

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

# The Foucault Pendulum



Acknowledgment of the California Academy Of Sciences for some of the diagrams and some of the general content

The Foucault Pendulum was invented by French physicist, Jean Bernard Foucault (pronounced *foo-ko*) in 1851 in Paris and was demonstrated for the first time at the world's fair in the Pantheon in Paris.

**Although the pendulum seems to change its path during the day, it is actually the floor beneath it that is moving.**

Centuries ago, Sir Isaac Newton discovered that when a body is set in motion it will move continuously in a straight line from its origin, so long as the body is not interrupted by an outside force that alters its direction. So if the pendulum seems to rotate with respect to the floor and we know there is no force available to make the pendulum rotate and there is no outside force that will interrupt the swing - then - it must be the floor that is rotating. As we know the floor is attached to the earth SO it must be the earth that is rotating!

**The first terrestrial device to demonstrate the rotation of the earth**

These activities 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 in the later pendulum units**. We suggest that you incorporate the preliminary work in the general course of the students and culminate that work with a visit to the Gravity Discovery Centre. What you expect the students the students to gain.

### ACTIVITIES BEING OFFERE

Activity	Preliminary work at school	Activity at the Gravity Discovery Centre
<b>Simple Pendulum</b> 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.
<b>The one second Pendulum</b>	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
<b>Conical Pendulum</b> Measuring the mass of the earth	Preliminary theory and trigonometry	Use the Gravity Discovery Centre pendulum to measure the mass of the earth
<b>Foucault Pendulum</b> 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

**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.

**WHAT IS A FOUCAULT PENDULUM** (*foo- ko pen-je-lem*)

The Foucault Pendulum was invented by French physicist, Jean Bernard Foucault (pronounced *foo-ko*) in 1851 in Paris and was demonstrated for the first time at the world's fair in the Pantheon in Paris.

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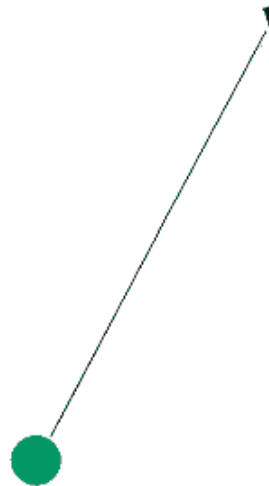
Centuries ago, Sir Isaac Newton discovered that when a body is set in motion it will move continuously in a straight line from its origin, so long as the body is not interrupted by an outside force that alters its direction. So if the pendulum seems to rotate with respect to the floor and we know there is no force available to make the pendulum rotate and there is no outside force that will interrupt the swing - then - it must be the floor that is rotating. As we know the floor is attached to the earth SO it must be the earth that is rotating!

**WHAT IS A PENDULUM**

The word comes from the Latin word "Pendulus" which means hanging

Something hanging from a fixed point which, when pulled back and released, is free to swing down by force of gravity and then out and up because of its **inertia**.

**Inertia:** means that bodies in motion will stay in motion; bodies at rest, will stay at rest, unless acted on by an outside force.

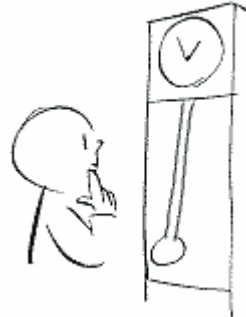


weight at the bottom is called a "**BOB**"

**In your own words state why the pendulum proves that the earth is revolving about its axis**

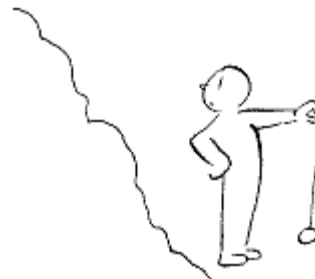
## WHY IS THE PENDULUM SCIENTIFICALLY IMPORTANT BECAUSE

- 1 it can be used to provide accurate  
**TIME KEEPING**



note: today we use **atomic vibrations** for the most accurate clocks.

