

**Physics**  
**Unit 3**  
**Motion in 1 and 2 Dimensions**

**Experiments**

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Selected experiments from Camberwell Grammar School  
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## Motion Prac 1: Elastic Potential Energy via Hooke's Law

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### Introduction

Materials change shape under the action of an applied force and they store potential energy in the process. If the applied force is released then that stored energy, or at least some of it can be released.

A very simple and often applicable law is Hooke's Law. It states simply that the amount of stretch in a material in a direction is directly proportional to the applied force in that direction.

$$F = kx$$

where  $F$  is the applied force (N),  $x$  is the extension or increase in length of the material (m) and  $k$  is called the stiffness of the material and has the units newton per metre ( $\text{N m}^{-1}$ ).

If a rubber band has a stiffness of  $k = 32 \text{ N m}^{-1}$  then it will stretch by one metre when a 32 N force is applied, provided it didn't break first; that is each 3.2 N will cause a 0.1 m increase in the length of the rubber band.

Plotting the applied force in newton on the  $y$ -axis and the extension in metre on the  $x$ -axis should result in a graph that is basically linear if the mathematical model is accurate since  $F \propto x$ .

- The gradient of the graph gives the value of  $k$  in  $\text{N m}^{-1}$
- The area under the graph gives the amount of work done stretching the rubber band and hence the stored energy in joule since the work done by the applied force = force  $\times$  distance.

In this prac we are going to do a simple experiment of firstly stretching a rubber band and then unstretching a rubber band. We will plot a **loading curve** and then an **unloading curve** on the one axes.

### Materials

Retort stand, boss head and clamp G-clamp, rubber band, 50 g slotted weights, ruler.

### Tasks

- 1) Clamp a retort stand to the desk and suspend a rubber band from the clamp with a ruler mounted vertically beside to take accurate length measurements.

#### Remember:

There are 100 cm in a metre, 1000 mm in a metre and 10 mm in a cm.

Remember: To determine the weight force of a mass close to the surface of the earth  $W = 9.8 \frac{\text{N}}{\text{kg}} \times m \text{ kg}$ .

- 2) Collect about 10 data points (50 gram increments would suffice) recording the extension of the rubber band (m) vs the applied force (N).
- 3) Now go backwards removing 50 gm at a time recording the extension vs applied force. Complete the table provided.
- 4) Plot a graph of applied force (N) vs extension (m) for both the loading and unloading sections of the experiment.
- 5) Using a linear portion of the loading graph, estimate the value of  $k$ , the stiffness of the rubber band by calculating the gradient of the graph. Note the unit for  $k$  is  $\text{N m}^{-1}$ .
- 6) By calculating the area under the graph, determine the energy stored in the rubber band at maximum extension. Note this area will have unit  $\text{N} \times \text{m} = \text{joule} = \text{J}$



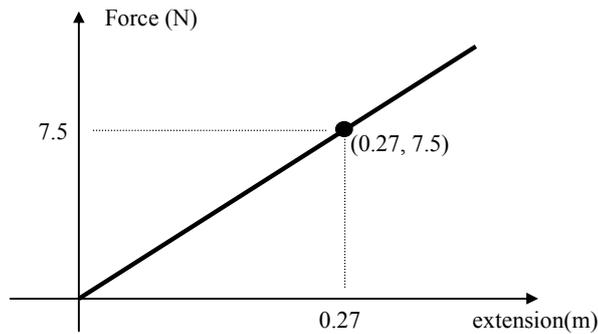
## Hooke's Law Problem

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For an ideal elastic material that is stretched by an amount  $x$  under the action of an applied force  $F$ , Hooke's Law states that  $F = kx$ . The graph, in the ideal case, is a straight line passing through the origin with gradient  $k$ . The quantity  $k$  is called the stiffness of the material.

The elastic potential energy stored in the material is given by the area under the graph.

In the ideal case this is  $PE_{\text{elastic}} = \frac{1}{2}kx^2$  or  $\frac{1}{2}Fx$ .



In the example the value of  $k = 28 \text{ N m}^{-1}$  and the stored energy in the stretched material at that point is 1.0 J.

