NAME : ....

TEACHER : ....

XXX SCHOOL

PHYSICS

Unit 2 2013

Motion

Index

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Jacki Freetall – Motion Data Analysis

Background

The motion of an athlete can be studied by using an acoustic radar system. The data obtained gives the position of the athlete down a track at half-second intervals. The athlete is running a 100 m race. At time $t = 0$, Jacki is in the starting blocks and the gun goes off.

Tasks

1) Take the data below in Table 1 and plot a distance versus time graph. Distance along the y-axis and time along the x-axis.

   Table 1: Distance-time data.

Time (s)	Distance (m)
0.00	0.00
0.50	0.60
1.00	2.40
1.50	5.40
2.00	9.60
2.50	15.0
3.00	21.0
3.50	27.0
4.00	32.9
4.50	38.9
5.00	44.7
5.50	50.6
6.00	56.4
6.50	62.1
7.00	67.8
7.50	73.4
8.00	79.0
8.50	84.5
9.00	89.9
9.50	95.4
10.0	100.7

2) By taking pairs of data, complete a new table for the average speed of Jacki for each half- second interval. Remember for each half-second the average speed is given by the distance covered during that time frame divided by the time interval which in this case is 0.50 second.

   The first one is $0.60 – 0.00 \div 0.50$ m s^{-1}. The speed in the first interval is 1.2 m s^{-1} and this occurs at the midpoint in time of the first frame. This will be at t = 0.25 second.

Table 2: Average speed versus time.

Time (s)	Average speed (ms^{-1})
0.25	1.20
0.75	3.60
1.25	6.00

3) Take the data from Table 2 and plot a graph of Jacki's average speed versus time.

Now we are going to find the acceleration of Jacki as a function of time.
Similar to Task 2, we now take the average of the speed-time data.
Acceleration is equal to the change in velocity over time, so we now find the difference between two speed values and divide by the time interval.
Again, we plot the acceleration at the midpoint of the time interval.
So point 1 would be the speed at 0.75s – speed at 0.25s, all divided by 0.5s
(3.60 – 1.20)/0.5 = 4.8 ms^{-2}

4) Complete Table 3 – acceleration vs. time

Table 3. Acceleration versus time.

Time (s)	Average acceleration (ms^{-2})
0.50	4.80
1.00	4.80

Staple your graphs inside this Prac Book

5) Plot a graph of Jacki's acceleration versus time.

6) Write a brief summary of the characteristics of short distance athletic performance in terms of:
   a. Speed over time
   b. Acceleration over time

- the skills you have developed in analysing kinematic data and
- characteristics of short distance athletic performance

Motion PRAC 1 : Acceleration of a cart down an inclined plane

Aim : To measure the acceleration of a cart down an inclined plane.

Equipment : Inclined plane
Cart
Ticker timer and tape
Power Pack

Method :

1. Set up the inclined plane
2. Connect the ticker timer to the AC output of the power pack
3. Connect the tape to the cart, put the tape through the ticker timer
4. Place the cart at the top of the inclined plane
5. Turn the ticker timer on and allow the cart to accelerate down the plan
6. Cut the tape into 5 dot sections. Each section will represent 0.10 second time intervals.

Results :

In a table of results record the following :

- The length of each section in metres
- The average speed of each section in m/ s (speed = length/ 0.10 second)
- The average acceleration of each section in m/ s/ s (acceleration = change in speed/ time)
- Graph displacement vs time, velocity vs time, acceleration vs time for the cart

Questions :

1 Calculate the average acceleration of the cart down the plane.
2 What factors affect the acceleration of the cart down the plane?
3 Write down any relationships you can observe that link the 3 graphs.

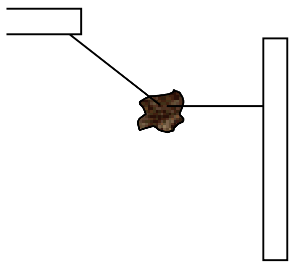
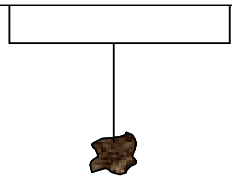
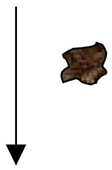
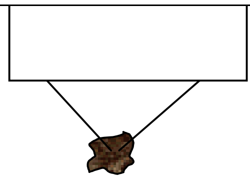
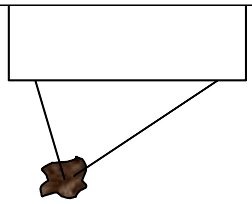
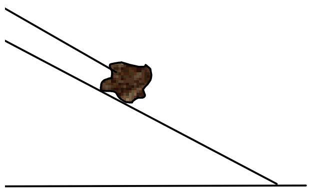
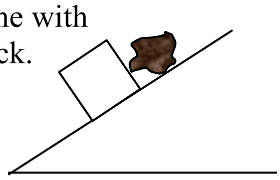
Theory Problem