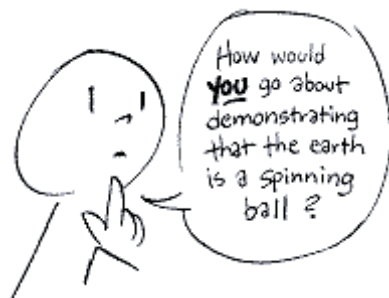
- 2 it can be used to measure “g”  
(the acceleration due to gravity)  
which is important in determining  
the **shape** of the earth and the  
distribution of materials within it  
(the science of **geodesy**)



the pendulum helps scientists determine “g”  
force which is affected by:

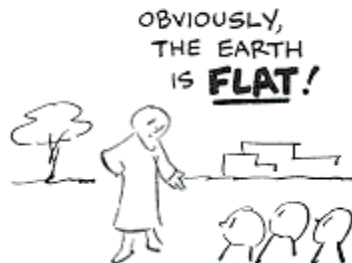
- 1) distance from centre of earth
- 2) masses attracting upwards (ie. mountains)
- 3) density of matter around you

- 3 **and also** it can be used to show  
that the **EARTH SPINS**



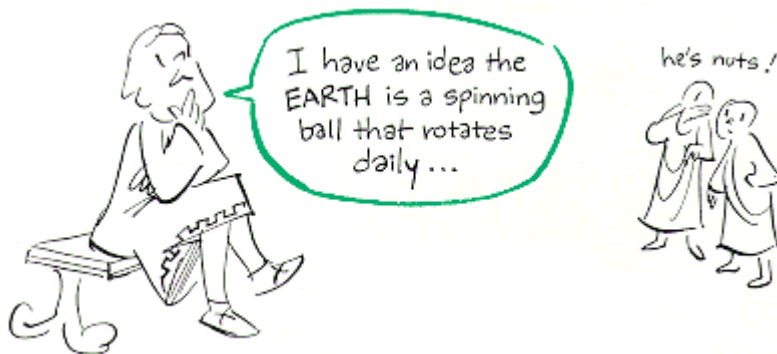
## THESE WRONG IDEAS

About the earth were believed by nearly everyone up to a few hundred years ago



## IN THE 6<sup>TH</sup> CENTURY B.C ARISTARCHUS OF SAMOS

see

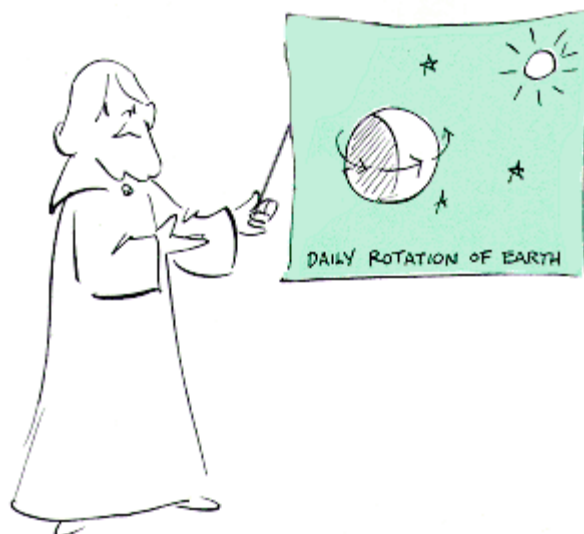


--but, of course, hardly anyone believed him because this was in conflict with what everyone could see with his own eyes.

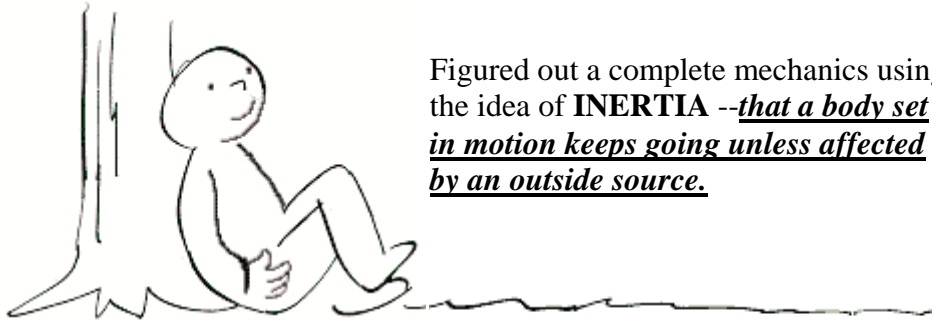
## IN FACT ABOUT 2000 YEARS WENT BY UNTIL COPERNICUS IN 1553

presented the idea of the earth rotating daily on its axis as part of his general theory that the earth revolves about the sun **yearly**.

