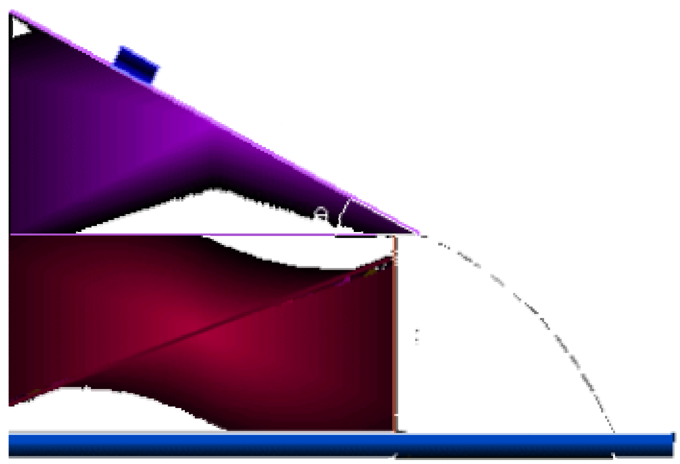
Slide Mechanics Coursework

DOWN THE SLIDE

Introduction

An object travels down a slide at distance *l* down the slide. The object then free-falls through a vertical distance *h* before hitting the ground. Obviously the greater *l*, the further the horizontal distance *d* that it lands away from the slide.



The relationship between *d* and *l* for a particular angle of inclination q for the slide. Experimental and theoretical data will be compared to see if the relationship in practice is that of the predicted data.

The aim of the experiment is to find the relationship between *l* and *d* for a given value of q.

The Model

An experimental model for the diagram shown above would be a slide on a table. A smooth object will travel down the slide and land on the floor with a precise measurable distance *d*. Before materials are named, certain modelling assumption will be made clear.

Modeling Assumptions & Materials

Taking into consideration that resistive forces must be minimal, or omitted altogether, in order for experimental and theoretical results to be compared with accuracy, suitable materials have to be used. Materials must have an appropriate arrangement and qualities to avoid such forces to effect results.

Object

The object that travels down the slide will be modelled as a particle with only one force acting on the object: its weight (*mg*). Any frictional forces will be ignored in preliminary modelling of the object down the slide. The object must remain rigid throughout the tests. If the object is not rigid, measured distances of its position would be inaccurate. Resistance with air should not influence its path down the slide and through the air before landing at *d*, with the indoor conditions where the tests will take place. There should no wind resistance present in this environment.

The Slide (inclined plane)

The plane has to be rigid enough to avoid bending when the object is placed on it. The slide must have minimal frictional forces between it and the object, the slide has to be smooth and have a non-grip *slippery* surface. The rate of acceleration would be affected if the inclined plane the object rested upon was not flat. This would also mean a varying change in q making comparisons infeasible over values of *l*. The angle of the slope will remain fixed for each set of tests.

The Floor (at *d*)

This is the surface that stops further downward vertical movement of the object. The floor must be flat otherwise values of *d* would be inaccurate and theoretical calculations would not be possible. Accurately measuring *d* must be addressed. If the value of *d* is purely observed by watching where the object lands, errors are bound to be made. If the object leaves a mark showing its first impact against the floor, the results will be more exact.

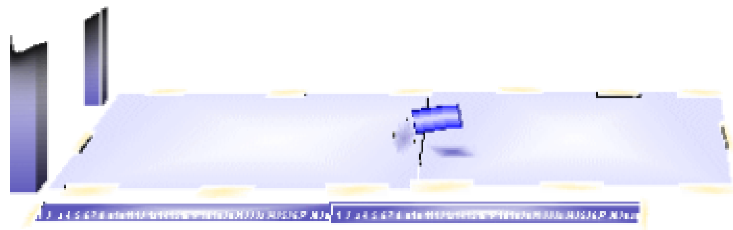
Distance between slide and floor

The distance *h* must remain the same throughout the whole experiment whatever the value of *d*. If the values of *h* varied it would be impossible to compare data obtained from the different methods and the theoretical predictions would not be possible to achieve.

Contact between object and slide

Contact between the object and slide should be a little as possible to reduce frictional forces between the two materials. The balance of weight must be equal over the surface of the object travelling down the slide. This will reduce any frictional forces present as one particular area will not slow the object more than another, thus equalising any frictional forces present. To have both minimal and equal contact between the top surfaces there must be more than one point of contact, but as few points of contact as possible. This leaves two areas of contact, the most practical shape for this would be a hollow cylindrical shape rested upon the edges of a rigid slide. The hollow cylinder would always have an equal weight upon the two edges of the slide (provided the edges are equal height), possible air resistance would be minimal due to small facing surface area. The depth of the cylinder would give a balanced pressure throughout the object. The ideal item to be used to travel down the slide is a metal ratchet socket. The ratchet socket must be larger than the distance between the raised edges of the slide, this means that there is a minimal sideways pressure on the side. The ratchet socket must be have a weight and shape that is equally spread throughout, avoiding unnecessary frictional forces and possible spinning motion. The slide must have minimal frictional resistance on the object, it must be smooth and have an equal shape throughout its length. There must be no dips, therefore the material must be ridged. The slide, as with the ratchet socket, will be made of metal with and have a smooth surface.

