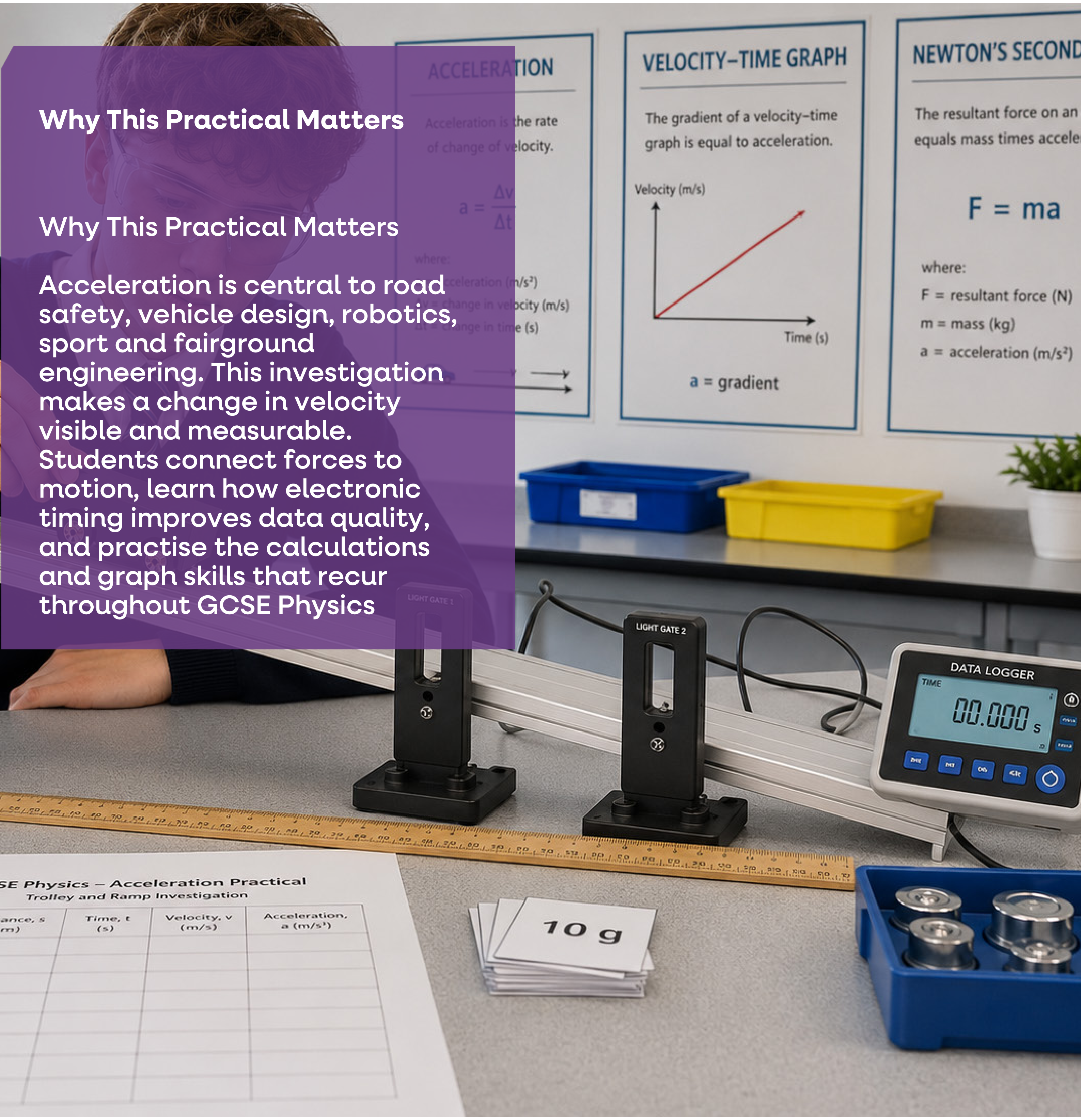
GCSE Physics Practical Guide

Acceleration Trolley and Ramp Investigations

Measuring acceleration with stopwatches, light gates and data loggers; investigating the effects of ramp angle, force and mass.

An enhanced practical guide featuring troubleshooting, retrieval practice, exam questions, differentiation and advanced evaluation support.



Why This Practical Matters

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Acceleration is central to road safety, vehicle design, robotics, sport and fairground engineering. This investigation makes a change in velocity visible and measurable. Students connect forces to motion, learn how electronic timing improves data quality, and practise the calculations and graph skills that recur throughout GCSE Physics

This resource is provided as a practical support guide to accompany laboratory equipment. Teachers should adapt procedures and risk assessments to suit their curriculum requirements, examination board specifications and local laboratory policies.

Practical Overview

In the core investigation, students release a dynamics trolley down a ramp and measure its acceleration. The recommended method uses two light gates and a data logger. A low-equipment stopwatch method is included for comparison, and an extension uses a trolley, pulley and hanging masses to investigate the effects of force and total mass.

Core enquiry question

How does ramp height or angle affect the acceleration of a trolley?

Students keep the trolley, release point, ramp surface and light-gate positions constant while changing only the ramp height or angle.