- 1) Determine the force required to stretch this material by 0.16 m.
- 2) Determine the amount by which the material would stretch if a force of 6.0 N were applied.
- 3) Calculate the energy stored in the material when stretched to an extension of 35 cm.

### Answers

1.4.4 N    2. 0.22 m or 21.6cm    3. 1.70 J

## Motion Prac 2: Analysis of a sticky collision

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### Introduction

- In a sticky collision, a glider from the left is moved towards a stationary glider on the right. It collides with the stationary glider and they move off together at a common speed. The single card on the left hand glider can be used to measure the forward speed of the left hand glider before and the common speed of both gliders after the collision.
- In this experiment, light-gates will perform the timing operations which will enable you to deduce velocities, momenta and kinetic energies for experimental trials.
- The system is illustrated below in Figure 1. You will need to measure the mass of both gliders, the width of the cardboard mounted on the glider and the transit times through the event timers.



Figure 1.

### Tasks (these are done on the accompanying sheet)

- 1) Determine the initial velocity in  $\text{m s}^{-1}$  for the incoming glider.
- 2) Determine the initial momentum of the system in  $\text{Ns}$ .
- 3) Determine the final velocity in  $\text{m s}^{-1}$  for the outgoing gliders which are stuck together.
- 4) Determine the final momentum of the system in  $\text{Ns}$ .
- 5) How does the initial momentum compare with the final momentum? Calculate the fraction
- 6)  $\frac{\text{total momentum after the collision}}{\text{total momentum before the collision}}$  and see how close to 1 it is.
- 7) Determine the Kinetic Energy of the system before and after the collision.
- 8) Calculate the fraction:  $\frac{\text{total kinetic energy after the collision}}{\text{total kinetic energy before the collision}}$
- 9) How much Kinetic Energy has been transferred out of the system? In what form is the energy most likely to have transformed?
- 10) Is momentum conserved? Is Kinetic energy conserved?

**Results**

mass of the light glider: \_\_\_\_\_ kg

mass of the heavy : \_\_\_\_\_ kg

width of cardboard card: \_\_\_\_\_ m

Quantity	Trial 1 (Light into Heavy)	Trial 2 (Heavy into Light)
<b>Before Collision</b>		
Transit time for incoming glider (s)		
Velocity of incoming glider (ms <sup>-1</sup> )		
Momentum of incoming glider (kgms <sup>-1</sup> )		
Kinetic energy of incoming glider (J)		
<b>After Collision</b>		
Transit time for pair of gliders (s)		
Velocity of pair of gliders (ms <sup>-1</sup> )		
Momentum of pair of gliders (kgms <sup>-1</sup> )		
Kinetic energy of pair of gliders (J)		
$\frac{\text{total momentum after collision}}{\text{total momentum before collision}}$		
$\frac{\text{total kinetic energy after collision}}{\text{total kinetic energy before collision}}$		
Has momentum been conserved?		
How much KE has been converted to sound and heat?		

11) Is the collision an isolated one?

12) Is the collision an elastic one?

## Motion Prac 3: Analysis of an Explosion

### Introduction

- Two gliders are held together by a cotton loop. Bar magnets are set in the ends of the gliders to repel. When the loop is broken the gliders move apart. After each trial, the timers will display on the screen the times for each glider card to pass the timing photodiodes.
- The two trials are illustrated below in Figure 1. The masses used will need to be measured accurately.

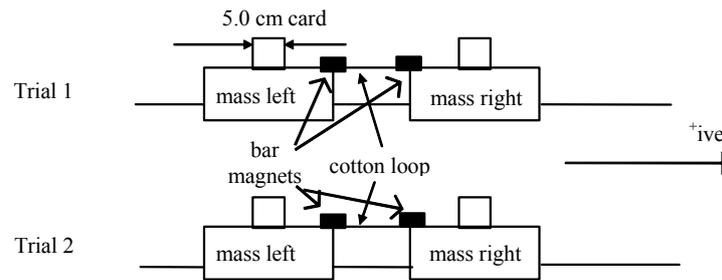


Figure 1.