Contact between object and floor

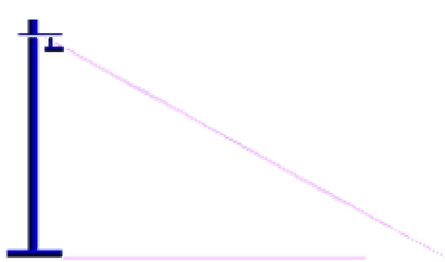


In order for accurate results to be obtained in the experimental method there must be a pre-specified method of recording data from the first contact between the object and the floor surface. One option could be covering the ratchet socket with ink, and a mark left on a piece of paper. However, this would make a mess of all the equipment and stain carpet and clothes, as well as adding unnecessary frictional forces when on the slide. As paper is easy to perforate, there is no need to cover the ratchet socket in anything. The perforation could simply be observed and measured with a ruler. The paper and ruler have to be kept in the same position throughout the experiment. The ensure this, sellotape will be used to stick the ruler and paper to the floor. Sellotape will also be used to secure the slide to the table edge.

Reducing error

To reduce error in the experimental tests, all values of *l* will be performed three times. This will improve accuracy and highlight any errors in method, if there are any. The three values will give some idea on the error bounds. Even if there is a draft in the room, despite the room having shut windows and the door will be closed. It would have a very small effect on a small heavy object like a ratchet socket. Use of sellotape to secure paper and measuring apparatus on the floor will verify consistent data on the experimental tests. The whole structure will be supported by a rigid structure (clamp stand) to avoid differing values of q and *l*. Three people will perform the tests. One person to place the ratchet socket at *l*, someone else to observe the ratchet socket as it hits the paper on the floor, plus a third person to record results. If people we to swap roles, it is possible that they would interpret what they do or see differently from another person. Therefore the same person should carry out their own task throughout the investigation. The slide and the ruler(s) on the floor must be parallel with each other, otherwise *d* will not be the true distance travelled horizontally. Lengths of *l* will be marked on the side of the slide every 10cm with a marker pen. This will clearly show the exact positioning of the ratchet before being slid down the slide and avoid variation as the tests progress.

Angles will be measured using sine and length of slide to the clamp stand and the height of the clamp stand to the slide.



arcsine = q

All measurements must be taken carefully otherwise error could be multiplied when q is calculated.

Performing Experimental Tests

Three people take part in the tests to increase efficiency and reduce errors as discussed previously. Data is noted down for each *d* and then recorded on a spreadsheet to calculate the averages. Values of q recorded were 24°, 30° and 35°. This should give a reasonable spread from which to compare at a later stage. The experimental tests are performed as discussed previously.

Results

Here are the results from the experimental tests, averages of mean and median are also shown. Values are listed against *l* and each value of q is contained in a separate table as the is a fixed value. Metres are the units for *l* as this unit of measurement will be used for the theoretical modelling, as experimental results were taken in centimetres these are used for values of *d*.

$\theta = 24°$

l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm
0.1	21.4	20.7	21.9	21.333	21.4
0.2	24.2	23.6	24.3	24.033	24.2
0.3	29.7	29	29.1	29.267	29.1
0.4	32.3	31.9	32.9	32.367	32.3
0.5	36.2	36.8	36.9	36.633	36.8
0.6	40	41.2	40.9	40.700	40.9
0.7	44.2	44.9	45	44.700	44.9
0.8	48.7	48.5	48.1	48.433	48.5
0.9	51.3	51.4	51.7	51.467	51.4
1	52.4	52.9	52.8	52.700	52.8

$\theta = 30°$

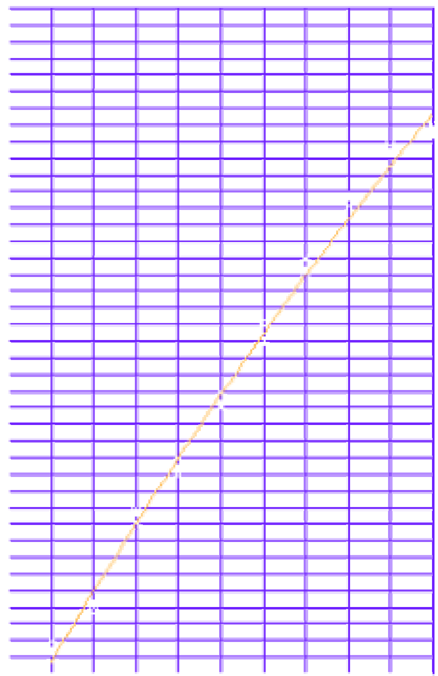
l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm
0.1	26	24.8	25.6	25.467	25.6
0.2	31.7	32.3	32.6	32.200	32.3
0.3	36.2	37.1	36.9	36.733	36.9
0.4	42.2	41.5	41.7	41.800	41.7
0.5	45.3	45.7	44.9	45.300	45.3
0.6	49.4	48.2	48.9	48.833	48.9
0.7	51.5	51.2	51.6	51.433	51.5
0.8	54.6	54.2	54.7	54.500	54.6
0.9	57	56.4	56.1	56.500	56.4
1	59.1	59.2	59.5	59.267	59.2