Learning Objectives

By the end of this practical students should be able to:

- Set up a trolley and ramp safely and securely.
- Use light gates, an interrupt card and a data logger correctly.
- Measure ramp height or angle, distance, time and speed accurately.
- Calculate acceleration using a = (v - u) / t.
- Explain how a resultant force causes acceleration.
- Plot and interpret a graph of mean acceleration against ramp height or angle.
- Investigate force and mass as extension variables.
- Evaluate the reliability, validity and accuracy of the method.

Suggested teaching sequence

Teach the ramp method first to establish how acceleration is measured. Use the trolley-pulley extension after students understand F = ma and the meaning of a fair test.

Scientific Background

Acceleration

Acceleration is the rate at which velocity changes. An object accelerates when it speeds up, slows down, or changes direction.

Acceleration equation

$a = (v - u) / t$

a = acceleration in metres per second squared (m/s^2)
v = final velocity in metres per second (m/s)
u = initial velocity in metres per second (m/s)
t = time for the velocity change in seconds (s)

Forces on the trolley	What changes on a steeper ramp?
Weight acts vertically downwards.	The downhill component of weight is larger.
The ramp exerts a normal contact force.	The resultant force down the ramp is larger.
Friction and rolling resistance oppose the motion.	For the same trolley mass, the acceleration is larger.
A component of the trolley's weight acts down the ramp.	The exact result is affected by friction and wheel condition.

Newton's second law

The acceleration of an object depends on the resultant force acting on it and its mass. The relationship is $F = ma$. For constant mass, a larger resultant force produces a larger acceleration. For constant force, a larger total mass produces a smaller acceleration.

Velocity-time graphs

The gradient of a velocity-time graph gives acceleration. A straight sloping line shows constant acceleration; a changing gradient shows non-uniform acceleration.

Equipment Required

Per Student Group - Core Ramp Method

- Dynamics trolley
- Rigid ramp or dynamics track
- Blocks or laboratory jack to raise one end
- Two light gates with data logger/electronic timer
- Interrupt card of known length
- Metre ruler or tape measure
- Stopwatch for method comparison
- Protractor, inclinometer or vertical ruler
- Masking tape or position markers
- Foam buffer, stop block or catch tray

Per Student Group - Force and Mass Extension

- Low-friction runway or level track
- Bench pulley
- Light string
- Mass hanger
- Slotted masses
- Balance (1 g resolution or better)
- Additional masses for trolley
- Clamp or pulley fixing
- Graph paper or spreadsheet software

Safety Equipment

- Eye protection, particularly when hanging masses are used.
- Closed shoes and a clear floor area.

Teacher / Technician Equipment

- Spare light-gate leads, interface cables, batteries or power supplies.
- Identical interrupt cards cut and labelled with their measured lengths.
- Spare trolleys with free-running wheels.
- Additional blocks, clamps and non-slip matting for securing ramps.
- Digital balance and check masses.
- Spare string, mass hangers and slotted masses.
- Prepared demonstration setup and sample results.

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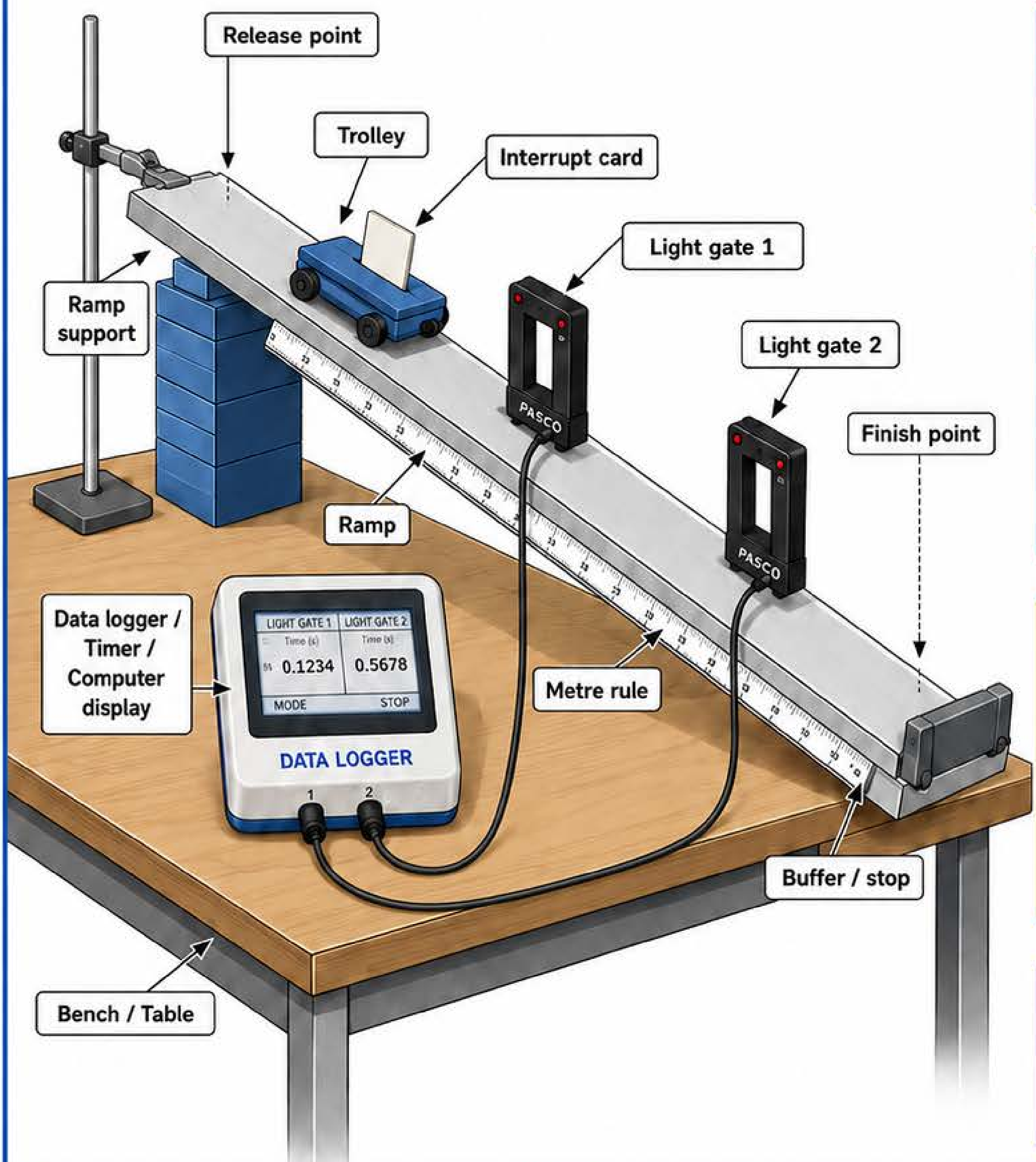
Complete Trolley and Ramp Apparatus Setup