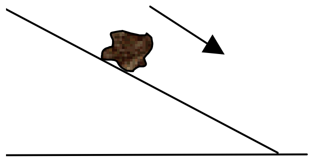
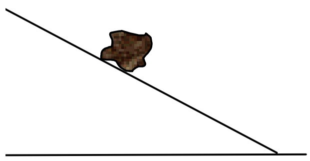
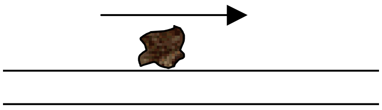
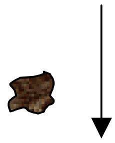
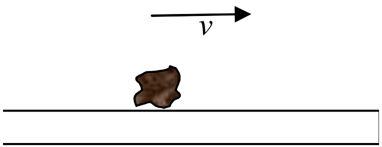
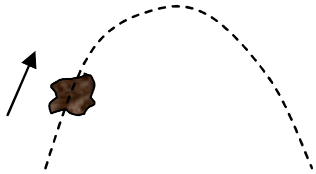
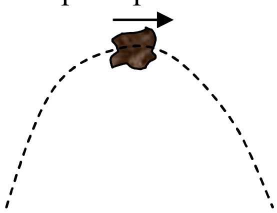
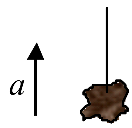
Tim is riding his bike. He starts at rest and accelerates to a velocity of 4.0 m/s North over 8.0 s. He maintains this speed for 4.0 s before braking and coming to a stop in the next 4.0 s. He then turns around and rides back to where he started with constant non- zero acceleration in 16 s.

1. Plot a velocity time graph for this situation.
2. Calculate the total distance covered by Tim during his journey.
3. Calculate Tim's acceleration and final speed on his return journey.

Forces Activity: Free Body Force Diagrams

In each case, below, a rock is acted on by one or more forces. Draw accurate **vector diagrams** showing all forces acting on the rock. Use a pencil so you can correct any that you get not quite right. A vector diagram consists of representing the object as a point and attaching arrows to the point to represent forces. The forces should all be labelled and you are encouraged to develop the following phrase when describing a force: "The force that the earth acts on the rock" = $\boldsymbol{F}_{earth \rightarrow rock}$ = commonly called the weight of the rock.

1. 	2. 
3. Rock is falling, no air resistance. 	4. 
5. 	6. stationary rock 
7. Rock on an inclined plane. 	8. Rock on an inclined plane with block. 

9. Rock on an inclined plane, sliding with no friction. 	10. Rock on an inclined plane, stationary. 
11. Rock with constant speed without friction. 	12. Rock falling with constant velocity. 
13. Rock decelerating due to dynamic friction. 	14. Rising in a parabolic trajectory, no air drag. 
15. In a parabolic trajectory, at the top or apex. 	16. Pulled up by a rope with $a = 9.8\ \text{m s}^{-2}$ upwards. 

Motion PRAC 2 : Friction

Background

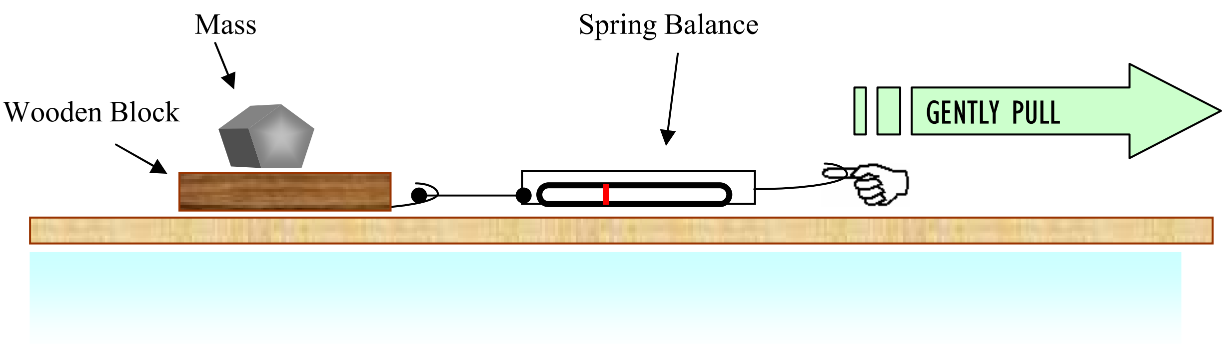
In this practical exercise you will look at the size of the force of friction when an object slides across a table and when it is stationary but just about to slide. The mass of the object will be systematically increased and the size of static friction will be measured.