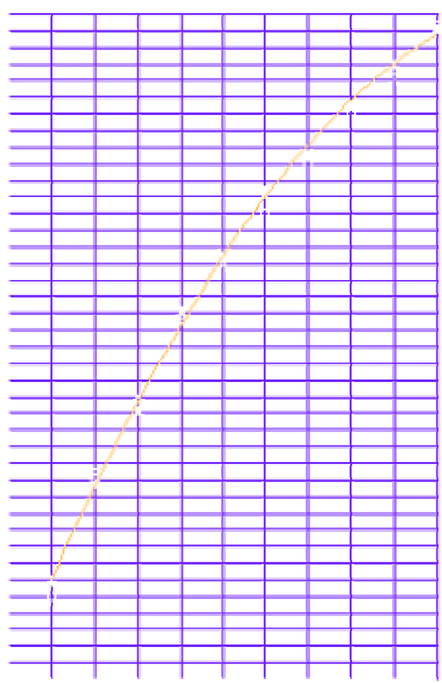
$\theta = 35°$

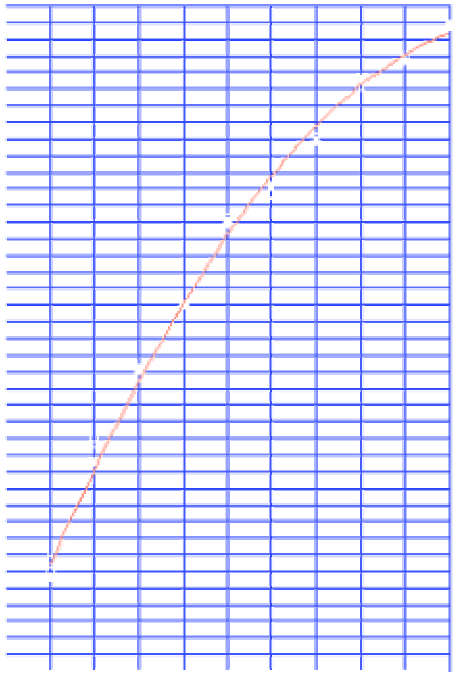
l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm
0.1	25.7	26.9	26.2	26.267	26.2
0.2	32.5	33.8	33.4	33.233	33.4
0.3	38.2	37.9	38.4	38.167	38.2
0.4	42	42.2	42.3	42.167	42.2
0.5	46.9	47.2	47.5	47.200	47.2
0.6	49.1	48.4	48.5	48.667	48.5
0.7	51.9	52	52.3	52.067	52.0
0.8	55.6	55.4	54.9	55.300	55.4
0.9	56.7	56.6	56.9	56.733	56.7
1	58.8	59	59.1	58.967	59.0

Median would be a more apt average to use in these circumstances. Median takes a *real* value, most representative of the three trials and is not effected by outliers. Mean is effected by outliers as there are few values and each significantly effects this measure of average.

From the tabulated results the following scatter graphs are plotted. The error bounds are shown for each value of *l*, this shows how consistent the results are. A line of best fit shows how *l* and *d* relate to each other. The *y*-axis *d* starts at 20 centimetres, this maximises the area the spread of data, for easy analysis and comparison. The Ï s represent the experimental values of *d*. The difference between the largest and smallest values are the error bounds for each value of *l*. Values of *d* are in centimetres and values of *l* are in metres.







Analysis

Clearly the graphs follow a near consistent path, with no erratic values. Inevitably error bounds occur, but these are low in relation to the range of *d*, smaller than 4cm. The values lie within 3cm of the line best fit and the furthermost value.

On average, by observing the plotted data error bounds are about 2cm. The larger *d* the smaller the error bounds. The error bounds are similar throughout values of q . But consistently greater the smaller the value of *l*. At a small distance of *l* a small error in positioning the ratchet socket would make a larger error for *d* than when *l* is large.

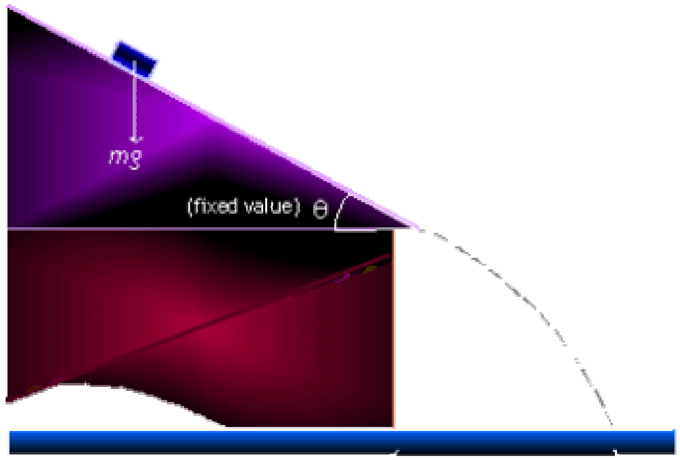
There are several possible explanations for the variation in results. Any tests taken in a human environment are prone to variation. Errors could be made as the ratchet socket was placed on the slide. It might have been off the exact value of *l*, the distances of *l* might be marked incorrectly on the slide.

