Physics Module 3, Investigation Validation

Name: ______________________________

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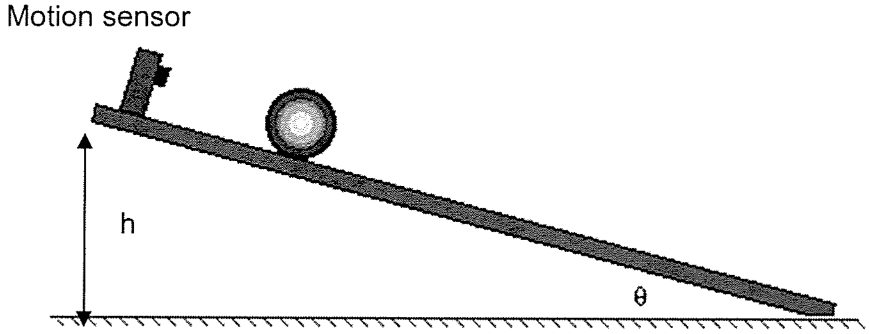
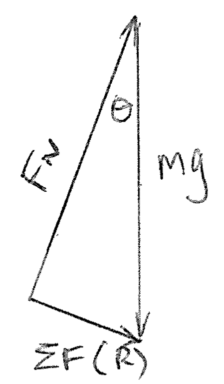
TIME ALLOWED: 55 minutes

Question One: Motion down an incline (20 marks)

Joan's group used a **frictionless** ramp to measure the acceleration due to gravity. They rolled a ball down the ramp and recorded the acceleration of the ball at different angles as measured by an ultrasonic motion detector and recorded on their Datalogger. The set up is shown below. The length of the ramp was **1.4 metres** and they measured the height, h, at each angle.



a) **In the space on the right,** construct a **vector diagram** to show the forces acting on the ball, and the resultant of these forces. Include the angle, θ. (3 marks)



✓ 2 forces, correct directions

✓ Labels correct (inc. θ)

✓ Sum of forces shown correctly & labelled

b) Use your understanding of these forces and Newton's laws to clearly show that the acceleration of the ball is given by a = g sinθ (2 marks)

$$\sin\theta = \frac{\Sigma F}{mg}$$ ✓

$$\Rightarrow \Sigma F = mg\sin\theta$$

$$ma = mg\sin\theta$$ ✓

$$a = g\sin\theta$$

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The students recorded the following data

height (cm)	Angle, θ (°)	Sin θ	Acceleration ($m\ s^{-2}$)			Mean acceleration ($m\ s^{-2}$)
			Trial 1	Trial 2	Trial 3	
10	4.10	0.0714	0.71	0.75	0.76	0.74
20	8.21	0.143	1.61	1.47	1.52	1.53
30	12.4	0.214	2.81	2.62	2.95	2.79
40	16.6	0.286	2.80	2.88	2.85	2.84
50	20.9	0.357	3.75	3.68	3.70	3.71