Investigating acceleration down a ramp using light gates



Purpose

Measure how the trolley speeds up as it travels down the ramp.

Key measurements

- Initial velocity
- Final velocity
- Time between light gates
- Distance / ramp height

Control points

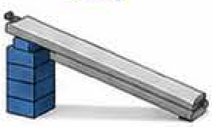
- Start from the same release point
- Keep the trolley mass the same
- Use the same card length
- Repeat readings and calculate a mean

Variable to change

Change the ramp height or angle to investigate its effect on acceleration.

What each part does

Ramp



Provides the slope so gravity pulls the trolley down the ramp, causing it to accelerate.

Trolley

Moves down the ramp. It is the object whose speed and acceleration we measure.

Light gates

Detect when the interrupt card passes through and measure the time taken.

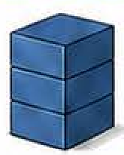
Interrupt card

Attached to the trolley. It blocks the light beam as it passes through.

Data logger / Timer

Records the times from the light gates accurately and calculates speeds and differences.

Ramp support



Changes the height (and angle) of the ramp to change the trolley's acceleration.

Set up carefully, check everything works, then take repeat measurements for reliable results.

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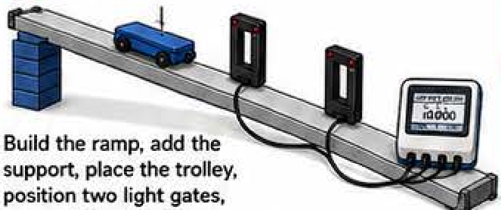
Step-by-Step Experimental Workflow

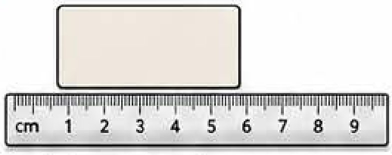
Investigating acceleration of a trolley down a ramp

1 Set up apparatus



Build the ramp, add the support, place the trolley, position two light gates, connect the data logger, and add a buffer stop.

2 Measure the card

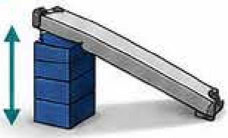


Measure the interrupt card length accurately. The logger uses this to calculate velocity at each light gate.

Goal

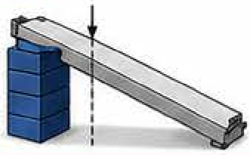
Find out how changing the ramp affects the trolley's acceleration.

3 Choose the variable



Decide what to change, such as ramp height or ramp angle. Keep the trolley mass and card length the same.

4 Mark the start point



Use the same release point each time so the test is fair.

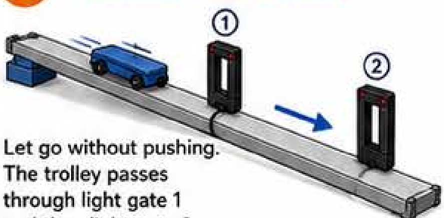
Control points

- Same trolley
- Same card length
- Same release point
- No push on release
- Repeat and average

5 Check the logger

Make sure both light gates are connected and the timer or data logger is ready to record.

6 Release the trolley



Let go without pushing. The trolley passes through light gate 1 and then light gate 2.

Evidence collected

- Velocities
- Time between gates
- Ramp height or angle
- Mean acceleration
- Graph and conclusion

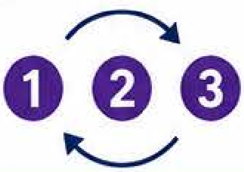
7 Record readings

Results

Trial	Initial velocity u (m/s)	Final velocity v (m/s)	Time between gates t (s)
1			
2			
3			

Record initial velocity, final velocity, and the time between the light gates.

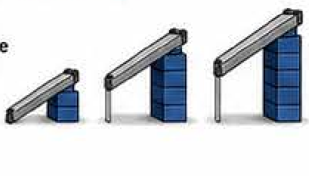
8 Repeat trials



Repeat at least three times for the same setting and calculate a mean.