Observations of where the exact point of impact by the ratchet socket on the paper is inclined to error. It is also possible that a dent from another value of *l* was taken by mistake. This, however is unlikely as no values overlap with other set values of *l*.

Other possible reasons for the slight errors could be the result of numerous unaccounted resistive forces. All points follow a similar curve shape, therefore a relationship between *l* and *d* can be applied using a theoretical model.

Theoretical Model

The theoretical model of *d* can be found by calculating the time *t* taken for the object to travel through the air.



The force of the object down the slope: *F* = *ma*.

F = *mgsin q mgsin q* can be replaced for *F* in *F* = *ma*.

mgsin q = *ma* Þ *~~m~~gsin q* = *~~m~~a* The mass of the object cancels out.

gsin q = a

To find *t*, *v* must be found first. $v^2 = u^2 + 2as$ is the equation linking acceleration, distance and velocity together.

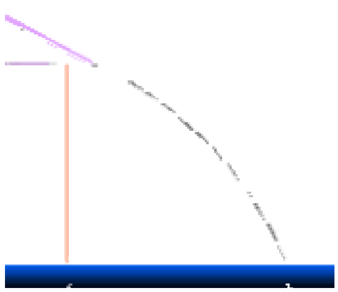
$v^2 = u^2 + 2as$ As *a* been found and *s* = *l*, the known variable, these can be placed in the equation.

$v^2 = u^2 + 2glsin\ q$ There is no starting velocity, so $u^2 = 0$

$v^2 = 0 + 2glsin\ q$

$v^2 = 2glsin\ q$

v = The velocity of the object is known.



As the object is sent over the edge of the slide, it moves in a vertical and horizontal direction. To simplify calculations, positive numbers will be used where possible. Vertically, down will be regarded as a positive direction, the same direction as *h* values; horizontally, the same direction as *d* values will be used.

Using $s = ut + ½at^2$ where the components of u are:
v *sin* q and > *cos q* .

v Vertically $h = vtsin$ q + ½gt^2

> Horizontally $d = vtcos$ q

Time t can be found with h being inserted into d.

$h = vtsin$ q + ½gt^2

$vtsin$ q + ½gt^2 – h = 0 Treat as a quadratic equation:

t = Þ t =

Now that t has been found it can be inserted into d (*vtcos* q) to give theoretical results for fixed values of q and changing values of l.

$d = v$ *cos* q

As there are a large number of calculations it would save time if d was found by an automated method. The following tablulated results of theoretical d were found using MS Excel, a spreadsheet.

$\theta = 24^0$

l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm	Velocity in ms^{-1}	Height in metres	Time in seconds	Theoretical d in cm
0.1	21.4	20.7	21.9	21.333	21.4	0.89286	0.71	0.34540	28.1730
0.2	24.2	23.6	24.3	24.033	24.2	1.26270	0.71	0.33184	38.2787
0.3	29.7	29	29.1	29.267	29.1	1.54648	0.71	0.32184	45.4695
0.4	32.3	31.9	32.9	32.367	32.3	1.78573	0.71	0.31369	51.1733
0.5	36.2	36.8	36.9	36.633	36.8	1.99650	0.71	0.30671	55.9401
0.6	40	41.2	40.9	40.700	40.9	2.18706	0.71	0.30056	60.0505
0.7	44.2	44.9	45	44.700	44.9	2.36229	0.71	0.29503	63.6702
0.8	48.7	48.5	48.1	48.433	48.5	2.52540	0.71	0.29001	66.9067
0.9	51.3	51.4	51.7	51.467	51.4	2.67859	0.71	0.28539	69.8341
1	52.4	52.9	52.8	52.700	52.8	2.82348	0.71	0.28110	72.5061

$\theta = 30^0$

l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm	Velocity in ms^{-1}	Height in metres	Time in seconds	Theoretical d in cm
0.1	26	24.8	25.6	25.467	25.6	0.98995	0.71	0.33348	30.1590
0.2	31.7	32.3	32.6	32.200	32.3	1.40000	0.71	0.31587	40.3986
0.3	36.2	37.1	36.9	36.733	36.9	1.71464	0.71	0.30310	47.4771
0.4	42.2	41.5	41.7	41.800	41.7	1.97990	0.71	0.29281	52.9622
0.5	45.3	45.7	44.9	45.300	45.3	2.21359	0.71	0.28412	57.4547
0.6	49.4	48.2	48.9	48.833	48.9	2.42487	0.71	0.27654	61.2593
0.7	51.5	51.2	51.6	51.433	51.5	2.61916	0.71	0.26980	64.5553
0.8	54.6	54.2	54.7	54.500	54.6	2.80000	0.71	0.26372	67.4580
0.9	57	56.4	56.1	56.500	56.4	2.96985	0.71	0.25818	70.0468
1	59.1	59.2	59.5	59.267	59.2	3.13050	0.71	0.25309	72.3788