Apparatus

1 wooden block (with nail or hook)
1 × 10N and 20N spring balance
1 × 0.5kg mass
1 × 1.0kg mass (or two 0.50kg masses)
1 × 2. kg mass

Tasks

1) Set up the apparatus as in the diagram below, starting with 0.5 kg on the wooden block. Check that the spring balance reads zero when in equilibrium and when placed horizontally.



2) Select a uniform patch of bench top (eg. one with no rough or sticky sections) and **<u>gently increase</u>** the force on the wooden block by pulling the spring balance.
3) Record the maximum force on the block **<u>just before</u>** the block begins to move. This maximum force is called **static friction**.
4) Now measure the average force needed to keep the block moving at as steady a speed as possible. This force is called the **sliding friction**
5) Increase the mass on the block in 0.50 kg steps and repeat the experiment.

Mass of block+masses (kg)	Upwards contact Force on block (N)	Static friction Force(N)	Sliding friction Force (N)

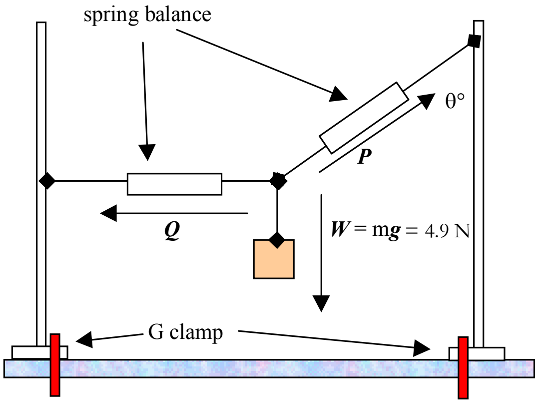
Analysis Tasks

1) In the second column record the size of the upward contact force using $\boldsymbol{g}$ = 10 N kg^{-1} down. Remember that Newton's Laws show that the upwards contact force on the block will equal the weight of the block + mass **if there is** equilibrium.
2) Plot on the same axes a graph of sliding friction and static friction against the normal contact force (N) What conclusion(s) do you draw from your analysis?
3) The coefficient of friction μ is a measure of the amount of friction between two surfaces. It is defined as a ratio of the friction force divided by the normal contact force. Using your graph, what value or values do you get for μ in your experiment? Explain how you calculated the coefficient of friction, μ.

Motion PRAC 3: STATIC EQUILIBRIUM IN 2–DIMENSIONS

Background and Tasks

Newton's First law of motion tells us that if all the forces acting on a body add up to zero, then the body will maintain its state of motion. That is it will have zero acceleration. In this prac we investigate a system in equilibrium and recognise that when a system is in equilibrium then the vertical components of all the forces and the horizontal components will all balance.



1) Measure the angle θ, but don't look at the spring balances yet. (θ= ___________ degrees)

2) Given a hanging mass of 0.5kg and $\boldsymbol{g}$ = 9.8 N/kg find the magnitudes of vertical and horizontal components of the forces shown below: (Hint use your knowledge about right angled triangles and trigonometric functions. Leave your answers in terms of variables P, Q and θ.

Vertical Components	Horizontal Components
1.	1.
2.	2.

3) Consider ONLY the vertical components. Because the system is in equilibrium, the sum of all forces is zero. Write an equation involving the vertical components and solve it for **P**. (Assume up is positive)

$$\sum F_{vert} = 0$$

4) Considering ONLY the horizontal components. Write an equation involving the horizontal components. Use the value for **P** obtained in 3) and solve for **Q** (Assume right is positive)

$$\sum F_{horizontal} = 0$$

5) Compare your values for **P** and **Q** with the spring balances and try to account for any difference.

