Conservation of Energy in the Gravitational Field

Number	134570-EN	*Topic*	Mechanical energy				
Version	2017-08-25 / HS	*Type*	Student Exercise	*Suggested for*	Grade 10-12	*p.*	1/4

Objective
To examine the conservation of mechanical energy.

Principle
A weight (pendulum bob) swings as a pendulum in a thread.

When in the extreme positions of the swing, we can determine the vertical position of the weight and hence its potential energy.

In the lowest (centre) position, the weight passes a photogate. We can thereby determine the speed of the weight and calculate its kinetic energy

Equipment
(Detailed equipment list at last page)

Two retort stands

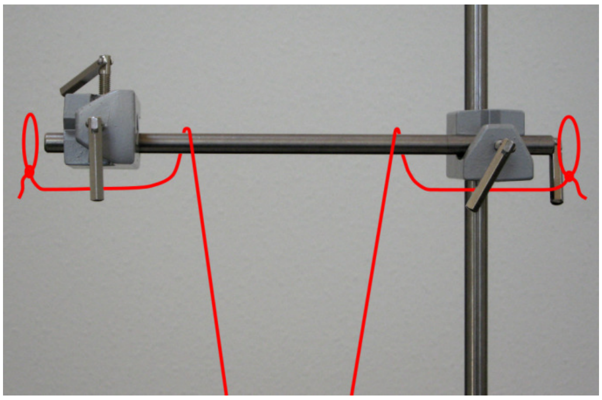
Weight and thread for the pendulum (see next page)

Photogate and 200280 Student Timer for measuring passage time of the weight. (Photos show older timer model 200260)

Tape measure or ruler

Procedure

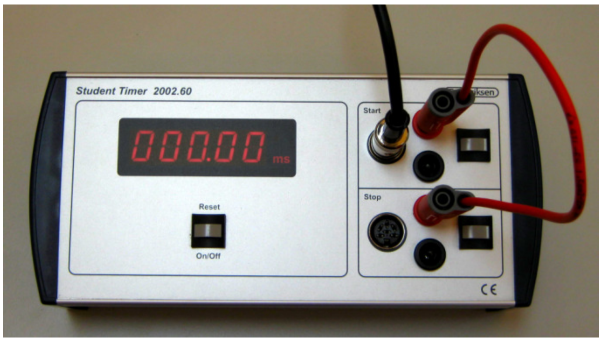
The button *Reset, On/Off* is used for turning on and zeroing. Furthermore, a long press will turn off the instrument.



When we speak of the *position of the weight*, we actually mean the position of its *centre of mass*. It is accurate enough to uses the centre of the thickest cylindrical part of the weight.
Eventually, mark the centre with a black line.

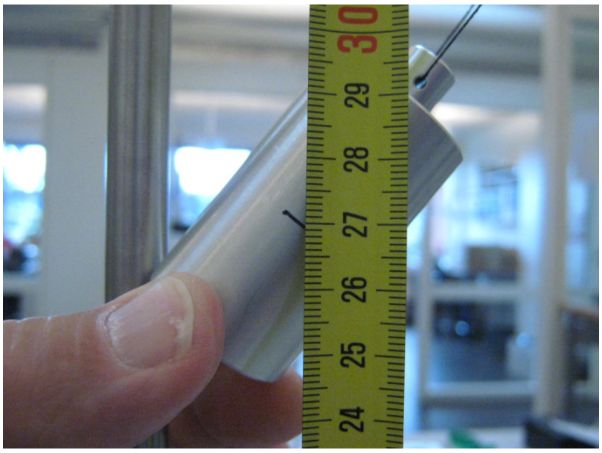
The weight is suspended by the thread. Use approx. 110 cm with a fixed loop at each end. With a simple knot the loop and knot can pass through the hole in the weight.

A 25 cm stand rod is fixed to the long retort stand rod and provided with an extra bosshead. The rod must protrude approx. 1 cm at both ends to enable the thread to be arranged, as shown in the figure.
This arrangement ensures that the thread is slightly wound on and off the rod when the pendulum is swinging. This happens virtually frictionless.