In the next three centuries after Copernicus, scientists came to accept this idea, and looked for demonstrations that could actually be performed on earth.



**NEWTON** (about 300 years ago)



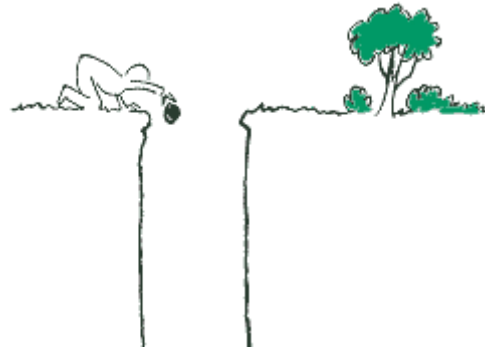
Figured out a complete mechanics using the idea of **INERTIA** --that a body set in motion keeps going unless affected by an outside source.

### **COULD THEY PROVE THE ROTATION OF THE EARTH**

*by dropping a stone down a mine shaft*

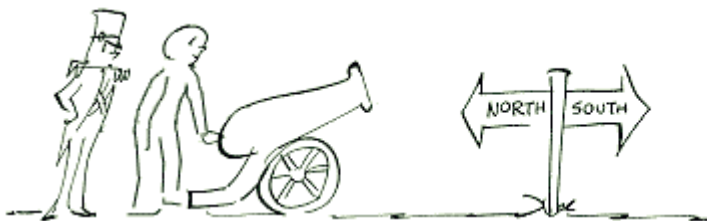
Would there be a noticeable **eastern** deflection of the stone due to earth's rotation? **NEWTON'S** physics said "yes."

**BUT**--the depth of the shaft was so slight compared to the radius of earth that the experiment was inconclusive.



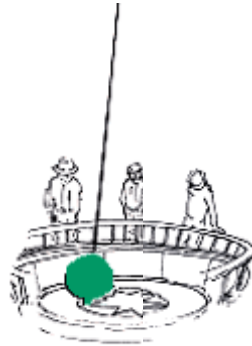
### **ANOTHER IDEA to prove that the earth rotates**

How about shooting a projectile in a north/south direction? Would it show a deflection?