$\theta = 35^0$

l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm	Velocity in ms^{-1}	Height in metres	Time in seconds	Theoretical d in cm
0.1	25.7	26.9	26.2	26.267	26.2	1.06029	0.71	0.33038	32.0016
0.2	32.5	33.8	33.4	33.233	33.4	1.49947	0.71	0.31176	42.7064
0.3	38.2	37.9	38.4	38.167	38.2	1.83647	0.71	0.29832	50.0490
0.4	42	42.2	42.3	42.167	42.2	2.12058	0.71	0.28754	55.7033
0.5	46.9	47.2	47.5	47.200	47.2	2.37088	0.71	0.27845	60.3093
0.6	49.1	48.4	48.5	48.667	48.5	2.59716	0.71	0.27055	64.1915
0.7	51.9	52	52.3	52.067	52.0	2.80526	0.71	0.26355	67.5401
0.8	55.6	55.4	54.9	55.300	55.4	2.99895	0.71	0.25725	70.4775
0.9	56.7	56.6	56.9	56.733	56.7	3.18086	0.71	0.25152	73.0875
1	58.8	59	59.1	58.967	59.0	3.35292	0.71	0.24626	75.4305

The MS Excel formulae used for q = 24° and l = 0.1; where A2 = l, G2 = v, H2 = h, I2 = t, 9.8 = g, are as follows:

Velocity *v* =SQRT(2*9.8*A2*SIN(RADIANS(24)))

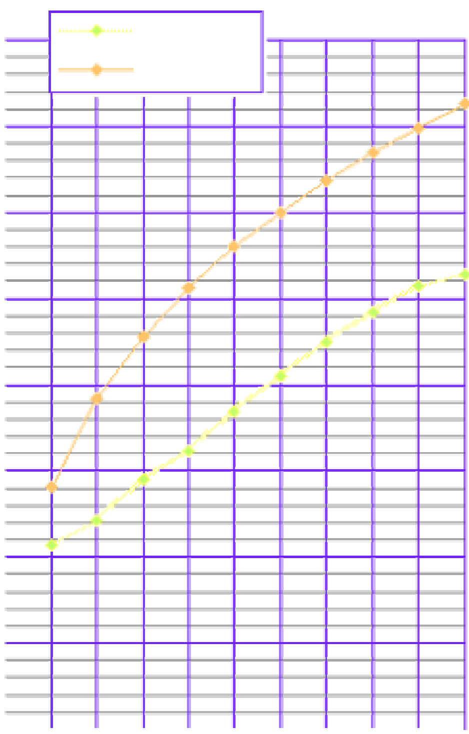
Time *t* =(-1*G2*SIN(RADIANS(24))+ SQRT((POWER(G2,2)) *POWER(SIN(RADIANS(24)),2)+ 2*9.8*H2))/9.8

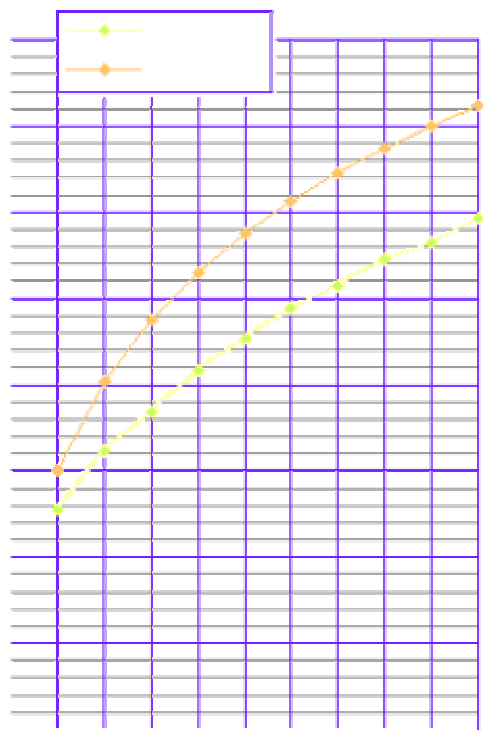
Theoretical *d* =100*G2*I2*COS(RADIANS(24))

The radian instructions convert degrees from the default radian angles. In the theoretical formula the answer is normally in metres, but in this case the answer is multiplied by 100 to give it in centimetres for comparison with the experimental data. There is one reason why the experimental data was taken in centimetres, it is the scale used on the rulers where the ratchet socket lands on the floor. This will have no negative effect on any formulae as values of *d* can be easily converted back into metres and vice versa with no reduction of quality.