6) Draw a vector diagram for the vectors **W, P** and **Q** acting on the central ring. Give a full specification of the vector **W**, **P** and **Q** (Their magnitude and their direction)

7) Construct a vector addition diagram (to small scale) and test to see if the three vectors add up to zero. If they do the three vectors will form a triangle.

Motion PRAC 4: FORCES IN BALANCE

Background

Newton's First law of motion tells us that if all the forces acting on a body add up to zero, then the body will maintain its state of motion. That is it will have zero acceleration. In this prac we investigate a system in equilibrium and recognise that when a system is in equilibrium then

1) The vector sum of all forces adds up to zero
2) Components of the forces also sum to zero in both perpendicular directions.

Method

1) Make the ring in the centre of the table become centred and stable by adjusting the weights on the ends of the strings and the direction of each of the three strings.

Analysis Task 1 – Addition of Vectors

8) Draw a vector diagram for the vectors ***W***, ***P*** and ***Q*** acting on the ring.
9) Give a full specification of the vector ***W***, ***P*** and ***Q***. That is the magnitude and the direction.
10) Now construct a vector addition diagram (to scale) and test to see if the three vectors add up to zero. If they do the three vectors will form a triangle.

Analysis Task 2 – Resolving vectors into perpendicular components

11) Now make the 0° – 180° line the *x*-axis. Secondly make the 90° – 270° line the *y*-axis.

12) Resolve each of the three vectors into 2 parts. One part parallel to the *x*-axis and one the remaining part parallel to the *y*-axis.

13) Test to see whether or not the sum of the three components add up to zero in both the *x* and *y* axes.

14) If the sums do not add up to zero, give a reason for this.

Motion PRAC 5: VERIFYING NEWTON II: ACCELERATION OF A CONSTANT MASS VARIOUS FORCES

Background

The purpose of this experiment is to investigate how the acceleration of an object varies when acted upon by various forces.

You will be using the air track to eliminate as much friction as possible. The glider will be attached to container of masses hanging by a pulley over the end of the air track. The weight force of this mass will provide the force to make the glider (and the falling mass) accelerate. This acceleration is uniform – so we can use the SUVAT equations in our analysis.

To vary the force, but still keep the moving mass constant throughout the experiment, we will be using a container holding several bolts. To decrease the force, a bolt is taken from the container. To keep the total moving mass constant, this bolt is then added to the glider.

Method

1) Measure and record the following quantities:

    a. Width of light shutter (card attached to glider) __________ m

    b. Separation of photo-gates ___________ m

    c. Mass of glider ____________ kg

    d. Mass of the container and four bolts ___________ kg

    e. Mass of one bolt ___________ kg

2) Set up the glider several centimetres before the first gate so it can stabilise after it is released
3) Repeat the experiment 3 times for each force to obtain an average acceleration and then relocate a bolt to vary the force (12 runs in total).
4) Acceleration is determined using kinematics, because we can calculate an initial and final speed and we know the distance this has occurred over (separation of the photo-gates).

   Using $v^2 = u^2 + 2as$, we can find ***a***. Make sure you understand this algebra before you start taking results.

5) Complete the following table with your results:

				Gate 1		Gate 2			
	Falling Mass (kg)	Falling Force (N)	Total Moving Mass (kg)	Time (s)	Speed (m/s)	Time (s)	Speed (m/s)	Acceleration (m/s^2)	Average acceleration (m/s^2)
1									
2									
3									
4									

6) Plot a scatter graph of **Force** (*y*-axis) vs. **Acceleration** and comment on the relationship between the two variables. Note there is a fifth point you can plot – where and why can you plot it?

7) Calculate the value of the gradient and note how this relates to your experiment.

8) Write a conclusion summarising the relationship between acceleration, constant mass and a variable force.

Motion PRAC 6: VERIFYING NEWTON II: ACCELERATION OF A VARIOUS MASSES BY A CONSTANT FORCE

Background

The purpose of this experiment is to investigate how the acceleration of an object depends on its mass when acted upon by a constant force. We will add mass to the glider to investigate the relationship between this acceleration and the mass.

Method

1) Measure and record the following quantities:

    a. Width of light shutter (card attached to glider) __________ m

    b. Separation of photo-gates ___________ m

    c. Mass of falling object ___________ kg

    d. Force of falling object (W = mg) ______________ N

2) Set up the glider several centimetres before the first gate so it can stabilise after it is released
3) Repeat the experiment 3 times for each force to obtain an average acceleration and then relocate a bolt to vary the force (12 runs in total).
4) Acceleration is determined using kinematics, because we can calculate an initial and final speed and we know the distance this has occurred over (separation of the photo gates).

