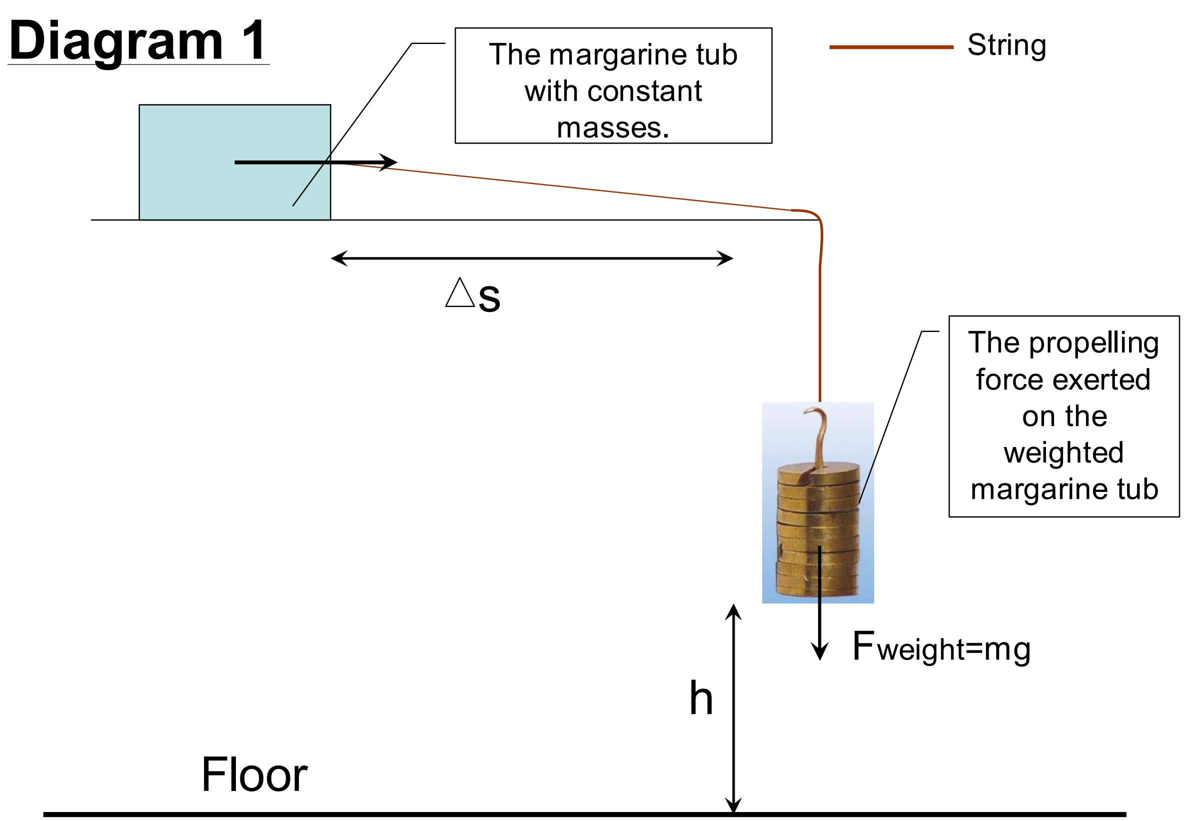
Title: Margarine tub investigation

Introduction:

This experiment is designed to investigate one factor affecting the distance travelled by a weighted margarine tub when it is propelled along a runway. I decide to investigate the relationship between the propelling force exerted on the weighted margarine tub and the distance travelled by the tub.



In this experiment, the propelling force is the gravitational force of those hanging weights and it is calculated by $F_{weight} = mg$. The distance travelled by the weighted margarine tub is equal to the total forward distance (Δs) minus the pulling distance, and the pulling distance is equal to the height from those hanging weights to the floor (h). Therefore $d = \Delta s - h$.

Research question:

How is the distance traveled by a weighted margarine tub (d) dependent on the magnitude of the propelling force exerted on it (F)?