## IN 1851 FRENCH PHYSICIST FOUND A WAY TO DO IT WITH A PENDULUM

### Who was Foucault?

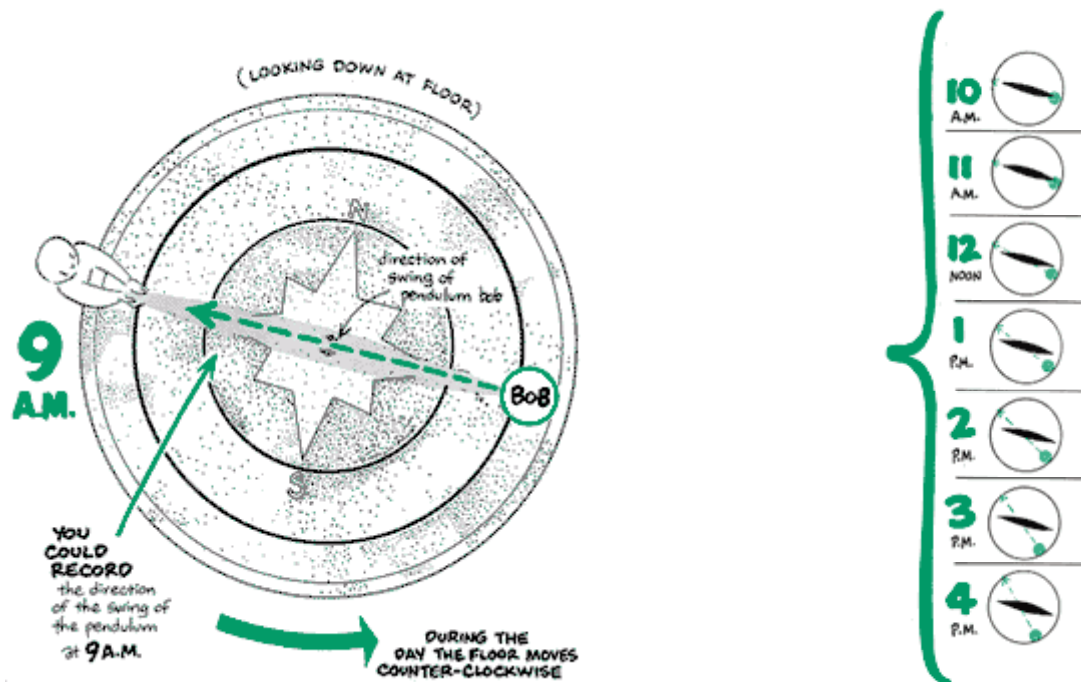


Jean Bernard Leon Foucault was born in 1819, the son of a French publisher. He showed early skill in making mechanical toys, studied medicine, but shifted to physical sciences at the Paris Observatory. He became one of the most versatile experimentalists of all time.

A year later, 1852, Foucault also invented the "GYROSCOPE," a flywheel device that pivoted freely about its centre of gravity. In rapid motion its axis indicates fixed direction in space.

THIS SPACE IS NOT CURVED, OR IS IT? Make a comment.

## HOW DOES THE FOUCAULT PENDULUM WORK?



At San Francisco latitude, the floor turns **about 220°** under the pendulum in **about 24 hours** (at North Pole, it would turn a full circle 360°)

**Note that while the Pendulum seems to change its path during the day -- actually it is the floor beneath it that changes, being twisted around by the daily rotation of earth.**

**WIRE CLAMPED** in tapered support which permits bending in a slightly different direction on each swing

**WIRE** is flexible steel cable **10m long** The longer the wire, the slower the bob swings and the **LESS** it is retarded by friction with the air.

### What keeps it moving?

In the model you will be using' a moving magnet in the ground is used to maintain the pendulum energy .

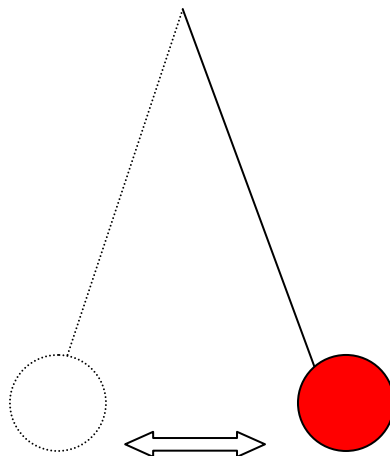
**Air resistance** would normally stop the pendulum after a few hours -- so in some models an **IRON COLLAR** is installed on the wire **surrounded by an electromagnet** that attracts the collar as the bob swings out, then shuts off automatically as it swings back, thus, keeping pendulum going.

The magnet is turned on and off by a switch which is activated when the support wire interrupts a beam of light shining across its path

## WHY DOES THE PENDULUM DEMONSTRATE THE ROTATION OF THE EARTH?

Because there is no force acting on the pendulum to make it's plane of oscillation rote or go around its own axis.

Let's consider -- what ARE the forces acting on the pendulum?



It's the pendulum's inertia that makes it swing straight **out** and the force of GRAVITY that pulls it straight **back**. (or rather "**down**"--it's the force of the wire that makes it go in an **arc** rather than straight **down**.)