    Using $v^2 = u^2 + 2as$, we can find ***a***. Make sure you understand this algebra before you start taking results.

9) Complete the following table with your results:

				Gate 1		Gate 2			
	Glider Mass (kg)	Total Moving Mass (kg)	Leave blank for Q3	Time (s)	Speed (m/s)	Time (s)	Speed (m/s)	Acceleration (m/s^2)	Average acceleration (m/s^2)
1									
2									
3									
4									

2) Plot a scatter graph of **Acceleration** (*y*-axis) vs. **Glider Mass** and comment on the shape of the graph. Predict the relationship between the acceleration *a* and the total moving mass *m*.
3) Now, test your prediction. What possible "acceleration vs …" could you plot so as to obtain a straight line? Use the blank column to enter values for this new *x* data and plot the new graph.
4) Establish a line of best fit and calculate the gradient of this new linear graph. Where has this value appeared before?
5) Write a suitable conclusion summarising the relationship between acceleration, mass and a constant force.

Motion PRAC 7: Air Track Sticky Collision

Background

- 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, a computer or light-gates will perform the timing operations which will enable you to deduce velocities, momentum 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 (a table version of these is on the next page)

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

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)
Before Collision		
Transit time for incoming glider (s)		
Velocity of incoming glider (ms^{-1})		
Momentum of incoming glider ($kgms^{-1}$)		
Kinetic energy of incoming glider (J)		
After Collision		
Transit time for pair of gliders (s)		
Velocity of pair of gliders (ms^{-1})		
Momentum of pair of gliders ($kgms^{-1}$)		
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?		

1) Is the collision an isolated one?

2) Is the collision an elastic one?

Motion PRAC 8: Energy Round Robin

 # 1 A Bouncing Ball

Equipment: A small rubber ball, metre ruler and scales.

Procedure: Drop the ball from a height of 1 metre. Measure the height to which it rebounds. Repeat until you are satisfied that you have determined the rebound height to the nearest cm.

Mass of ball (kg): Rebound height (m): Average height (m):

1) How much gravitational potential energy did the ball lose as it fell?

2) How much of this potential energy did it regain?

3) Explain any discrepancy between your answers to 1) and 2)

 # 2 Push-ups

Equipment: 2 kg mass, a metre ruler and stop watch.

Procedure: Hold the mass level with your shoulder and then extend your arm vertically. Get your partner to time you while you do this ten times with right arm and also with your left arm. Measure the distance you lifted the mass.

Distance mass lifted (m): Time for 10 lifts (sec):

1) Calculate the amount of work you did against gravity with each arm.

2) Calculate the rate at which you were working.

 # 3 Up, up, up

Equipment: A stop watch and a tape measure.
Procedure: Run up a flight of stairs as fast as you can while your partner times you. Measure the vertical distance you climbed.

Vertical distance (m): Time (sec):

1) Calculate the rate at which you were working against gravity. (What units must you use for your measurements of distance and time for your answer to be in watts.)

 # 4 Rolling Trolleys

Equipment: A trolley, bricks, a beam, scales, a ruler and a stop watch.
Procedure: Raise one end of the beam with the bricks. Allow the trolley to roll down the incline and measure how long it takes, t. Also measure the distance (x), the trolley rolled, the difference in heights of the beginning and end of its run, and the mass of the trolley. The trolley's average speed will be x/t. This will be its speed half way down the run. Its speed at the end of the run will be 2x/t.

Distance rolled (m): Height difference (m): Trolley mass (kg): Time (sec):

1) Calculate the trolley's kinetic energy at the bottom of the run.

2) Calculate the change in the trolley's gravitational potential energy during the run.

3) Compare and comment on your answers to a) and b). Explain any variation.

 # 5 Down, down, down

Equipment: A table tennis ball, ball bearing, a small rubber ball, tape measure and a stop watch.
Procedure: Drop the table tennis ball from the stair landing and time how long it takes to reach the ground. Do the same thing with the ball bearing and the rubber ball. Use the measuring tape to measure the distance the balls have fallen.

Dist fallen (m): Time (tt ball) (sec): Time (bearing) (sec): Time (rubber) (sec):

1) Use the same type of calculation as above to calculate the kinetic energy of the balls as they reach the ground.