### Tasks

Record all the values indicated below in the spaces provided over the page.



mass of the left glider: \_\_\_\_\_ kg

mass of the right glider : \_\_\_\_\_ kg

Quantity	Trial 1	Trial 2
Total momentum before explosion (Ns)		
Transit time for left glider (s)		
Velocity of left glider (ms <sup>-1</sup> )		
Transit time for right glider (s)		
Velocity of right glider (ms <sup>-1</sup> )		
Momentum of left glider (kgms <sup>-1</sup> )		
Momentum of right glider (kgms <sup>-1</sup> )		
Total momentum after explosion (Ns)		
Kinetic energy of left glider (J)		
Kinetic energy of right glider (J)		
Potential energy stored in magnetic field (J)		

### Questions

1) Use conservation of momentum to derive an expression for  $\frac{v_{left}}{v_{right}}$  in terms of the masses.

2) Derive an expression for  $\frac{KE_{left}}{KE_{right}}$  in terms of the masses.

## Motion Prac 4: Analysis of an Elastic Collision

### Introduction

- In this final experiment, an event timer will perform the timing operations which will enable you to deduce velocities, momenta and kinetic energies for experimental trials where one glider collides with a second stationary glider.
- In this simulation of an elastic collision, a glider from the left moves towards a stationary glider. Bar magnets are mounted at the ends of the gliders so that they repel each other. The left hand glider collides with the stationary glider **but without contact** and they move apart after the collision.
- In Trial 1 the left hand timing photodiode will time the passage of the left hand glider both before and after the collision as it recoils. The right hand photodiode will record the time for the right hand glider. The moving glider recoils backwards since it has a mass less than the stationary glider.
- In Trial 2 the right hand photodiode will time the successive passages of the right hand glider and then the left hand glider. In this second trial the moving glider follows on because it has a mass greater than the stationary glider.
- The two trials are illustrated below in Figure 1.

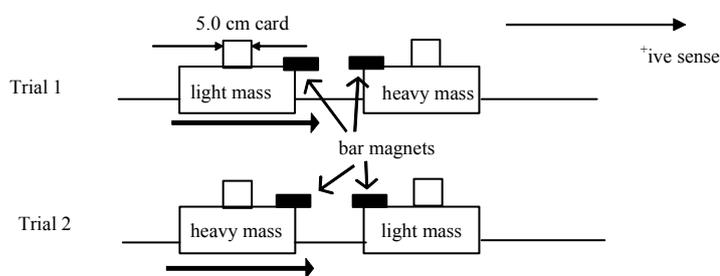


Figure 1.

### Tasks (these can be recorded on the results page)

- 1) Measure the mass of the two gliders.
- 2) Determine the initial velocity in  $\text{m s}^{-1}$  for the incoming glider.
- 3) Determine the initial momentum of the system in  $\text{Ns}$ .
- 4) Determine the final velocities in  $\text{m s}^{-1}$  for both gliders. [remember + or - to indicate direction]
- 5) Determine the final momentum of the system in  $\text{Ns}$ . remember momentum is a vector quantity
- 6) How does the initial momentum compare with the final momentum?
- 7) This can be determined by calculating the fraction:  $\frac{\text{total momentum after the collision}}{\text{total momentum before the collision}}$ .
- 8) Determine the Kinetic Energy of the system before and after the collision by calculating the sum of the kinetic energy of both gliders before and after the collision.
- 9) Calculate the fraction  $\frac{\text{total kinetic energy after the collision}}{\text{total kinetic energy before the collision}}$ . How much Kinetic Energy has been transferred out of the system?
- 10) Is momentum conserved?
- 11) Is Kinetic energy conserved?[note: for this type of experiment agreement should be to within 10%]