Air friction makes it swing in **shorter arcs** --but just as **straight arcs** (in the demonstration, the electromagnet booster merely counteracts this air resistance)

Minor disturbances such as AIR CURRENTS may throw its path a centimetre or two off centre

however, since it is tied to the building, the pendulum will **travel laterally** as the building moves **laterally**—BUT because of the way it is suspended IT WON'T TWIST around if the building twists around.

if the pendulum **seems** to rotate with respect to the **floor**--and we know there is no force available to **make** the pendulum rotate --**THEN**-- it must be the **floor** that is rotating--and--if the floor is attached to the **earth**—**THEN**

**IT MUST BE THE EARTH THAT IS ROTATING**

## TWO KINDS OF MOTION AROUND THE EARTH'S AXIS



**TWISTING**

motion of a plane around a perpendicular axis



**TRAVELLING**  
plane

motion of a plane in a circle around an axis parallel to the

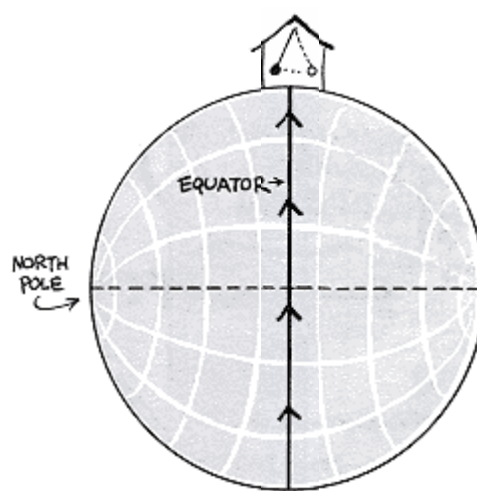
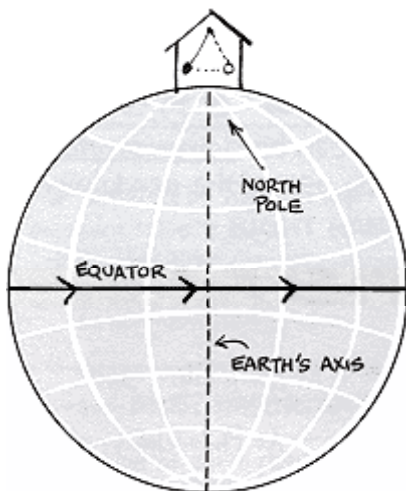
### IF THE PENDULUM WAS AT THE POLE

The **floor** would **twist under** the pendulum -- the building floor would **twist** around the earth's axis every 24 hours. The pendulum --**which doesn't twist**-- would stay in its original plane.

### IF THE PENDULUM WAS AT THE EQUATOR

The **building floor** would not twist at all but the building would travel eastward on the earth's axis

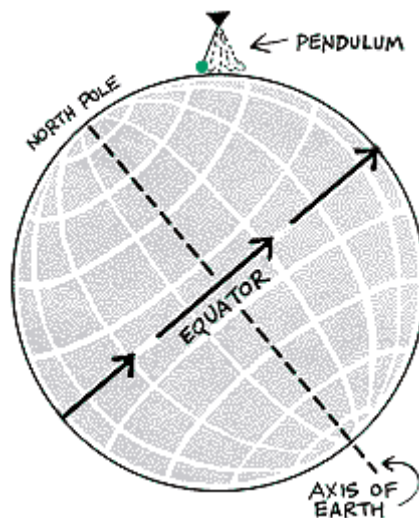
The pendulum--being **tied** to the building -- would **travel** right along **with** the building with **no visible** effect -- since there is no **twisting** motion.



## WHAT HAPPENS AT POINTS BETWEEN THE POLE AND EQUATOR?

SOME TWISTING SOME TRAVELLING the **amount** of **twist** being made **visible** by the pendulum, but the amount of **travel** cannot be seen.

The amount of twisting motion of the building floor around the earth's axis varies with the latitude but is less than a Pole. The pendulum does **not** share this motion and therefore **lags** behind the floor -- **and this can be seen**. But the **travelling** motion of the pendulum eastward with the building is slower than the Equator -- but this you **cannot** see! That's why the pendulum lags behind only the **twisting** part of the floor's rotation and hence only loses part of the full circle to it in 24 hours.