9 Change the ramp

Increase or decrease the ramp height or angle, then repeat the investigation for several values.



10 Process results

Calculate acceleration using "$a = (v - u) / t$", plot a graph, and write a conclusion about the relationship.

Key calculation

$$a = \frac{v - u}{t}$$

a = acceleration
u = initial velocity
v = final velocity
t = time between light gates

What the workflow leads to

Reliable results
Repeats improve reliability.

Fair test
Control variables are kept the same.

Calculations
Acceleration is calculated from measured values.

Conclusion
Use the graph to describe the relationship.

Work carefully, release the trolley consistently, and collect repeat measurements before drawing conclusions.

Method

1.Secure the ramp
Place the ramp on the bench with a foam buffer or stop block at the lower end. Raise the upper end using blocks or a laboratory jack. Check that the ramp cannot slip.

2.Prepare the trolley
Attach the interrupt card firmly and measure its length. Check that the trolley wheels rotate freely and that no added mass can fall off.

3.Fix the measurement positions
Mark a release line. Position light gate 1 a fixed distance below it and light gate 2 farther down the ramp. Measure and record the separation between the gates.

4.Set the first ramp height or angle
Measure the vertical height of the raised end or use a protractor/inclinometer to record the angle. Use a modest starting angle so the trolley remains controlled.

5.Configure the timer or logger
Select the correct mode. If the logger does not calculate acceleration directly, record the velocity at each gate and the time between those velocity measurements.

6.Release the trolley
Place the trolley at the marked release line. Release it without pushing and keep hands clear of the light gates.

7.Record the motion data
Record initial velocity u, final velocity v and time interval t, or record the acceleration displayed by the logger. Catch the trolley safely at the bottom.

8.Calculate acceleration
Use $a = (v - u) / t$. Include units and use a sensible number of significant figures. If the logger gives acceleration, retain the raw speed/time readings where possible.

9.Repeat and calculate a mean
Repeat at least three times at the same ramp setting. Investigate any anomalous reading before calculating the mean acceleration.

10.Change the ramp setting
Increase the height or angle in measured steps. Do not move the release line or light gates. Repeat the full procedure for at least five settings.

Results Table

Ramp height (cm)	Angle (°)	Acceleration 1 (m/s^2)	Acceleration 2 (m/s^2)	Acceleration 3 (m/s^2)	Mean (m/s^2)	Range (m/s^2)

Example Results

Ramp height (cm)	Angle (°)	Accel. 1 (m/s^2)	Accel. 2 (m/s^2)	Accel.3 (m/s^2)	Mean acceleration (m/s^2)	Range (m/s^2)
5	2.4	0.30	0.32	0.31	0.31	0.30-0.32
10	4.8	0.70	0.72	0.71	0.71	0.70-0.72
15	7.2	1.08	1.11	1.10	1.10	1.08-1.11
20	9.6	1.48	1.51	1.50	1.50	1.48-1.51
25	12.0	1.84	1.89	1.88	1.87	1.84-1.89

Example values are illustrative only. Actual results depend on ramp surface, trolley condition, angle, gate positions and friction.

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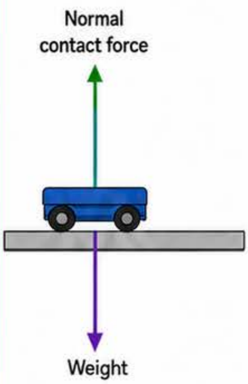
Why a Trolley Accelerates Down a Ramp

Explaining the forces that make the trolley speed up

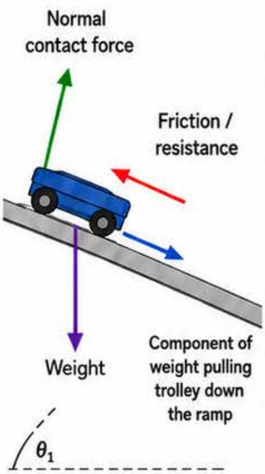
Flat surface



No component of weight along the surface.

No acceleration unless pushed.

Shallow ramp

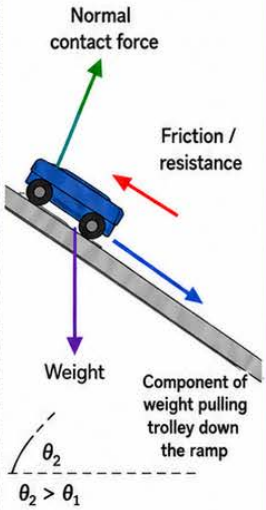


Small component of weight down the ramp.

Friction is partly overcome.

The trolley accelerates modestly.

Steeper ramp



Larger component of weight down the ramp.

Friction is more easily overcome.

The trolley accelerates more strongly.

Why does the speed increase?

- Gravity pulls the trolley downward.
- On a ramp, some of that pull acts along the slope.
- If this downhill force is bigger than friction, there is a resultant force.
- A resultant force causes acceleration.

What changes on a steeper ramp?

- The component of weight down the slope gets bigger.
- The resultant force increases.
- The trolley gains speed more quickly.
- So the acceleration is larger.

Physics link

Resultant force = mass x acceleration

$$F = ma$$

Larger resultant force → larger acceleration (if mass stays the same).

Key idea

The trolley accelerates because the forces are unbalanced.