2) Calculate how much gravitational potential energy the balls have lost as they fall.

3) Compare your answers to a) and b) for each of the balls.

4) Why do you think the comparisons are different for the different balls?

 # 6 Up and Down

Equipment: A rubber ball, scales and a stop watch.

Procedure: An outdoor activity. Throw the ball as high as you can and then catch it while your partner times how long it is in the air. Measure the mass of the ball. To calculate the maximum height the ball reached, you can use the equations for constant acceleration. Consider the downward part of the motion: Accel'n, $a = 10\ m/s^2$*, at top of flight* $u = 0$*, time to fall,* t *= half the measured time. Use* $x = ut + \frac{1}{2}at^2$*.*

1) Once you have calculated a value for x, you can calculate the amount of gravitational potential energy the ball had at the top of its path. If all the kinetic energy you gave the ball was changed into potential energy (and then back to kinetic energy as the ball returned to your hand) you can make a statement about how much work you did on the ball as you threw it.

2) Calculate how much work you did on the ball. Show all your working.

3) What assumptions have been made in these calculations? Do you think that all the initial kinetic energy of the ball was converted to potential energy and then back to kinetic energy? if not, why not?

Mini Energy Investigation – Stretched springs

In this experimental project, you will gain further experience at

- **collecting** reliable data, and recording it in an orderly fashion using tables and diagrams
- **recognising** the importance of repeated trials to gain confidence in the reliability of a measurement,
- **dealing** with numbers and ways of representing them in science: significant figures, random and systematic error, standard notation are all to be addressed.
- **fitting** a simple continuous mathematical function to a finite set of data. Here the notions of extrapolation and interpolation and reliability of the fit are explored.
- **using** spreadsheets and charting to generate formatted tables and appropriately constructed graphs and charts.
- **arriving** at a valid conclusion for the experiment and **evaluating** the methods employed.

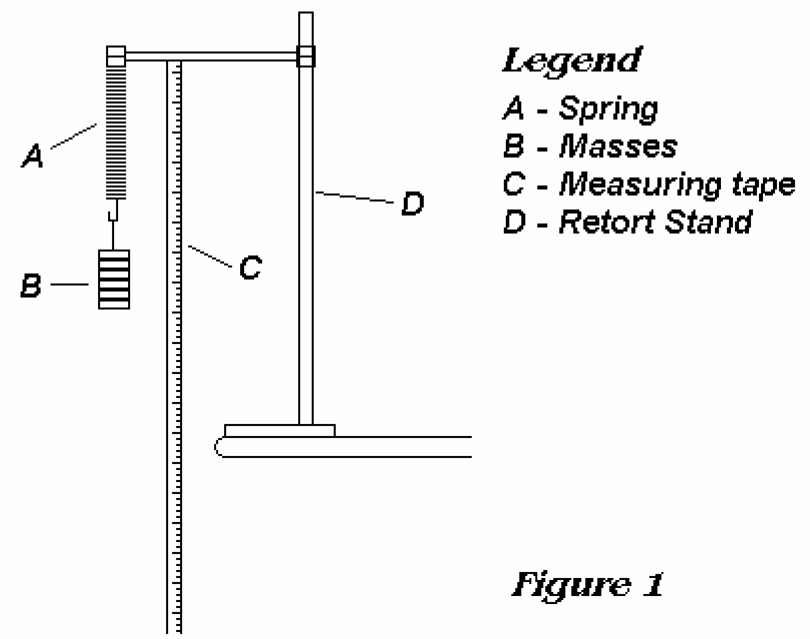


Figure 1

In this experiment, a variable mass m is suspended from a vertical spring. Due to the force that the mass exerts on the spring, the spring will increase in length; that is it will stretch and store elastic potential energy.
The suspended mass should range from 50 g to approximately1.0 kg.

In this experiment the length of the spring l (in metre) is to be measured as a function of the weight of the mass W (in newton) of the mass suspended from the spring.
A graph of weight versus length is to be plotted and from this graph the elastic potential energy stored in the spring as a function of length is to be determined in graphical form.

The report should be about 3 – 4 A4 pages in length including tables and graphs.

Use the dot points below to help you Write an aim, apparatus list, method and draw a diagram labelling on it the variables to be measured in this experiment.

- Systematically measure the length *l* (m) of the spring and the mass of a suspended object *m* (kg). You will need to consider what procedure you adopt to measure the length of the spring and whether you need to make repeat measurements. How will you measure the mass?

