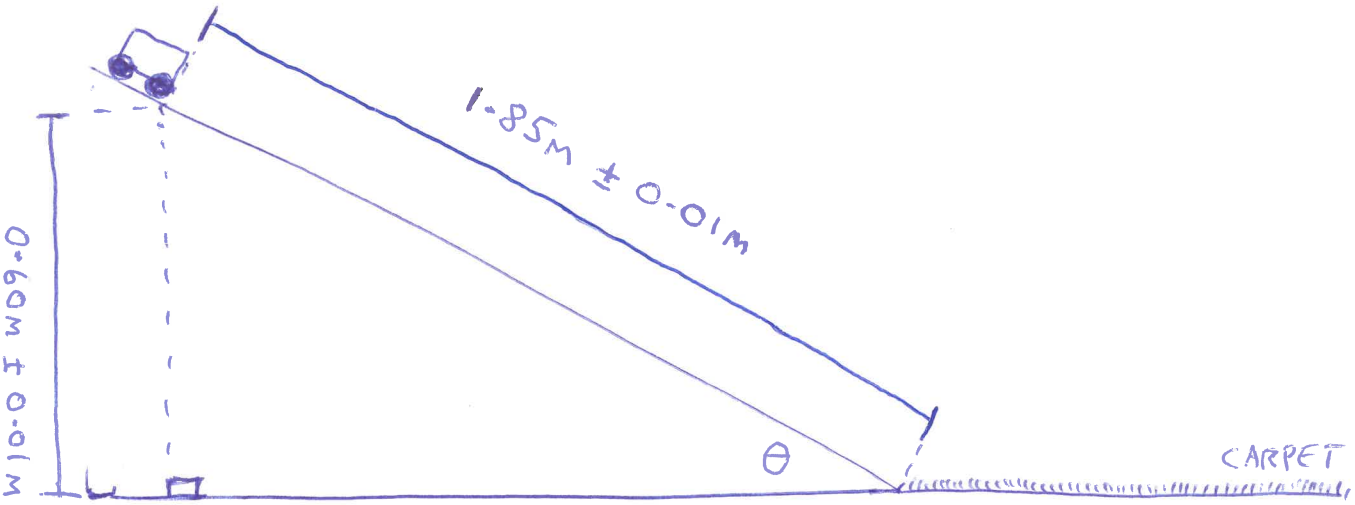
SAMPLE CALCULATIONS



$$\theta = \sin^{-1}\left(\frac{0.60}{1.85}\right) = 18.9^\circ$$

$$\theta_{min} = \sin^{-1}\left(\frac{0.59}{1.86}\right) = 18.5^\circ$$

$$\theta_{max} = \sin^{-1}\left(\frac{0.61}{1.84}\right) = 19.4^\circ$$

$$\therefore \boxed{\theta = 18.9^\circ + 0.5^\circ / -0.4^\circ}$$

THEORETICAL ACCELERATION:

$$a = g \sin\theta = 9.8 \sin 18.9^\circ = 3.17 M/s^2$$

$$\therefore a_{max} = 9.8 \sin 19.4^\circ = 3.26 M/s^2$$

$$a_{min} = 9.8 \sin 18.5^\circ = 3.11 M/s^2$$

$$\therefore \boxed{a = 3.17 M/s^2 + 0.09 / -0.06}$$

THEORETICAL TIME TO BASE OF RAMP: $\left(s = ut + \frac{1}{2}at^2,\ u = 0 M/s\right)$

$\theta = 18.5^\circ$	$\theta = 18.9^\circ$	$\theta = 19.4^\circ$
$s = 1.86 M$	$s = 1.85 M$	$s = 1.84 M$
$a = 3.11 M/s^2$	$a = 3.17 M/s^2$	$a = 3.26 M/s^2$
$t = 1.09 s$	$t = 1.08 s$	$t = 1.06 s$

∴ If force on ramp is negligible, time to base will, on average, be between 1.06 – 1.09 s

(*) I would expect the results here to allow for the assumption that friction on the ramp was negligible, but if not...

Mass of Cart = 0.250 kg

Table 1: Time to base of ramp.

	Trial 1	Trial 2	Trial 3
Time to Base of Ramp	1.36 s	1.38 s	1.37 s
Uncertainty (Reaction Time) = ±0.1 s		Average : 1.37 ± 0.10 s	

∴ Average time between 1.27 - 1.47 s

This is outside of theoretical range of 1.06 - 1.09 s,

∴ Friction of ramp is not negligible.