Variables:

Independent variable: The magnitude of the mass of the hanging weights.

* $F_{weight} = mg$, this is how I link my independent variable to the magnitude of the propelling force exerted on the weighted margarine tub. Then I can further investigate the relationship between the propelling force and the distance travelled by the tub.

Dependent variable: The distance travelled by a weighted margarine tub

Controlled variables:

- The total mass of the weighted margarine tub
- The friction of the runway
- The height from the hanging weights to the floor

Hypothesis:

As shown in diagram 1 above, the margarine tub and the hanging weights are connected by a string, therefore they are in the same system. Theoretically, the total energy in the system is conserved, which means the loss in the gravitational potential energy when the weights drop (PE) is equal to the kinetic energy gained by the weighted margarine tub (KE) which propels the tub to move. After the tub is propelled, the only horizontal force exerted on it is the friction between the tub and the runway (f), and it is the friction that slows the tub down and finally stops it. Therefore the kinetic energy gained by the tub is equal to the work done by the friction between the tub and the runway.

- Formula rearrangements:

$$PE = mgh = F_{weight} \times h$$

$$\therefore KE = F_{weight} \times h$$

$$\therefore \text{Work done by friction} = F_{weight} \times h$$

$$\therefore f \times d = F_{weight} \times h$$

$$\therefore d = \frac{h}{f} \times F_{weight}$$

Also $$d = \frac{h}{f} \times mg$$

As the height from the weights to the floor is controlled to be constant, and the friction is kept constant by using the same runway, I expect Fweight will be proportional to d.

Method:

Apparatus List
Margarine tub
Masses
Long lab table as runway
Long sting
Rulers
Pencil

1. Set up the apparatus as shown in diagram 1 in the introduction.
2. Add weights into margarine tub and fasten them tightly. Record the total mass and keep this mass constant throughout the experiment.
3. Hang 100g (150g, 200g, and 250g) weights on string. **(The mass here is the independent variable. And because $F_{weight} = mg$, I can then get the magnitude of the propelling force)**
4. Drop the weights from the constant height every time to propel the weighted margarine tub.
5. Record the total forward distance (Δs) by the tub. ($d = \Delta s - h$, **this is how I get the dependent variable**)

Controlling the controlled variables:

- The total mass of the weighted margarine tub is kept constant throughout the experiment by adding constant weights in it.
- The friction of the runway is kept constant by using the same runway throughout the experiment.
- The height from the hanging weights to the floor is kept constant by recording the height and dropping weights from this height every time.

Collecting the raw data:

The experiment will be repeated 3 times for each of 4 different masses of the hanging weights. (100g, 150g, 200g, 250g)

I select 100g to be my minimum value of the mass of the hanging weights because 50g is too light to propel the weighted margarine tub and make it move.

I select 250g to be my maximum value of the mass of the hanging weights because the runway is too short for the weighted margarine tub to finish travelling under the propelling force from 300g weights.

Results:

Raw Data Table:

Below is a table of the data collected from 3 repeating experiments for each of 4 different masses of the hanging weights.

Mass (kg) **Symbol: m** $\pm 0.00005\ kg$	**Total distance 1 (m)** **Symbol:** $\Delta s1$ $\pm 0.01\ m$	**Total distance 2 (m)** **Symbol:** $\Delta s2$ $\pm 0.01\ m$	**Total distance 3 (m)** **Symbol:** $\Delta s3$ $\pm 0.01\ m$	**Average total distance (m)** **Symbol:** Δs $\pm 0.01\ m$
0.10000	0.65	0.63	0.64	0.64
0.15000	0.87	0.87	0.85	0.86
0.20000	0.99	0.97	1.00	0.99
0.25000	1.09	1.11	1.11	1.10

* The mass of the weighted margarine tub is $0.166 \pm 0.00005\ kg$, and it is kept constant throughout the experiment.

* The height from hanging weights to the floor is $0.5 \pm 0.0005\ m$, and it is kept constant throughout the experiment.