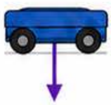
On a slope, part of the trolley's weight acts down the ramp. This creates a resultant force, so the trolley speeds up.

Important vocabulary

- weight
- resultant force
- acceleration
- friction
- normal contact force

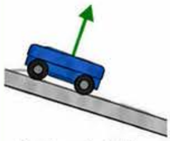
What each force does

Weight



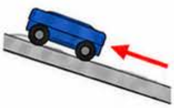
Acts vertically downward because of gravity.

Normal contact force



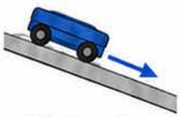
Pushes at right angles to the ramp surface.

Friction / resistance



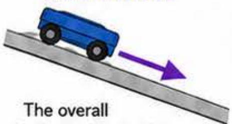
Opposes motion along the ramp.

Downhill component of weight



Pulls the trolley down the slope.

Resultant force



The overall unbalanced force that causes acceleration.

If the ramp gets steeper and the trolley mass stays the same, the trolley usually accelerates more.

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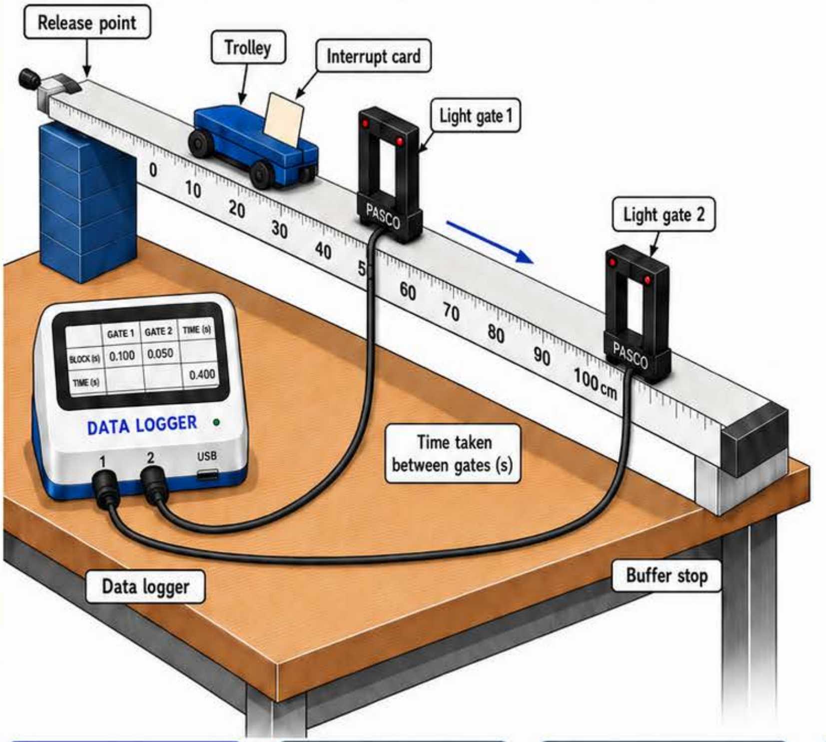
Measuring Acceleration with Light Gates

Using a trolley, interrupt card, and two light gates to calculate acceleration



What do the light gates measure?

- Block time at gate 1
- Block time at gate 2
- Time between the gates
- These let us calculate velocity and acceleration

Control points

- Use the same trolley
- Use the same interrupt card length
- Release from the same point
- Do not push the trolley
- Repeat and average

Key formulae

$$u = \frac{L}{t_1} \qquad v = \frac{L}{t_2}$$

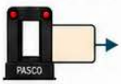
$$a = \frac{v - u}{t}$$

u = initial velocity
v = final velocity
L = card length
t_1 and t_2 = block times
t = time between gates

1 Measure the interrupt card

Record the card length, L.

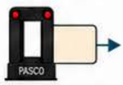
2 Velocity at gate 1



The logger measures how long the card blocks light gate 1.

Initial velocity: $u = \dfrac{L}{t_1}$

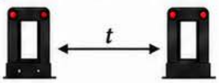
3 Velocity at gate 2



The logger measures how long the card blocks light gate 2.

Final velocity: $v = \dfrac{L}{t_2}$

4 Time between gates



Use the time from gate 1 to gate 2.

Acceleration: $a = \dfrac{v - u}{t}$

How the calculation works

1. Card length (L)

Measure the interrupt card length in metres.

2. Initial velocity (u)

$u = L/t_1$

Use block time at gate 1.

3. Final velocity (v)

$v = L/t_2$

Use block time at gate 2.

4. Acceleration (a)

$a = \dfrac{v - u}{t}$

Use time between gates.

5. Unit

m/s^2

Acceleration is measured in m/s^2.

Worked example

Interrupt card length, L = 0.050 m
Block time at gate 1, t_1 = 0.100 s
Block time at gate 2, t_2 = 0.050 s
Time between gates, t = 0.400 s

$$u = \frac{0.050}{0.100} = 0.50 \text{ m/s}$$

$$v = \frac{0.050}{0.050} = 1.00 \text{ m/s}$$

$$a = \frac{1.00 - 0.50}{0.40} = \mathbf{1.25\ m/s^2}$$

Why two gates?