✓✓ no mistakes

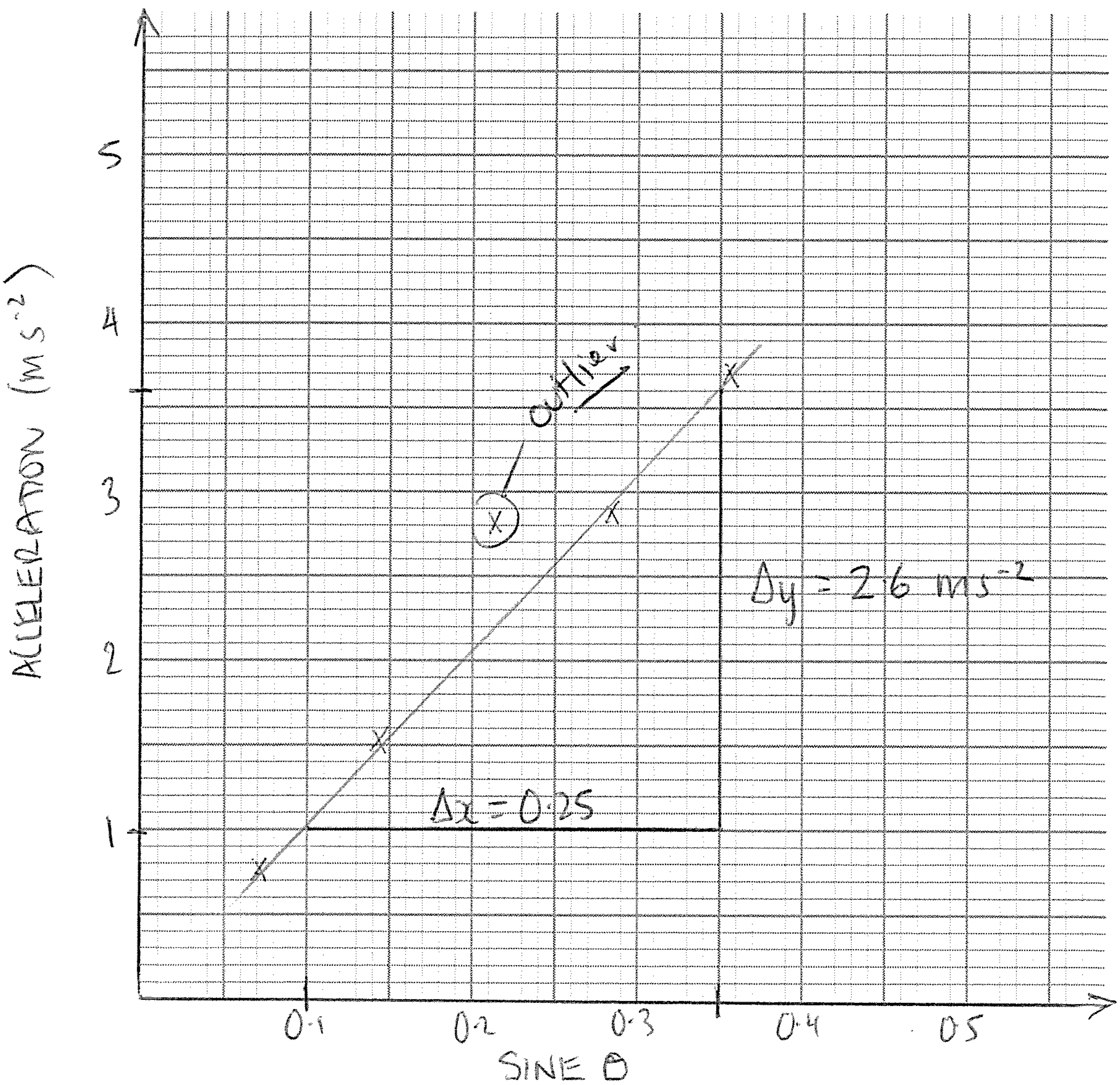
- x, y axes labelled & appropriate scales ✓
- plotting ✓
- outlier indicated & ignored for LOBF ✓✓

c) Complete the table (2 marks)

d) Plot acceleration against sin θ below and insert an appropriate line of best fit (4 marks)

or (• outlier not indicated LOBF correctly done with outlier ✓ out of 2)

ACCELERATION VS SINE OF RAMP ANGLE



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e) Showing all working and reasoning clearly, calculate the gradient of the line of best fit and use it to calculate the free fall acceleration due to gravity near the Earth's surface, g. (3 marks)

Indicates construction on graph ✓

$$m = \frac{\Delta y}{\Delta x} = \frac{2.6}{0.25} = 10.4\ ms^{-2}$$ ✓

$$g = \frac{a}{\sin\theta} = m = 10.4\ ms^{-2}$$ ✓

f) Calculate the percentage difference between your value and the accepted value in Perth (as published in your data sheet) (1 mark)

$$100 \times \frac{10.4 - 9.8}{9.8} = 6.12\%$$ ✓

g) Is it likely that friction is causing some or all of the error? Explain. (1 mark)

No, friction would result in an under-estimate. ✓

h) In an effort to explain the difference (calculated in part f), Joan suggested that due to thickness of their ramp and other factors, their measurement of the height of the end of the ramp was only accurate to within ±1 cm.