Estimate friction on ramp using t_{av} = 1.37 s & θ = 18.9°

$s = 1.85 m$
$u = 0 m/s$
$t = 1.37 s$
$a = ?$

$s = ut + \frac{1}{2}at^2$

$\therefore 1.85 = (0)(1.37) + \frac{1}{2}a(1.37)^2$

$\therefore \frac{1.85 \times 2}{(1.37)^2} = a = 1.97 m/s^2 = a_{NET}$

F_{NET} (Down Slope) = $Mg \sin\theta - F_{FRICTION}$

$\therefore F_{FRICTION} = Mg \sin\theta - F_{NET}$

$= (0.25 \times 9.8 \sin 18.9°) - (0.25 \times 1.97)$

$= 0.30$ N up slope

Find velocity at base of ramp

$s = 1.85m$

$u = 0 m/s$

$a = 1.97 m/s^2$

$t = 1.37 s$

$v = ?$

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

$\therefore v^2 = 0^2 + 2(1.97)(1.85)$

$= 7.289$

$\therefore \boxed{v = 2.70 m/s}$

V_{max} $(t_{av} = 1.27s,\ \theta = 19.40^\circ)$ $= 2.89 m/s$

V_{min} $(t_{av} = 1.47s,\ \theta = 18.5^\circ)$ $= 2.53 m/s$

$\therefore \boxed{v = 2.70 m/s + 0.19/-0.17 m/s}$ at base of ramp.

* Students would need to repeat this process for different masses in the trolley, as $F_{FRICTION} \propto$ mass. If we could ignore friction of the ramp, velocity could be assumed to be identical for each run down the ramp. For simplicity, I will continue as though velocity at the base of the ramp were identical for each trial.

Table 2: Mass of Trolley vs. Stopping Distance

Mass (kg) (± 0.01 kg)	Stopping Distance (m) (±0.01 m)			
	Trial 1	Trial 2	Trial 3	Average
0.25	0.99	1.00	1.01	1.00m
0.30	0.94	0.95	0.96	0.95m
0.35	0.89	0.90	0.91	0.90m
0.40	0.84	0.85	0.86	0.85m
0.45	0.79	0.80	0.81	0.80m

Sample Calculation of Friction Force of Carpet

$$v^2 = u^2 + 2as \quad \Rightarrow \quad \frac{v^2 - u^2}{2s} = a$$

For $m = 0.25$ kg ...

$$a = \frac{0^2 - 2.70^2}{2(1)} = -3.645 \text{ m/s}^2$$

$$F_{FRICTION} = ma = 0.25(-3.645)$$

$$= -0.91125 \text{ N}$$

$$= \boxed{9.11 \times 10^{-1} \text{ N against motion}}$$

To find upper limit of $F_{FRICTION}$, maximise 'u' & 'm', minimise 's'...

$$\therefore a_{max} = \frac{0^2 - 2.89^2}{2(0.99)} = -4.218 \text{ m/s}^2$$

$$F_{max} = ma = 0.26(-4.218)$$

$$= -1.0967 \text{ N}$$

$$= \boxed{1.10 \times 10^{0} \text{ N against motion}}$$

To find lower limit, minimise 'u' & 'm', maximise 's'...

$$\therefore a_{min} = \frac{0^2 - 2.53^2}{2(1.01)} = -3.169 \text{ m/s}^2$$

$$F_{min} = ma = 0.24(-3.169)$$

$$= 0.7605 \text{ N}$$

$$= \boxed{7.61 \times 10^{-1} \text{ N against motion}}$$

⊛ Students need only show such a calculation once, but they would need to perform it repeatedly for each mass.

(*) Students would need only show the results of the remaining calculations (perhaps in a table):

Table 3 : Mass vs. Friction Force on Carpet

Mass (kg)	Friction Force (N)
0.25 ± 0.01	0.91 + 0.19/-0.15
0.30 ± 0.01	___
0.35 ± 0.01	___
0.40 ± 0.01	___
0.45 ± 0.01	___

(*) Students would then ideally plot the results on a graph (Mass vs. Friction Force) with both vertical & horizontal error bars included, then comment on the trend (if any).