* The uncertainty in mass is estimated to be $\frac{1}{2}$ of the smallest division of the scale (0.0001kg)

$$\frac{1}{2} \times 0.0001\ kg = 0.00005\ kg$$

* The uncertainty in height is estimated to be $\frac{1}{2}$ of the smallest division of the ruler (0.001m)

$$\frac{1}{2} \times 0.001\ m = 0.0005\ m$$

* The uncertainty in total distance is calculated from $\frac{(\max - \min)}{2}$.

Sample calculation (experiment #1 when mass = 0.1kg ± 0.00005kg):

$$\text{The uncertainty in distance} = \frac{65.4cm - 62.7cm}{2}$$

$$= 1.35\ cm$$

$$= 0.0135\ m$$

$$\approx 0.01\ m$$

* Sample calculation for average total distance (experiment #1 when mass = 0.1kg ± 0.00005kg):

$$\Delta s = \frac{\Delta s1 + \Delta s2 + \Delta s3}{3}$$

$$= \frac{0.065\ m + 0.063\ m + 0.064\ m}{3}$$

$$= 0.064\ m$$

Processed Data Table:

Mass (kg) **Symbol: m** $\pm 0.00005\ kg$	**Propelling force (N)** **Symbol: F**weight $\pm 0.0005\ N$	**Average distance (m)** **Symbol: d** $\pm 0.01\ m$
0.10000	0.98	0.14
0.15000	1.47	0.36
0.20000	1.96	0.49
0.25000	2.45	0.60

* Sample calculation for force (experiment #1 when mass = 0.1kg ± 0.00005kg):

$$F = mg$$

$$= 0.1kg \times 9.8N/kg$$

$$= 0.98\ N$$

* Sample calculation for uncertainties within force (experiment #1 when mass = 0.1kg ± 0.00005kg):

$$\text{Percentage uncertainty} = \frac{0.00005\ kg}{0.10000\ kg} \times 100\ \%$$

$$= 0.05\ \%$$

$$\text{Uncertainty in force} = 0.05\ \% \times 0.98\ N$$

$$= 0.00049\ N$$

$$\approx 0.0005\ N$$

* Sample calculation for average distance (experiment #1 when mass = 0.1kg ± 0.00005kg):