- One gate gives a speed at one point
- Two gates give two speeds and the time between them
- This allows acceleration to be calculated

Common mistakes to avoid

Wrong card length entered — Enter the correct value in the logger.

Pushing the trolley — Release gently. Avoid a push.

Misaligned light gates — Ensure gates face each other and are level.

Forgetting repeats — Take several trials and calculate a mean.

Measure carefully, enter the correct values, and take repeat readings for reliable acceleration values.

Variables

Variable Type	Variable
Independent variable	Ramp height (cm) or ramp angle (°)
Dependent variable	Acceleration of the trolley (m/s^2)
Control variables	Same trolley and total mass
	Same release position and release method
	Same light-gate positions and separation
	Same ramp surface and wheel condition
	Same interrupt card and card length
	Same logger settings and data-processing method

Processing Results

Students should

- Calculate acceleration for every trial using the same method
- Record values with units and a consistent number of decimal places
- Identify anomalous readings and justify whether they should be repeated or excluded
- Calculate a mean acceleration for each ramp setting
- Calculate a range to compare the spread of repeated readings
- Plot mean acceleration on the y-axis against ramp height or angle on the x-axis
- Draw a line or smooth curve of best fit rather than joining dot-to-dot
- Describe the pattern before explaining it using forces.

Expected Observations

- The trolley passes gate 2 at a greater speed than gate 1.
- The acceleration is positive when down the ramp is chosen as the positive direction.
- Increasing ramp height or angle generally increases acceleration.
- At very low angles the trolley may move slowly or inconsistently because friction is a large fraction of the driving force.
- Light-gate repeats should usually be closer together than stopwatch repeats.

Evidence Based Conclusion

Under the conditions of the investigation, increasing the ramp height or angle increased the trolley's mean acceleration. The steeper ramp produced a larger component of the trolley's weight down the slope, increasing the resultant force. For the same trolley mass, the larger resultant force produced a larger acceleration.

A good conclusion refers to the measured trend and the controlled conditions. It should not claim that the relationship is perfectly proportional unless the graph supports that claim.

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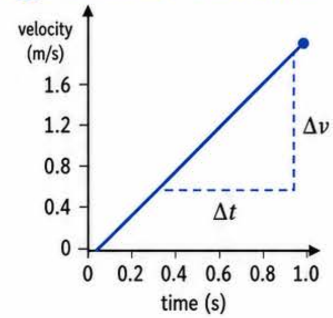
Acceleration Graphs Explained

How to read, draw, and interpret graphs in a trolley-and-ramp acceleration investigation

1. Velocity–time graph

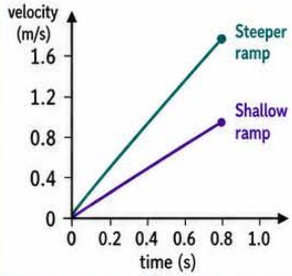


gradient = acceleration

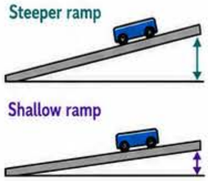
$$a = \frac{v - u}{t}$$

- Steeper line = greater acceleration
- Straight line = constant acceleration

2. Comparing ramps

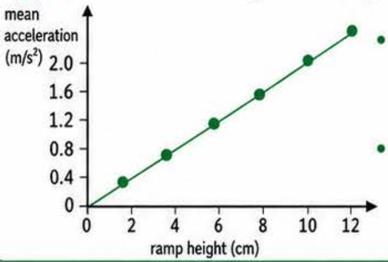


The steeper ramp produces the steeper velocity–time line.



A steeper ramp usually gives a larger acceleration.

3. Acceleration against ramp height



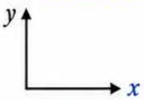
- As ramp height increases, acceleration usually increases.
- Use the mean acceleration for each height.

4. What the graph tells you

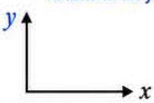
- Gradient on a velocity–time graph = acceleration
- A steeper positive gradient means greater acceleration.
- A horizontal line would mean no acceleration
- A downward gradient would mean slowing down
- Look for the overall trend, not just one point

How to draw a good graph

1. Put the independent variable on the x-axis



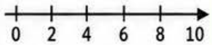
2. Put the dependent variable on the y-axis



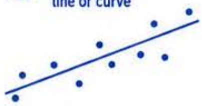
3. Use units in brackets

(units)

4. Choose a sensible even scale

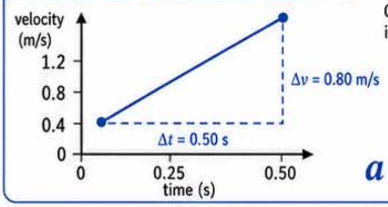


5. Draw a neat best-fit line or curve



For this practical, if you vary ramp height or angle, that goes on the x-axis. Mean acceleration goes on the y-axis.

Worked gradient example



If velocity changes from 0.40 m/s to 1.20 m/s in 0.50 s:

$$a = \frac{v - u}{t}$$

$$a = \frac{1.20 - 0.40}{0.50}$$

$$a = 1.6\ m/s^2$$

Common graph mistakes

- Missing units
- Wrong axes
- Scales that waste space
- Joining points dot-to-dot when a best-fit line is better
- Calculating the gradient from one tiny section instead of a large triangle
- Forgetting to use mean values

Key takeaways

- Gradient = acceleration
- Steeper line = greater acceleration
- Best-fit line shows the trend
- Axes, scales, and units matter

Draw graphs neatly, include units, and use the gradient of a velocity–time graph to find acceleration.