**Results**

mass of the light glider: \_\_\_\_\_ kg

mass of the heavy glider: \_\_\_\_\_ kg

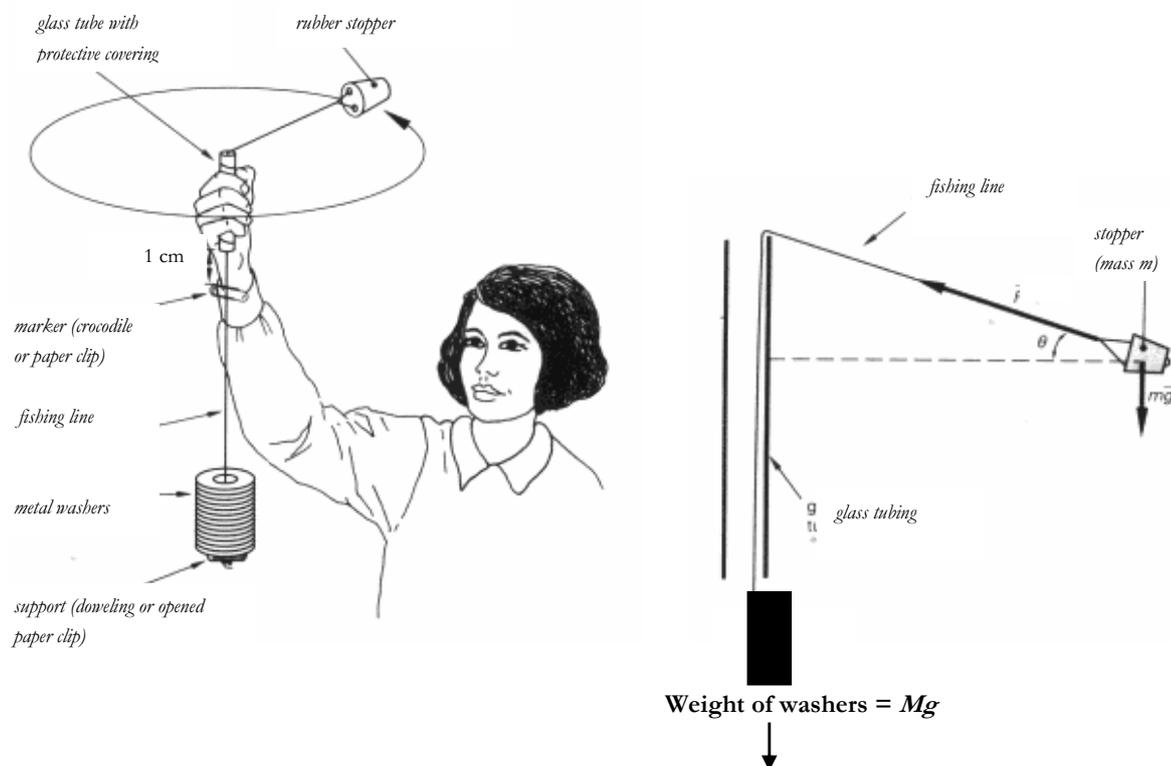
Quantity	Trial 1 (Light into Heavy)	Trial 2 (Heavy into Light)
<b>Before Collision</b>		
Transit time for incoming glider (s)		
Velocity of incoming glider (ms <sup>-1</sup> )		
Total = Momentum of incoming glider (kgms <sup>-1</sup> )		
Total = Kinetic energy of incoming glider (J)		
<b>After Collision</b>		
Transit time for “recoiling/follow-on” glider (s)		
Transit time for “hit” glider (s)		
Velocity of “recoiling/follow-on” glider (ms <sup>-1</sup> )		
Velocity of “hit” glider (ms <sup>-1</sup> )		
Momentum of “recoiling/follow-on” glider (kgms <sup>-1</sup> )		
Momentum of “hit” glider (kgms <sup>-1</sup> )		
Total momentum of system after collision (be careful of direction) (J)		
Kinetic Energy of “recoiling/follow-on” glider (J)		
Kinetic Energy of “hit” glider (J)		
Total kinetic energy of system after collision (J)		
$\frac{\text{total momentum after collision}}{\text{total momentum before collision}}$		
$\frac{\text{total kinetic energy after collision}}{\text{total kinetic energy before collision}}$		
Has momentum been conserved?		
How much KE has been converted to sound and heat?		

## Motion Prac 5: Moving in a circular path

### Aim

To determine how *the centripetal force acting on a mass* varies with its *frequency* of revolution when the mass is moving in a circular path at constant speed.

In the diagram below a student is performing an experiment much like the one you will do today – joy!



