and this can affect the use and transfer of energy.
2. Understand models and concepts used to explain the transfer of energy in an energy equation.

General notes on levelling

Level	Level Descriptors
2	**Describe**s a number of features but does not **relate** them
3	Describes **patterns** and makes **generalisations** from **concrete** experience
4	Describes **non observable** properties or events
5	Explains in terms of a **concept.**
6	**Chooses applies** and **quantify** concepts and principals

Appendix 2: Questions and associated levels

*Explain in your own words how you will measure the effects of these variables on the dependant variable the **period***

To demonstrate level 6
The students need to be able to derive the relationship they used to calculate the mass of the earth without help.

They need to state how they are going to keep the variables not being tested constant.

They need to state how they are going to get valid and reliable data.

They need to state how they will know that they have valid and reliable data.

It is important that you find the period by allowing the pendulum to complete multiple(say 10) cycles then divide the time by ten to get the period. Why is this?
To demonstrate a level 6

The students need to demonstrate that averaging a greater number of events decreases the error margin in the results. They should also state that you should remove the outliers on graphs before using a line of best fit.

This method of measuring the earths mass considered indirect. Why?
To demonstrate a level 6
The students should show that they understand that that it is the force of gravitational attraction between the earth and the bob that controls the behaviour of the conical pendulum. By using this behaviour and measuring the period in seconds (an indirect measurement) can be put in to the derived relationship to get a measurement of the earths mass.

Some web based resources that may be helpful to teachers and students in preparing for the visit.

Web based resources

http://www.delphiforfun.org/Programs/pendulum.htm

http://online.cctt.org/physicslab/content/phyapb/lessonnotes/centripetal/lessonpendulums.asp

http://ephysics.physics.ucla.edu/ntnujava/Pendulum/esimple_pendulums.htm

There are so many applets and good sites that you can get by using a good search engine. Give it a go.