DEGREES OF TWIST (n) per day may be determined **mathematically** by this formula

$$N = 360^\circ \sin \phi$$

Where  $\phi$  is the latitude

## HOW THE ROTATION OF THE EARTH AFFECTS OUR LIVES.

### IN PLANE FLIGHT

Navigators must allow for deviation to right when flying in Northern Hemisphere -- and to left in Southern Hemisphere.

### IN SPACE FLIGHT

The rotation of the earth creates special problems on flights to and from the moon.

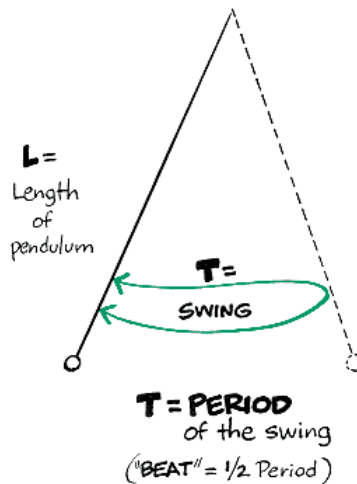
### WINDS

Winds created by high to low pressure have a **right hand** deflection that creates cyclones, hurricanes and typhoons, in the Northern Hemisphere. The rotation of earth results in wider distribution of rain over the earth.

If no there were no spin, there would be a steady flow of cool air from pole to equator. The cool air would be near the surface; as it warmed, the air would gradually rise and flow back toward the pole, dropping its water content as it again cooled. This would tend to produce constant rain near the equator and deserts in the northern and southern parts of the world. The rotation of the earth helps break up this north-south cycle by introducing an east (or west) deflection.

CAN YOU THINK OF ANY OTHER EFFECTS THE ROTATION MAY HAVE? WILD IDEAS ARE GREAT.

## HOW TO WORK OUT THE PERIOD OF A PENDULUM



Period of the swing =  $T$   
Length of the pendulum =  $L$   
Acceleration due to gravity =  $g$

$$T = 2\pi\sqrt{L/g}$$

At the California Academy of Sciences the length of the pendulum is:  
**10m. =  $L$**

The acceleration of gravity at this location is:  
**9.8/sec.<sup>2</sup> =  $g$**

Using Equation:

$$T = \mathbf{6.1 \text{ seconds}}$$

time for simple pendulum to swing from side to side and back

## HOW TO WORK OUT THE DEGREES OF ROTATION

How do you figure out the number of degrees of rotation of the earth beneath the pendulum in 24 hours

The number of degrees of a circle that the earth will "twist" "rotate" under a pendulum in 24 hours at any given latitude ( $n$ ) may be determined by the following formula:

$$n = 360 \times \sin \text{ of the latitude}$$

Example

Latitude - California Academy of Sciences =  $37^\circ 46.2'$

Sin Latitude = .6125

$n = 220.5^\circ$  in 24 hours

1 Revolution = 39.18 hrs.

## WHAT NEXT

Here you are full of information about the Foucault pendulum lets experiment and see if the calculated value matches the experimental value..

**TASK** Calculate how long it would take for 1 revolution of the pendulum in Gingin

What is the latitude of Gingin.

Use the relationship on the previous page to complete the calculation.

**TASK** How far will the pendulum swing (in degrees) in 30 minutes

Work out in your group how you will do this and write it up below. Remember to work out methods of measurement and what to control.

**TASK**

Carry out your experiment and compare your result to your calculated value in terms of % error