### Background

$$\text{Net Force} = \text{Mass} \times \text{Acceleration} = m \frac{v^2}{r} = m \frac{4\pi^2 r}{T^2} = m \times 4\pi^2 r f^2 \text{ for circular motion}$$

- In this experiment you will be spinning a rubber stopper above your head. The rubber stopper is moving in a circle. The forces acting on the rubber stopper are its Weight downwards,  $mg$ , due to the gravitational attraction of the Earth, and the Tension inwards in the line due to the Weight of the washers,  $Mg$ .
- The line is at an angle  $\theta$  to the horizontal. This means that the weight of the washers through the Tension provides an upward vertical force to balance the downward force due to the weight of the stopper.
- The horizontal component of the tension provides an unbalanced inward horizontal force to produce the centripetal acceleration.
- The Tension force in the string has two components: Tension vertical =  $Mg \sin \theta$ ; this will balance the weight of the mass  $m$ . and Tension horizontal =  $Mg \cos \theta$ . This provides the centripetal force for the circular motion.
- Thus 
$$Mg \cos \theta = \frac{4\pi^2 r m}{T^2} \Rightarrow \text{weight of the washers} = \frac{4\pi^2 r m}{T^2 \cos \theta} = \frac{4\pi^2 r m}{\cos \theta} \times f^2$$
- Most importantly because  $[4\pi^2 r m \div \cos \theta]$  is sufficiently constant [constant radius, constant rubber stopper mass and reasonably constant angle  $\theta$ ] it follows that the weight of the washers is proportional to the frequency of the motion.
- **Thus, we will see if the number of washers is proportional to the frequency squared.** For example if the number of washers increases by a factor of 4 then the frequency should only increase by a factor of 2.

### Equipment

Ruler; Stop watch; Circular motion apparatus consisting of a rubber stopper, fishing line, a glass tube, a crocodile clip and wing nut; 20 metal washers.

### Tasks

With the arrangement shown above, a rubber stopper is whirled in an horizontal circle. This experiment requires some space and practice. It should be done in the spaces between the benches or in the middle of the room.

In this experiment the *mass* of the object moving in circular motion will be kept constant, as will the *radius* of the circle.

- 1) Attach the crocodile clip about 3 cm below the bottom end of the tube, so that the radius of the circle is some value between 0.7 and 1.0 m.
- 2) Record your selected radius in case the clip slips during the experiment.
- 3) Thread the wing nut through about 20 washers. You will be investigating how the frequency of revolution  $f$  is related to the centripetal acceleration,  $a$ . The frequency,  $f$ , can be determined by your partner measuring the time taken for, say, 20 revolutions.
- 4) Practice spinning the stopper above your head. It is difficult at first to establish a horizontal circle. Initially hold the line below the tube until the Tension from the washers can hold the stopper in a constant circle. Ensure that the crocodile clip is clear of the end of the tube. If it starts to move down due to friction losses, give the top of the tube a little tweak to keep the stopper moving.
- 5) Repeat with two less washers each time until it is too hard to maintain the rotation, usually about 10 washers.
- 6) Record your results in the table below.

No. of Washers	Time for 20 revs (s)			Average Time (s)	Freq (Hz)	$f^2$ (Hz <sup>2</sup> )
20						
18						
16						
14						
12						
10						
8						

- 7) Now graph the number of washers ( $Y$  axis) against frequency ( $X$  axis)

The graph you obtained is unlikely to be a straight line. If the data is accurate the graph should have a parabolic shape.

When a body moves in a circle with a constant speed the centripetal force (ie number of washers) is proportional to the inverse square of the period ( ie the square of the frequency).

- 8) Thus to test this plot the number of washers ( $Y$  axis) versus the square of the frequency ( $X$  axis).  
If the number of washers is proportional to the square of the frequency then such a plot should yield a straight line passing through the origin.

**Questions**

- 1) Why is it essential to keep the mass of the moving object and the radius of its circular path constant?


- 2) What is the assumption made, if we say that the centripetal acceleration is given by the number of the suspended metal washers? [Hint: think about the angle of elevation of the string]


- 3) Describe the shape of your number of washers against frequency graph.


- 4) Did you find that the number of washers was in fact proportional to the square of the frequency?  
How can you tell?