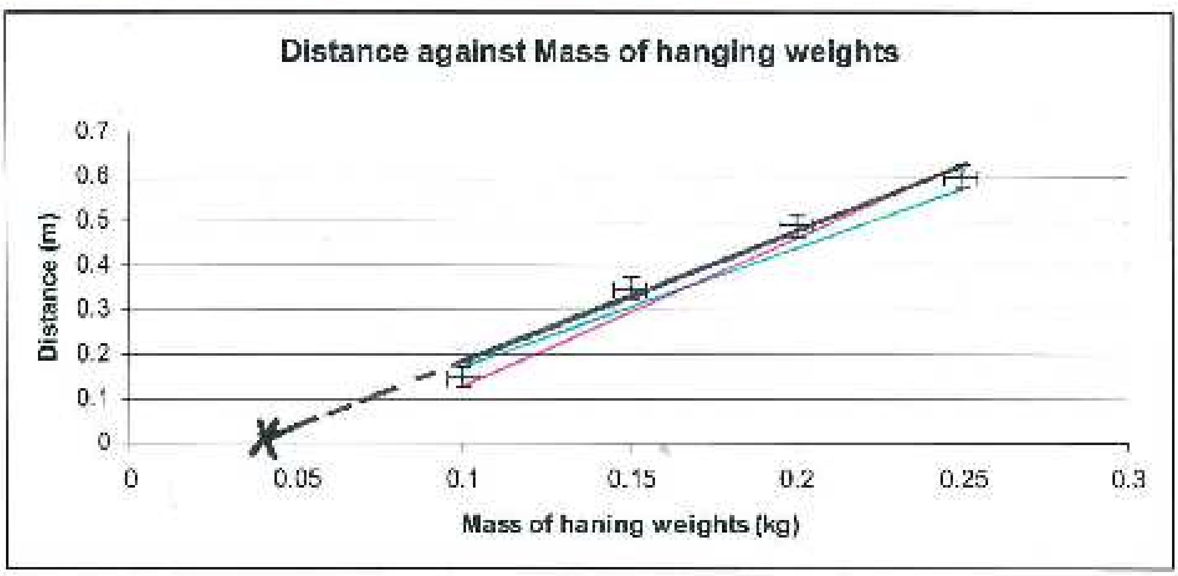
$$d = \Delta s - h$$

$$= (0.64 \pm 0.01) - (0.5 \pm 0.005)$$

$$= (0.64 - 0.5) \pm (0.01 + 0.005)$$

$$= 0.14 \pm 0.01\,m$$

Graph 1: Distance against mass of hanging weights



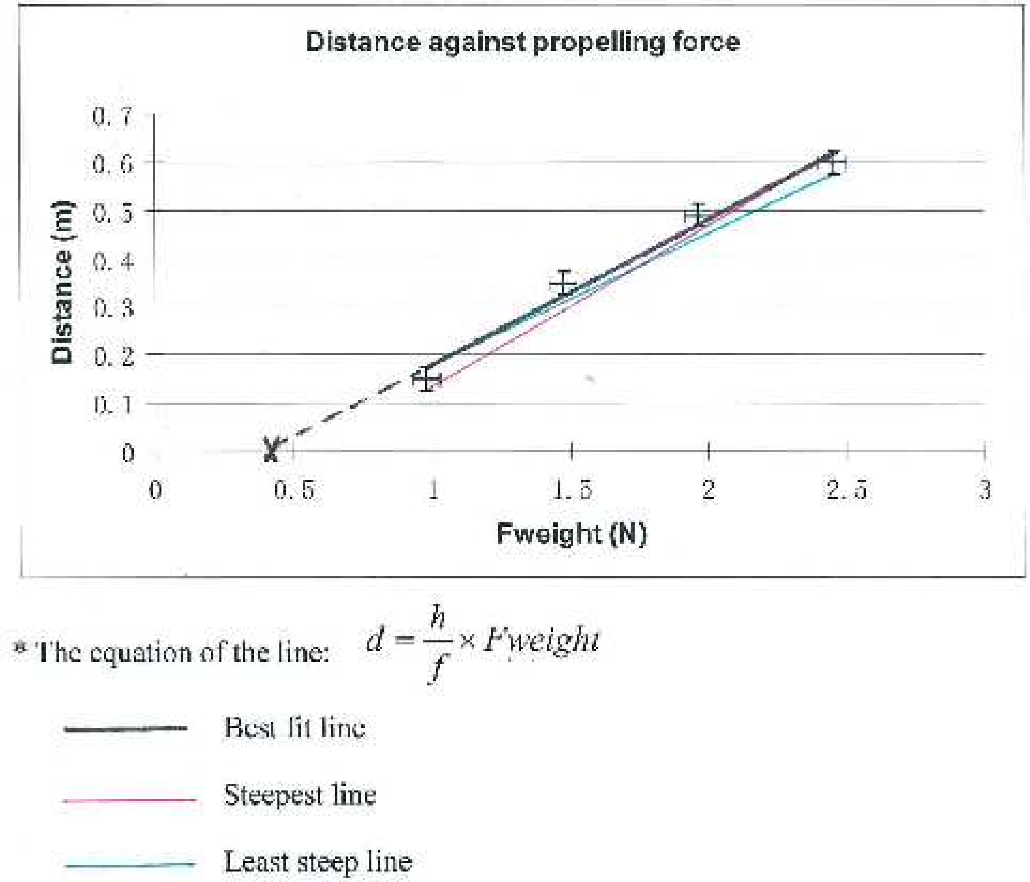
* The equation of the line: $d = \frac{hg}{f} \times m$

Best fit line

Steepest line

Least steep line

Graph 2: Distance against propelling force



Conclusion & Evaluation:

Conclusion:

From graph 1 it can be seen that within the uncertainties in the experiment distance is proportional to the mass of the hanging weights.