In the space below, using calculations and clear reasoning, determine whether or not this uncertainty is a reasonable explanation for the difference determined in (f). (note that more than one approach is possible) (4 marks)

Various approaches possible, including re-calculation of entire LOBF. Behaviours looked for:

+ Recognises that +1cm will overestimate g (compared to −1cm) ✓
+ General logical approach (explained) ✓
+ checks one data point & draws appropriate conclusion ✓
+ checks at least one more data point (or replots LOBF, even roughly) ✓

E.g. for h = 10 cm

$h = 11\text{cm} \Rightarrow \sin\theta = 0.0786$

$$g = \frac{0.74}{0.0785} = 9.41\ ms^{-2}$$

(or % difference)

For h = 50cm

$h = 51\text{cm} \Rightarrow \sin\theta = 0.3643$

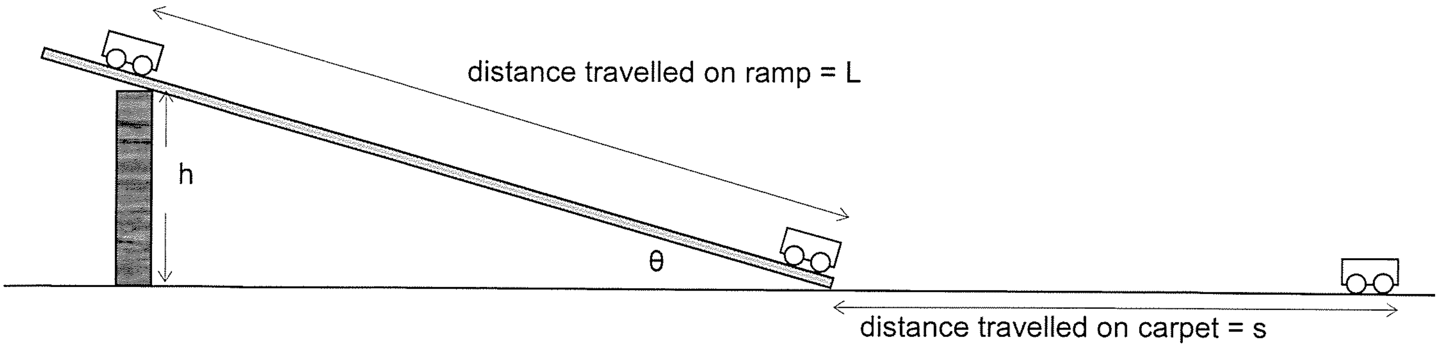
$$g = \frac{3.71}{0.3643} = 10.2\ ms^{-2}$$

Although ±1cm would account for discrepancies in low-gradient results for higher gradients, it doesn't. Without plotting whole LOBF again, it seems unlikely (or any reasonable...)

Question Two - Friction investigation (17 marks)

Joan and her group then carried out an investigation to study the effect of weight on the rolling friction force of a trolley, just as your class did.

Friction is a force which opposes motion when moving surfaces come into contact. Rolling friction is a complex type of friction present in the situation when wheels are rolling on a surface. Below is a diagram of the experiment.



Joan believed that the friction down the ramp was negligible, but she wanted to test this assumption. With the angle of the ramp, θ, set at 20°, they used a stopwatch to measure the time the trolley took to roll distance L down the ramp starting from rest (t). They obtained the following data:

L (m)	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)
1.2	0.83	0.87	0.86

a) Using an appropriate calculation, show that, based on this data, the friction appears to be negligible **within experimental error**. Justify your explanation. (3 marks)

Frictionless:

$a = g\sin\theta$

$= 9.8\sin 20°$

$= 3.3518$ ✓

$s = \cancel{ut} + \frac{1}{2}at^2$ (0)

$\rightarrow t = \sqrt{\frac{2 \times 1.2}{3.3518}}$

$= 0.846\ s$ ✓

this is between our lowest & highest measurements in the three trials, so it is reasonable to assume friction is negligible. ✓

b) Ignoring friction, calculate the expected speed at the base of the ramp (1 mark)

$v = u + at$

$= 0 + 3.3518 \times 0.846$

$= 2.84\ ms^{-1}$ ✓

or ($v = \sqrt{2as}$

$= \sqrt{2 \times 3.3518 \times 1.2}$

$= 2.84\ ms^{-1}$)

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Confident that the rolling friction was negligible, they group then changed the angle slightly to decrease the final speed of the trolley. At 15°, they calculated that the trolley speed should be 2.5 m/s at the base of the ramp.