When the pendulum hangs vertically, the light ray of the photogate should hit the centre of the weight. Connect the photogate to the *Start* input and connect the two red sockets with a short lab lead.

The weight is pulled to one side and released. As a marker for this position, use the extra retort stand.



Pull the weight to the marker rod with its axis parallel to the thread. Measure the height h_2 from the table top to the centre of mass of the weight.
This must be done without pushing the rod away.

Reset the timer and release the weight to that it swings through the photogate.
Write down the passage time.

Measure the height h_1 from the table top to the centre of the weight when in the lowest position.

The height h that is used in further calculations is the differences: $h = h_2 - h_1$.

Repeat the time and height measurements a few times. If you are more than one, you can take turns to measure the heights.

Next, move the marker stand to repeat the measure-ments with a new initial height. Do this for a range of different positions.

Theory

The velocity of the weight as it passes the photogate is given by

$$v = \frac{\Delta s}{\Delta t}$$

where Δs is the distance the weight moves during the passage – i.e. its diameter - and Δt is the time measured at the timer.

The kinetic energy of the weight is

$$E_{\text{kin}} = \frac{1}{2} \cdot m \cdot v^2$$

where m is the mass of the weight.

Similarly, the potential energy is given by

$$E_{\text{pot}} = m \cdot g \cdot h$$

where g is the acceleration due to gravity and h is the height of the weight, relative to a given zero point.

We choose to define the potential energy to be zero at the lowest position of the weight.

Per definition, the mechanical energy is the sum of these:

$$E_{\text{mech}} = E_{\text{kin}} + E_{\text{pot}}$$

As the velocity at any instant is perpendicular to the direction of the thread, no work is done by the tension force. The only other force to act on the weight is gravity (we will ignore air drag).

In this experiment, we want to demonstrate that the mechanical energy is conserved, in accordance with gravity being a conservative force.

Calculations

Present the measurements in a table – a spreadsheet program is highly recommended.

For every fixed position of the marker stand, calculate the average of the heights h_1 and h_2 and for the passage time Δt .

Calculate the potential energy in the start position and the kinetic energy at the passage of the photogate.

Calculate the percentage difference between these two figures – i.e. the change in the mechanical energy when the weight swings down.

Discussion and evaluation

According to theory, what could be expected of the results?

Are the actual results as expected?

It can be an idea to try to get a feel for how accurate the measurements are.
As you have repeated measurements for each marker position, you can try to find a “typical” percentage deviation from the average. This can be used as the size of the experimental uncertainty.

If the results were only affected by random uncertainties, the changes in mechanical energy should also be randomly distributed – in particular, you should observe both negative and positive deviations.

Is this the case?

Teacher's notes

Concepts used

Velocity
Potential energy
Kinetic energy

Force
Work

Mathematical skills

Inserting numbers in a formula
Percent

About the equipment

The timer reacts on both positive-going and negative-going edges. When the *Start* and *Stop* inputs are connected, the timer is started and stopped by any change in the photogate state.

When the display says ”low bat.”, change batteries at once for the sake of the precision of the measurements.

A more advanced variant of the experiment is possible.

Instead of just testing if the mechanical energy is approximately conserved, you can look closer at the energy loss due to friction. A couple of ideas:

By letting the weight swing through the photogate more than once (reading and resetting the timer in the extreme positions), you will discover that the time increases slightly for each swing.
You can let the students try to establish a mathematical model for the energy loss.

The length of the path can be varied by using a longer thread. If you take care to let it start at the same heights as in the original measurements, the speed of the weight when passing the photogate should theoretically be the same as before. Describing the results mathematically can again be an open exercise for the students.

Detailed equipment list

Specifically for the experiment

200280	Student Timer (or older model 200260)
197550	Photogate
272502	Aluminium weight 100 g

Standard lab equipment

140500	Ruler, wood, 50 cm
105711	Lab lead 25cm, red
000850	Retort stand rod 25 cm
000830	Retort stand rod 50 cm
000800	Retort stand rod 150 cm
002310	Square bosshead (3 pcs.)
000100	Retort stand base 2.0 kg (2 pcs.)

Spare parts and consumables

116500	Extra strong thread
351005	Battery LR6 1.5V [AA] (200260 uses 6 at a time – included)