From graph 2 it can be seen that within the uncertainties in the experiment distance is proportional to the magnitude of the propelling force.

Graph 1:

The gradient of the line in graph 1 gives me the value of $\frac{hg}{f}$ where h represents the height from the hanging weights to the floor and f represents the friction between the weighted margarine tub and the runway.

Gradient 1 $= \frac{0.6 - 0.14}{0.25 - 0.1} = 3.0667 \quad m/kg$, therefore the value of $\frac{hg}{f}$ is 3.0667m/kg.

The uncertainty in gradient 1 can be found from the steepest and least steep lines in graph 1:

Maximum value $= \dfrac{0.61 - 0.13}{0.25 - 0.1} = 3.2000 \quad m/kg$

Minimum value $= \dfrac{0.59 - 0.15}{0.25 - 0.1} = 2.9333 \quad m/kg$

Uncertainty $= \dfrac{Max - Min}{2}$

$= \dfrac{3.2000 - 2.9333}{2}$

$= 0.1334 \quad m/kg$

$\approx 0.1 m/kg$

Therefore $\dfrac{kg}{f} = 3.1 m/kg \pm 0.1 m/N$

Graph 2:

The gradient of the line in graph 2 gives me the value of $\dfrac{h}{f}$ where h represents the height from the hanging weights to the floor and f represents the friction between the weighted margarine tub and the runway.

Gradient 2 $= \dfrac{0.60 - 0.14}{2.45 - 0.98} = 0.3129 \quad m/N$, therefore the value of $\dfrac{h}{f}$ is 0.3129m/N.

The uncertainty in gradient 2 can be found from the steepest and least steep lines in graph 2:

Maximum value $= \dfrac{0.61 - 0.13}{2.45 - 0.98} = 0.3265 \quad m/N$

Minimum value $= \dfrac{0.59 - 0.15}{2.45 - 0.98} = 0.2993 \quad m/N$

Uncertainty $= \dfrac{Max - Min}{2}$

$= \dfrac{0.3265 - 0.2993}{2}$

$= 0.0136 \quad m/N$

$$\approx 0.01\ m/N$$

Therefore $\dfrac{h}{f} = 0.31\ m/N \pm 0.01\ m/N$

Calculating g:

$$g = \frac{\frac{h}{f} \times g}{\frac{h}{f}}$$

$$= \frac{gradient\ 1}{gradient\ 2}$$

$$= \frac{3.1 m/kg}{0.31\ m/N}$$

$$= 10\ N/kg$$

The uncertainty in g = (% error in gradient 1 + % error in gradient 2) $\times$ g

$$= \left(\frac{0.1}{3.1} \times 100\ \% + \frac{0.01}{0.31} \times 100\ \%\right) \times 10\ N/kg$$