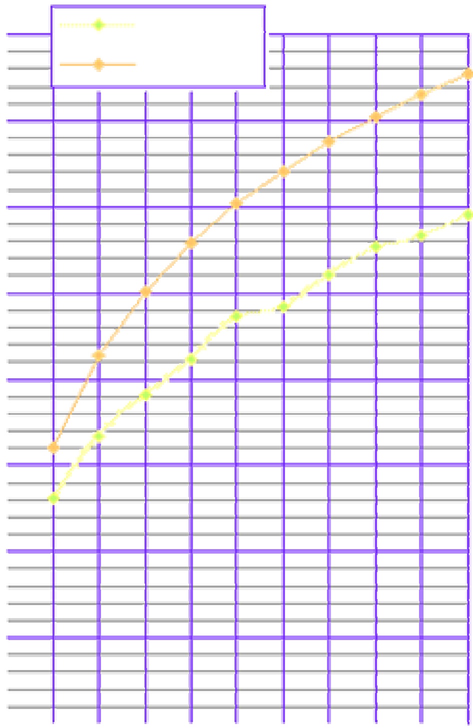
Modelling Comparisons

These graphical comparisons between experimental and theoretical results are shown in different colours on the same axis for each value of q . Only the median experimental value of *d* is used to plot the graphs as this is representative of all the experimental values of *d*. Centimetres are used as units for *d* and *l* are in metres.





A graph for q = 35° can be found on the next page.



Analysis

Throughout values of q it is easy to observe that the theoretical results for *d* are substantially larger than experimental results. Error bounds for experimental data may account for a small part of the different between values of *d*, but not as much as almost 20cm (q = 24°, *l* = 1). Differences between experimental and theoretical are less for q = 30° and q = 35°, this perhaps suggests less resistive forces acting upon the ratchet socket. If the resistive force was friction is would explain why, as q increases the difference between theoretical and experimental results is reduced. For small values of *l* the difference between experimental and theoretical values is comparably small, there are less resistive forces present when there is a small distance travelled by the ratchet socket over the slide.

Measuring of q is prone to errors Using a ruler to measure two lengths of the slide, values could be out by only a small distance. Yet when these values are used to calculate q they are divided. This multiplies any small errors that occur through measuring and could have a large effect if there is a negative error in the divisor and a positive error on the top:

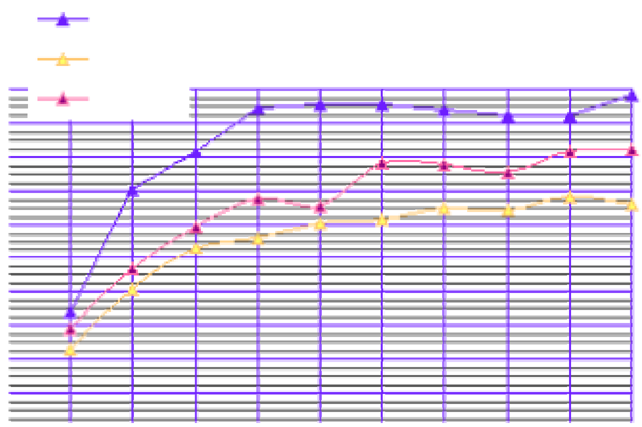
As q becomes larger, the difference in *d* between the two modelling methods, diminishes. The experimental and theoretical results never meet, showing that the theoretical is not considering a vital variable that effected the experimental.

Evaluation

There are forces other than present which were not taken into consideration when the theoretical model was made. Wind and air resistance are negligible in a room with windows and doors closed whilst the experiment took place. Moreover if there was a draft it would have a very small effect on a heavy object like a ratchet socket. The main resistive force is clearly the friction between the ratchet socket and the slide. When the socket slid down it made a noise, when there is a sound present there is energy being lost. The sound was the result of friction between the two metal surfaces. After consideration, there are no other possible reasons for such a difference between the two models. As three sets of data have been obtained, further corrections to the theoretical model will be more comprehensive. The theoretical model must be adapted to allow for friction and other negative forces on the object.

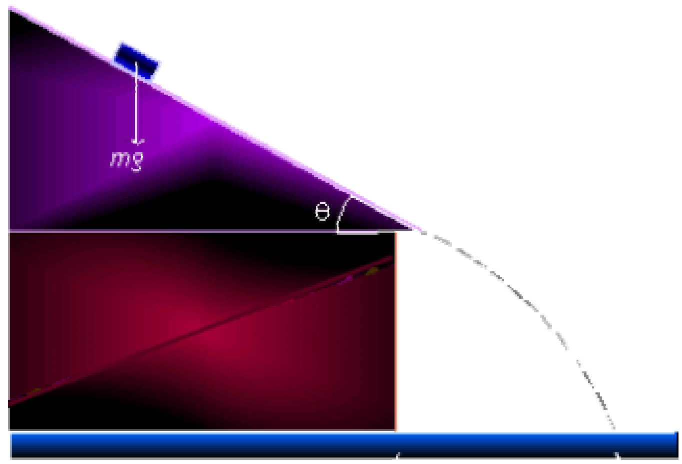
Improving the Theoretical Model

The ratchet socket travels a shortest distance *d* is than the theoretical model predicts this could be due to the socket travelling slower than calculated. This is most likely due to friction between the object and the slide. Initial assumptions must be reconsidered, there is a resistive force going against the object as it travels down the slide. The graph, below, shows how differences vary between theoretical and experimental models over the three values of q .