- What are the causes which limit the **range** of **independent variable**? What is the difference between an **independent variable** and a **dependent** one? What does the word "**range**" mean?
-
- For each of these two measurements *l* and *W* estimate the error involved and write your results in the form: $l = 15.5 \pm 0.2$ cm ie $1.55 \pm 0.02 \times 10^{-1}$ m for example. What is the typical **percentage error** in your results here? (How do you calculate a **percentage error**?)
- Record your results into a table with clear column headings.
- Construct a graph of weight *W* (N) **versus** length *l* (m) [Use $\boldsymbol{g} = 9.8$ N kg^{-1} down] [Note *y*-axis versus *x*-axis]
- Does your graph look like it can be fitted with a single straight line of best fit, or do you need to consider only part of the data to achieve this?
- From your graph draw a line of best fit through the set of data and establish an equation of the form: $mg = W = k(l - c)$ where *k* is the gradient of the graph and *c* is the *l*-axis intercept.
- What is the meaning of the value *c*?
- What physical property does *k* indicate? Find out about **Hooke's Law**.
- The class has all been given springs of the same type of stiffness. Collect a table of the class values for *k* and find the average value for *k* and well as an the range in *k* values obtained.
- What reasons could be given to account for the range of values in the stiffness *k*?
- The elastic potential energy stored in the spring is determined from the area under the graph. By counting squares or calculating an estimate for the area under your graph, draw a graph of the potential energy stored in the spring as a function of the stretch (not the length this time) of the spring.

Results check and conclusion

You should have 1) a weight vs length table 2) weight vs. length graph, 3) an estimate of the stiffness of your spring *k* and a class average for the value of *k* and 4) a graph of the elastic potential energy vs. stretch graph for the spring.

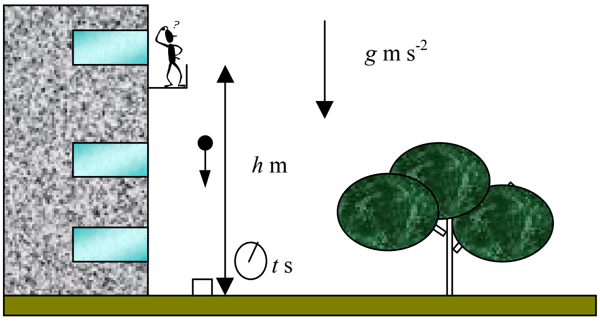
Background Theory

1) When a spring is stretched, for small extensions, the increase in its length is proportional to the applied force. This means that a graph of applied force (*F*, in this case the reaction to the weight of the mass) versus extension (m) will be well modelled as a straight line. The gradient of the line is a measure of how stiff or rigid the spring is and is accordingly called the spring constant or stiffness. This quantity *k* has unit N m^{-1}.
2) The gradient of a straight line is given by $k = \dfrac{rise}{rin} = \dfrac{\Delta y}{\Delta x}$
3) The work done stretching the spring is equal to the energy stored in the spring. The amount of work done and hence the elastic potential energy stored in the spring is equal to the area a force vs extension graph. The word: "extension" = the word "stretch"
4) The average value of a variable is $\bar{x} = \dfrac{\sum x}{n}$
5) The range in a variable is = largest value – smallest value

Demonstration: Simple Measurement of free-fall acceleration a and hence g

Background

In this simple demonstration we will determine the acceleration due to gravity by simply dropping an object and measuring the time it takes to fall to the ground.
The experiment is shown in the diagram below.



We will release the ball from a measured height *h* above the ground and it will take a time *t* s to reach the ground.
The initial velocity of the object is $u = 0$ m s^{-1}.
The final velocity of the object is v m s^{-1}.

Tasks

Record the class results in a table and find the average time of flight for the ball.
Class results: time for ball to fall from rest (seconds)

Use the above set of results to determine the acceleration due to gravity in units of m s^{-2}.

The average time to fall is _____________s.
The height that the ball fell is ________________m
The average speed of the object is ____________________ m s^{-1}.
The initial speed of the ball is 0 m s^{-1} (the ball was released from rest)
The final speed of the ball is ______________________ m s^{-1} (you need to think how to find this out)
Acceleration of the ball is _________________ m s^{-2}

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Extension Derive an expression for *g* in terms of drop height *h* and fall time *t*. Show your reasoning.

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