$$= 0.6452\ N/kg$$

$$\approx 0.6 N/kg$$

$$\therefore g = 10.0 \pm 0.6 N/kg$$

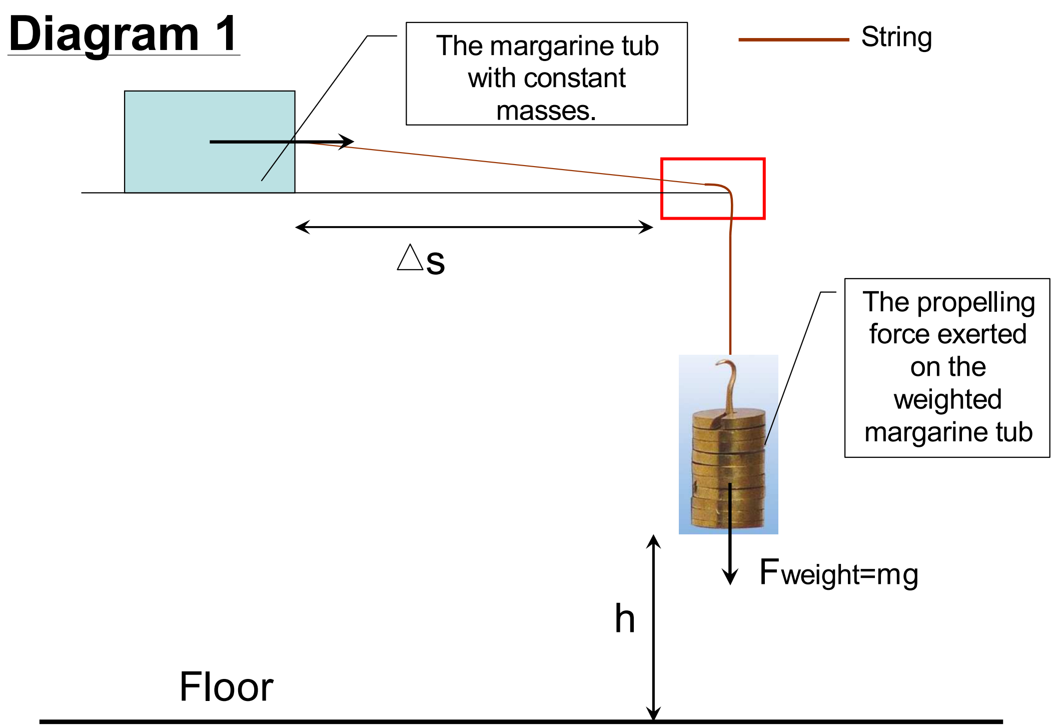
The accepted value of g established by the third General Conference on Weights and Measures is 9.80665 m/s^2. This lies within the experimental value obtained with uncertainties.

Evaluation:

From the observation of the graph, I can see that all data points lie relatively close to the best fit line although there are some small deviations. Those error bars realistically reflect the uncertainties within the measurements. The conclusion that distance travelled by the weighted margarine tub is proportional to the propelling force exerted on it has been supported by the linear graph. Also the calculated value of g is quite close to the accepted value which supports the accuracy and reasoning of this experiment.

The x-intercept is not very close to the theoretical point (0, 0). Also, I can't predict the trend of the line as the propelling force goes smaller because the friction force will be larger than the propelling force which prevents the weighted margarine tub from moving. Those results will be unavailable for this experiment.

I have managed to keep the controlled variables constant throughout the experiment although there may be some small deviations within the height from the hanging weights to the floor. I have tried my best to make sure that all measurements take place when the ruler is parallel to the runway to reduce parallax errors.



At the red rectangular area in diagram 1, there is an uncertainty caused by the friction between the string and the corner of the lab table. The friction here also consumes a part of the kinetic energy, which decreases the total amount of kinetic energy gained by the weighted margarine tub.

Also, the string in this experiment is not horizontal, which means it is not parallel to the runway. The angle in between decreases the magnitude of the propelling force exerted on the weighted margarine tub. Therefore the angle causes uncertainties as well.

I have tried my best to make sure that the weighted margarine tub always be propelled from the rest throughout the experiment to avoid uncertainties within the measurements of the distance travelled.

I finished my experiment within the time limit (three classes). However, the range of values and the number of repetitions don't seem enough for my graph. The reason for the limited range of values is that smaller propelling force can't make the tub move, and the runway is not long enough for the weighted margarine tub to finish travelling under larger propelling force. I have done my experiment under the largest possible range.

Improvements:

To improve my results, I would try to avoid those uncertainties within my method as shown in diagram 1 that I have mentioned in evaluation. A way to do that is to install a fixed pulley at the corner of the lab table. The fixed pulley will reduce the amount of friction, and also keep the string parallel to the runway. By doing this, I can probably get more accurate results.

My results are also limited by my relatively small number of repetitions of my experiment. More repetitions can definitely make my result more accurate as they may give me a wider data to determine the uncertainties.

To make the uncertainties even less, I would like to choose a totally inelastic string to do the experiment because the stretch of the string may consume energy as well, therefore make the result less accurate.