When the object is on a slight slope, q = 24° the resistive forces are greatest, with almost 20cm difference when the ratchet socket is placed 1 metre from the edge of the slide. Resistance at q = 30° appears to be smaller than both greater and lesser values of q . This is possibly where resistive forces are minimal between the socket ratchet and the slide compared to q = 24°; the ratchet socket is projected more horizontally than q = 35°.

q = 30° and q = 35° have similar values for *d*. At q = 30° friction will be greater than q = 35°, but at q = 35°, where the slope is steeper, the ratchet socket is propelled more vertically downwards than at smaller values of q . The similar values for *d* between q = 30° and q = 35° allows for the experimental model to *catch up* with the theoretical model, therefore differences are smaller between the two.



To find the resistive force *R*, fundimental laws must be applied and established formulae can be used with them.

F = *ma* Þ *F* = *mgsin* q *F* can now be written as a known value

mgsin q – *R* = *ma* Where *R* is the resistance to be found

a = *gsin* q - $^{R}/_{m}$ *m* is divided out to leave *a*

To find $^{R}/_{m}$ the median values of *d* will be used from the experimental model. As *d* =

vtcos q when the object starts at rest, *t* = . The velocity of the object must be calculated firstly, the position of the object horizontally will be used to calculate *v*. To find $^{R}/_{m}$ the new formulae must be found by working backwards from where the ratchet socket lands on the floor back to the start, on the slide.

h = *vtsin q* - ½gt^2 *t* = and *h* = 0.71

h = *dtan q* - ½*g* replaces *t* as both are equal to each other, eliminates *v*

h = *dtan q* – Each term is squared individually, so terms can be seperated

h – *dtan q* = *dtan q* is subtracted

$2v^2cos^2$ q = $2v^2cos^2$ q multiplied out of the divisor

$v^2 =$ $2cos^2$ q divided out to leave v^2

$v^2 =$ Simplified

$v^2 = u^2 + 2as$ $s = l$ in the context of the model

$= u^2 + 2al$ As v^2 has now been found, terms in $u^2 + 2as$ are known

$= 0 + 2(gsin\ q - {}^R/_m)l$

$= gsin\ q - {}^R/_m$

${}^R/_m = gsin\ q -$ where $v^2 =$

${}^R/_m$ could be better than theoretical model as it takes into consideration the resistance against the ratchet socket, probably due to friction.

A2 = *l*, (F2/100) = *d*, H2 = *h*, 9.8 = *g*

${}^R/_m$ =(9.8*SIN(RADIANS(24)))-((9.8*POWER((F2/100),2))/(2*POWER(COS(RADIANS(24)),2)*(H2-(F2/100)*TAN(RADIANS(24)))))/(2*A2)

As the experimental tests were carried out using centimetres, the median value of *d* in F2 had to be converted to metres before being calculated. This does not effect the outcome in any way as "F2/100" is enclosed in brackets.

Results showing Resistance

The tables show the proportional value of ${}^R/_m$ that will improve the theoretical predictions of *d*. ${}^R/_m$ is better than the theoretical model as it takes into consideration the resistance as the object travels.

$\theta = 24^\circ$

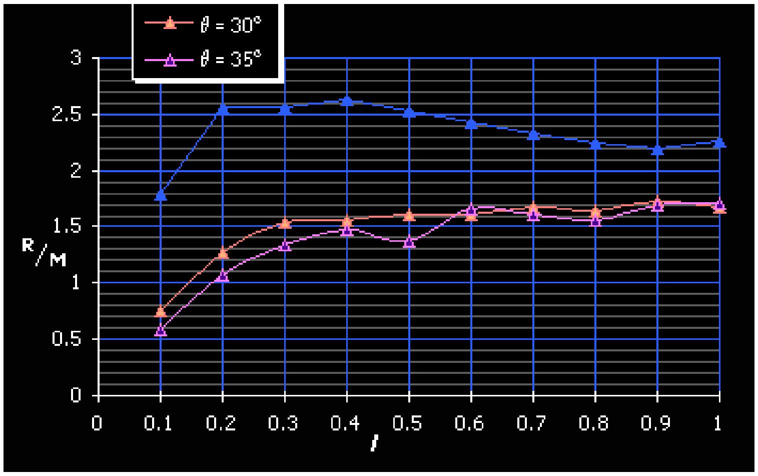
l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm	Velocity in ms^{-1}	Height in metres	Time in seconds	Theoretical d in cm	$^R/_M$
0.1	21.4	20.7	21.9	21.333	21.4	0.89286	0.71	0.34540	28.1730	1.7990
0.2	24.2	23.6	24.3	24.033	24.2	1.26270	0.71	0.33184	38.2787	2.5587
0.3	29.7	29	29.1	29.267	29.1	1.54648	0.71	0.32184	45.4695	2.5584
0.4	32.3	31.9	32.9	32.367	32.3	1.78573	0.71	0.31369	51.1733	2.6337
0.5	36.2	36.8	36.9	36.633	36.8	1.99650	0.71	0.30671	55.9401	2.5302
0.6	40	41.2	40.9	40.700	40.9	2.18706	0.71	0.30056	60.0505	2.4356
0.7	44.2	44.9	45	44.700	44.9	2.36229	0.71	0.29503	63.6702	2.3285
0.8	48.7	48.5	48.1	48.433	48.5	2.52540	0.71	0.29001	66.9067	2.2389
0.9	51.3	51.4	51.7	51.467	51.4	2.67859	0.71	0.28539	69.8341	2.1950
1	52.4	52.9	52.8	52.700	52.8	2.82348	0.71	0.28110	72.5061	2.2627