Sources of Error

- The trolley is pushed or released from slightly different positions.
- The ramp, release marker or light gates move between settings.
- The interrupt card is not vertical or clips a light gate.
- Wheel friction changes because of dust, damaged axles or wobbling wheels.
- Ramp height or angle is measured with parallax error.
- The logger is in the wrong mode or uses an incorrect card length.
- Manual stopwatch readings are affected by reaction time.
- The trolley strikes the buffer before all data have been recorded.

Improvements

- Use a mechanical or electromagnetic release so the trolley is not pushed.
- Clamp or tape the ramp and mark every fixed position.
- Use light gates or a motion sensor instead of manual timing.
- Use a longer run and a wider range of measured ramp settings where safe.
- Clean and check trolley wheels before the lesson.
- Measure angle with a digital inclinometer, or measure height and ramp length carefully.
- Repeat more times and investigate anomalous results.
- Use the same trolley and interrupt card for the full data set.

Reliability

Reliability is improved by repeating each setting; calculating a mean; reporting the range; using an identical procedure; checking anomalies; and comparing results between groups using the same apparatus.

Validity

The investigation is valid when ramp height or angle is the only factor deliberately changed. The trolley, total mass, release point, gate positions, card length, ramp surface and data-processing method should remain constant.

Validity warning

Changing the ramp angle changes the component of weight along the ramp. It is therefore valid to conclude that angle affects acceleration. Do not describe ramp height itself as a force.

Accuracy

- Use light gates to reduce reaction-time error.
- Measure the interrupt card length with millimetre resolution and enter it correctly.
- Read rulers and protractors at eye level to avoid parallax.
- Align both light gates so the same part of the card cuts each beam.
- Use a release mechanism and a clearly marked starting point.
- Use appropriate significant figures that reflect the resolution of the equipment.
- Check the data logger with a test run before collecting the final data.

Uncertainty

- Repeated measurements reveal random variation but do not remove systematic error. A consistent zero error in an inclinometer, an incorrectly measured card length or persistent pulley friction can shift every result in the same direction.

Random variation	Systematic effects
• Release differences • Wheel vibration • Small timing fluctuations • Slight changes in card alignment	• Incorrect card length • Mis-calibrated angle sensor • Constant track friction • Logger configuration error

GCSE Required Practical Skills Assessed

Students demonstrate:

- Safe setup and control of moving apparatus
- Accurate measurement of length, time, speed, mass and acceleration
- Use of light gates, data loggers and appropriate motion-measurement techniques
- Identification of independent, dependent and control variables
- Systematic recording of repeated measurements
- Calculation of means, ranges and acceleration
- Graph plotting, line of best fit and gradient interpretation
- Evidence-based conclusions and evaluation of method quality
- Risk assessment and appropriate control measures.

Apparatus and Techniques

Skill	How it is developed
AT 1	Measure and record length, mass and time accurately.
AT 2	Measure and observe the effect of force in the trolley-pulley extension.
AT 3	Determine speed and rate of change of speed (acceleration/deceleration).

Mathematical Skills

- Substitute into and rearrange $a = (v - u) / t$ and $F = ma$.
- Convert centimetres to metres and grams to kilograms.
- Calculate arithmetic means and ranges.
- Plot two variables and select suitable scales.
- Calculate a gradient using a large triangle.
- Recognise direct and inverse proportionality.
- Use an appropriate number of significant figures.

GCSE Specification Links

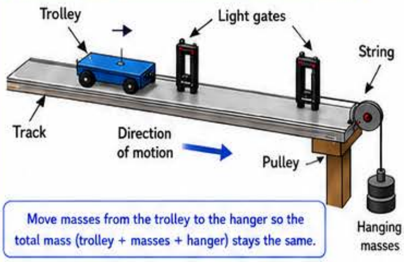
The ramp route strongly develops acceleration measurement. For full AQA Required Practical 7 coverage, students should also investigate varying force at constant mass and varying mass at constant force using the extension on pages 23-25.

GCSE PHYSICS

Newton's Second Law: Force and Mass Extension

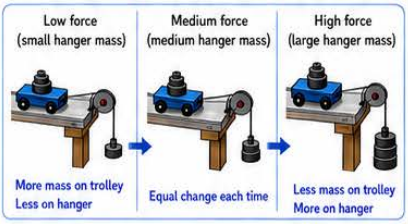
Investigating how force and mass affect acceleration using a trolley, pulley, and masses

1. Varying force (constant total mass)

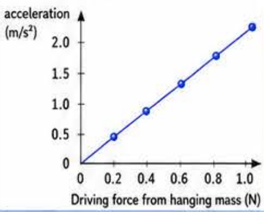


Move masses from the trolley to the hanger so the total mass (trolley + masses + hanger) stays the same.

Increase the driving force by moving masses to the hanger

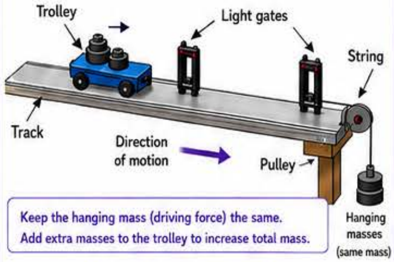


As driving force increases, acceleration increases.