**REMEMBERING**

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

**RULES**

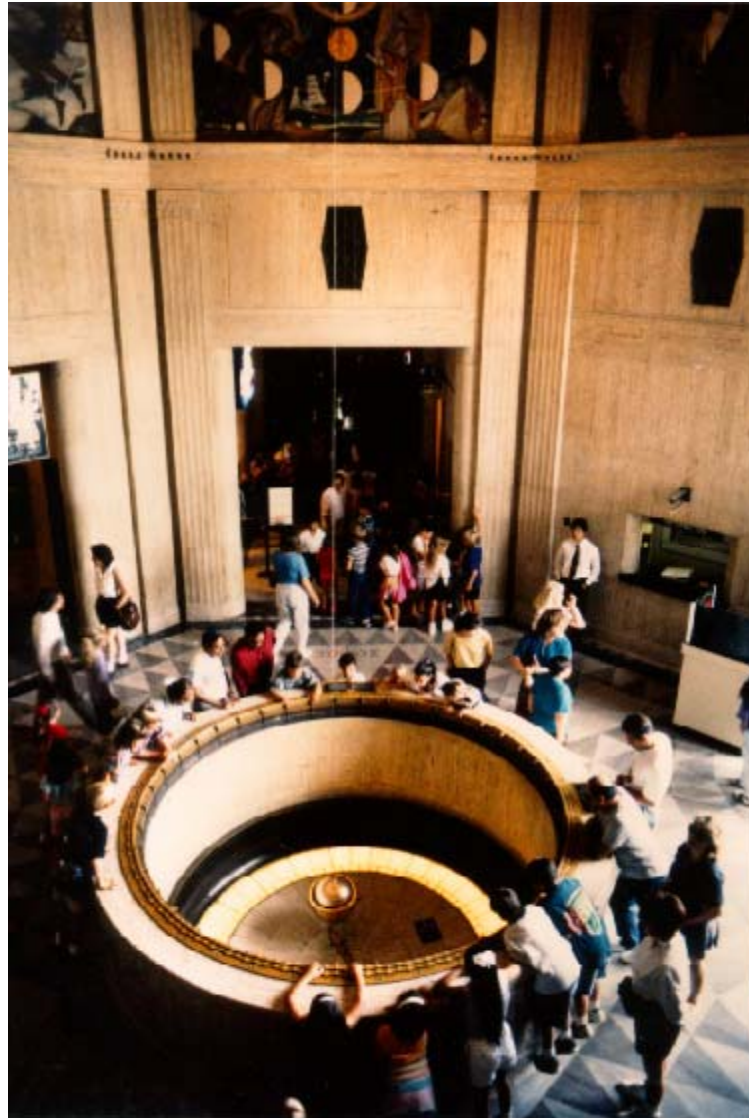
4. A teacher or supervisor must be present.
5. Instruction must be given to all attending the session.
6. Only one person inside the fence when the bob is in motion.

**RESULTS AND ANALYSIS**

**IN YOUR OWN WORDS** describe how the Foucault pendulum demonstrates that the earth is turning.

**CAN YOU SUGGEST ANOTHER USE OF A FOUCAULT PENDULUM?**

ANOTHER PENDULUM TRYING TO FOOL THE WORLD THAT THE EARTH IS ROTATING



WHAT DO YOU THINK THE PEOPLE ARE THINKING AS THEY WATCH?

## **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	<b>Describes</b> a number of features but does not <b>relate</b> them
3	Describes <b>patterns</b> and makes <b>generalisations</b> from <b>concrete</b> experience
4	Describes <b>non observable</b> properties or events
5	Explains in terms of a <b>concept</b> .
6	<b>Chooses applies</b> and <b>quantify</b> concepts and principals

**Appendix 2: Questions and associated levels**

How far will the pendulum swing (in degrees) in 30 minutes

*Work out in your group how you will do this and write it up below. Remember to work out methods of measurement and what to control.*

**To demonstrate level 6**

The students need to identify and isolate each of the variables to be tested in turn against the dependant variable.

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.

**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.

**IN YOUR OWN WORDS** describe how the Foucault pendulum demonstrates that the earth is turning.

**To demonstrate a level 6**

Because the pendulum is tied to the a structure, the pendulum will travel laterally as the building moves laterally—**BUT** because of the way it is suspended *IT WON'T TWIST* around if the building twists around.

If the pendulum seems to rotate with respect to the floor--and we know there is no force available to make the pendulum rotate --**THEN**-- it must be the floor that is rotating--and--if the floor is attached to the earth—then *it must be the earth that is rotating*



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



### Web based resources

[http://www.phys.unsw.edu.au/PHYSICS\\_/FOUCAULT\\_PENDULUM/foucault\\_pendulum.html](http://www.phys.unsw.edu.au/PHYSICS_/FOUCAULT_PENDULUM/foucault_pendulum.html)

<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](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.**