The group performed three trials each measuring the distance travelled on the carpet by the trolley, loading the trolley up with different masses. They obtained the following data:

Ramp angle = 20°, Starting velocity u = 2.5 m s^{-1}							
Mass in trolley (g)	Weight in trolley (N)	Distance, s (m)			Mean distance (m)	Deceleration (m s^{-2})	Average Friction Force (N)
		Trial 1	Trial 2	Trial 3			
100	0.98	6.23	6.40	6.3	6.31	0.495	0.0495
200	1.96	6.15	6.20	6.20	6.18	0.506	0.101
300	2.94	6.2	6.2	6.15	6.18	0.506	0.152
400	3.92	6.1	6.3	6.15	6.15	0.508	0.203

c) Calculate the values for the missing cells and fill them in the table. Show and explain your working clearly. (3 marks)

Deceleration:

$v^2 = u^2 + 2as$

$a = \frac{v^2 - u^2}{2s}$

$= \frac{0 - 2.5^2}{2 \times 6.15} = 0.50813$

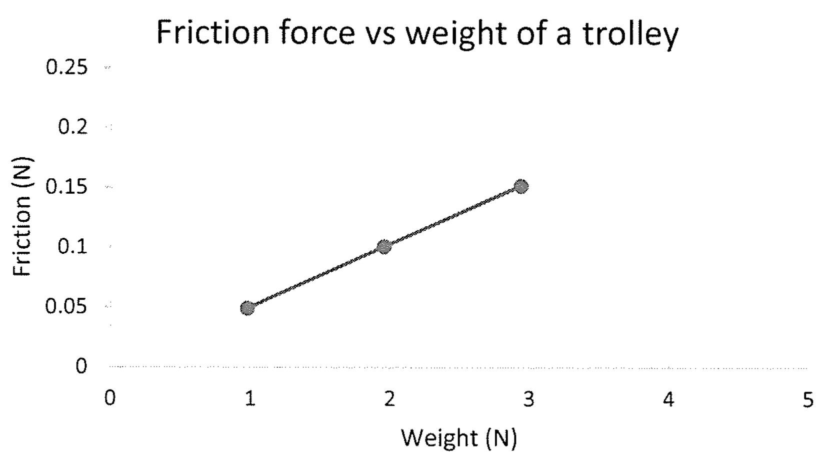
Friction

$F_f = ma$

$= 0.4 \times 0.50813$

$= 0.203.$

This data is plotted below. You may wish to add your calculated data point.



d) We set out to investigate the relationship between friction force and weight of the trolley. Summarise this relationship in a sentence (2 marks):

F_f is directly proportional to weight.
✓ ✓

e) You may have noticed that the students forgot to weight the trolley and include it in their calculations. The mass of the trolley was small (less than 100 g) but significant. Explain the effect of this mistake on the following by circling the correct words (2 marks):

i. The calculated decelerations on the carpet would have been **higher / lower / the same** in magnitude if they included the mass of the trolley in their calculations. ✓
ii. The calculated friction force would have been **higher / lower / the same** in magnitude if they included the mass of the trolley in their calculations. ✓

f) Joan's group was surprised to find that the distance their trolley travelled was almost constant (about 6.15 - 6.3 m) and so did not appear to be affected by the mass of the trolley. They did a little research and found that, if other variables are kept constant, the rolling friction force can generally be modelled as proportional to the weight of the body which is rolling (i.e. $F_f = k \times mg$), where *k* is a constant, and *m* is the total mass of the cart. This, of course, agreed with their own results!

The group realised that this was why the trolley distances stayed almost constant. Use work/energy concepts to explain this conclusion. (3 marks)

Work done = KE at base

$F_f s = \frac{1}{2} m v^2$ ✓

If mass is increased then both KE and $F_f s$ are increased proportionally ✓ & therefore s is unchanged ✓

(or: $kmg s = \frac{1}{2} m v^2$
$\Rightarrow s = \frac{v^2}{2gk}$ $\Rightarrow$ independent of mass) ✓✓

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g) The students also tried to do a trial with 500 g in the trolley but they noticed that with this much mass in it, the trolley crashed quite heavily when it rolled from the ramp to the carpet. Although the trolley continued on forward in a measurable straight line, the group reasoned that the crashing would likely affect their results and they decided not to include this data. Circle the correct answer

The 'crashing effect' would cause the calculated experimental friction force to be **higher / lower / the same as** the actual friction force between the trolley and carpet (1 mark) ✓

Explain. (2 marks)

The loss of KE ✓ in 'crash' would incorrectly be attributed to work done $W = F_f \times s$, thus, suggesting F_f is higher. ✓

or Since the initial velocity is reduced by 'crash' ✓, the actual decelerations would be less than our calculated values and thus, our calculated F_f ($= ma$) would be artificially high. ✓

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