$\theta = 30^\circ$

l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm	Velocity in ms^{-1}	Height in metres	Time in seconds	Theoretical d in cm	$^R/_M$
0.1	26	24.8	25.6	25.467	25.6	0.98995	0.71	0.33348	30.1590	0.7581
0.2	31.7	32.3	32.6	32.200	32.3	1.40000	0.71	0.31587	40.3986	1.2813
0.3	36.2	37.1	36.9	36.733	36.9	1.71464	0.71	0.30310	47.4771	1.5444
0.4	42.2	41.5	41.7	41.800	41.7	1.97990	0.71	0.29281	52.9622	1.5521
0.5	45.3	45.7	44.9	45.300	45.3	2.21359	0.71	0.28412	57.4547	1.6157
0.6	49.4	48.2	48.9	48.833	48.9	2.42487	0.71	0.27654	61.2593	1.6094
0.7	51.5	51.2	51.6	51.433	51.5	2.61916	0.71	0.26980	64.5553	1.6721
0.8	54.6	54.2	54.7	54.500	54.6	2.80000	0.71	0.26372	67.4580	1.6430
0.9	57	56.4	56.1	56.500	56.4	2.96985	0.71	0.25818	70.0468	1.7250
1	59.1	59.2	59.5	59.267	59.2	3.13050	0.71	0.25309	72.3788	1.6814

$\theta = 35^\circ$

l in metres	d_1 in cm	d_2 in cm	d_3 in cm	Mean d in cm	Median d in cm	Velocity in ms^{-1}	Height in metres	Time in seconds	Theoretical d in cm	$^R/_M$
0.1	25.7	26.9	26.2	26.267	26.2	1.06029	0.71	0.33038	32.0016	0.5898
0.2	32.5	33.8	33.4	33.233	33.4	1.49947	0.71	0.31176	42.7064	1.0687
0.3	38.2	37.9	38.4	38.167	38.2	1.83647	0.71	0.29832	50.0490	1.3413
0.4	42	42.2	42.3	42.167	42.2	2.12058	0.71	0.28754	55.7033	1.4828
0.5	46.9	47.2	47.5	47.200	47.2	2.37088	0.71	0.27845	60.3093	1.3692
0.6	49.1	48.4	48.5	48.667	48.5	2.59716	0.71	0.27055	64.1915	1.6566
0.7	51.9	52	52.3	52.067	52.0	2.80526	0.71	0.26355	67.5401	1.6160
0.8	55.6	55.4	54.9	55.300	55.4	2.99895	0.71	0.25725	70.4775	1.5553
0.9	56.7	56.6	56.9	56.733	56.7	3.18086	0.71	0.25152	73.0875	1.6942
1	58.8	59	59.1	58.967	59.0	3.35292	0.71	0.24626	75.4305	1.7015



Analysis

The values of $^R/_m$ are very similarly related to the differences between experimental and theoretical data. This confirms the validity of $^R/_m$ as an aid to adjusting the theoretical predictions. The downward *bump* in the data for *l* = 0.5, q = 35°, is also reflected in the differences between theoretical and experimental data. On a larger scale: q = 24° remains considerably greater than other values of q . As *l* increases $^R/_m$ stabilises, this shows that the friction exerted on the object has a limit. When the ratchet socket has a long slide the friction ceases to increase. This indicates that the socket ratchet has to overcome initial resistive force or friction.

The use of $^R/_m$ would greatly improve the accuracy of predictions of where an object will fall when dropped down a slide, this is confirmed by its close relation to the differences between the models.

Evaluation

On reflection, the experimental collection of data went without any problems. All aspects mentioned when reducing error were carefully followed to give accurate results when collecting the experimental data. Using Excel to calculate the theoretical data saved time in the long run. The formulae, after being type in once, could be copied down to calculate all values of *l* and q . The formulae in Excel were checked rigorously against written formulae to minimise mistakes. Use of the program also made any error correction of formulae easy. It was also very practical for displaying results in tabulated and as graphs.