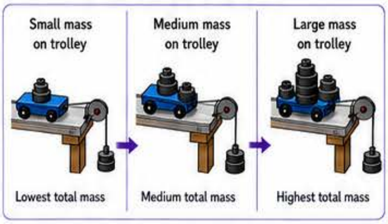
- Move masses from trolley to hanger
- Keep total mass constant
- Measure acceleration each time
- Repeat and calculate a mean

2. Varying mass (constant driving force)

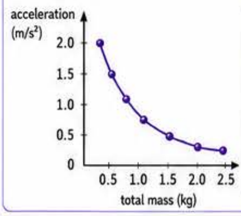


Keep the hanging mass (driving force) the same.
Add extra masses to the trolley to increase total mass.

Increase the mass on the trolley



As mass increases, acceleration decreases.



- Keep the hanging mass the same
- Add masses to the trolley
- Measure acceleration each time
- Larger mass gives smaller acceleration

A) What stays the same?

- Same trolley
- Same track
- Same release method
- Same distance
- Repeat trials

B) What do you measure?

- Hanging mass (used to calculate driving force)
- Total mass of system
- Acceleration
- Repeat values
- Mean acceleration

C) Expected pattern

- Bigger driving force → bigger acceleration
- Bigger mass → smaller acceleration
- If driving force is constant, acceleration is inversely proportional to mass

Newton's second law

$$F = ma \qquad a = \frac{F}{m} \qquad m = \frac{F}{a}$$

F = resultant force (N)
m = mass (kg)
a = acceleration (m/s²)

Driving force vs resultant force

The driving force is the weight of the hanging mass:

$$F_{\text{driving}} = m_{\text{hanger}} \times g$$

The resultant force on the whole system is only approximately equal to the driving force if resistive forces (e.g. friction, air resistance) are negligible.

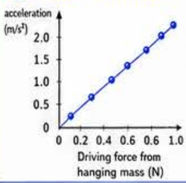
In general: $F_{\text{resultant}} = F_{\text{driving}} - F_{\text{resistive}}$

Method summary

1. Set up trolley, track, string, and pulley.
2. Decide whether to vary force or vary mass.
3. Measure acceleration using light gates or a timer.
4. Change the masses for the next run.
5. Repeat at least three times and calculate a mean.
6. Plot a graph and draw a conclusion.

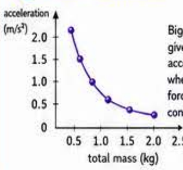
What the results show

1 Force vs acceleration



Direct relationship when mass is constant.

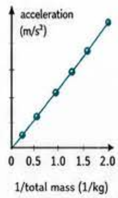
2 Mass vs acceleration



Bigger mass gives lower acceleration when driving force is constant.

Extension idea

A graph of acceleration against $\frac{1}{\text{total mass}}$ would be a straight-line relationship if driving force is constant.



Common mistakes to avoid

- Not keeping total mass constant in the force investigation.
- Changing the hanging mass in the mass investigation.
- Not releasing the trolley cleanly.
- Friction from a rough track or misaligned pulley.
- Not repeating trials or not using mean values.

Key takeaways

- More driving force → more acceleration
- More mass → less acceleration (if driving force is constant)
- Use repeat readings and mean values
- Newton's second law links force, mass, and acceleration.

Investigate one variable at a time, keep the test fair, and use $F = ma$ to explain the pattern in your results.

Common Misconceptions

✗ Acceleration means moving fast.

✓ Acceleration is a change in velocity per unit time. An object can move fast at constant velocity and have zero acceleration.

✗ A heavier trolley must accelerate faster down the same ramp.

✓ In the ideal model, mass cancels. Real differences are more likely to come from friction, wheel condition or the way masses are attached.

✗ The whole weight of the trolley pulls it down the ramp.

✓ Only the component of weight parallel to the ramp contributes directly to motion down the slope.

✗ A negative acceleration always means the object is slowing down.

✓ The sign depends on the chosen positive direction. A negative acceleration can speed an object up in the negative direction.

✗ The gradient of a distance-time graph gives acceleration.

✓ The gradient of a distance-time graph gives speed. The gradient of a velocity-time graph gives acceleration.

✗ A force is needed to keep an object moving at constant velocity.

✓ A resultant force is needed to change velocity. Constant velocity occurs when the resultant force is zero.

✗ The data logger always measures acceleration directly.

✓ Some systems only measure beam-blocking times or speeds. Students must understand what the instrument is actually recording.

Common Student Mistakes

Common Student Mistake	Consequence
Pushing the trolley at release	Adds an uncontrolled initial force and makes comparisons invalid.
Changing the release point	Changes the speed at gate 1 and prevents a fair comparison.
Moving light gates between settings	Changes the measured interval as well as the ramp angle.
Entering the wrong card length	Produces a systematic error in every calculated speed.
Mixing cm, m, g and kg	Produces acceleration or force values with the wrong magnitude.
Plotting acceleration on the x-axis	Reverses the independent and dependent variables.
Letting the hanger hit the floor	The driving force changes before the trolley has completed the measurement interval.
Adding mass without stating total system mass	Makes the force-mass analysis incomplete or incorrect.
Joining points dot-to-dot	Hides the overall trend and is not a best-fit representation.
Ignoring an anomalous reading	Can distort the mean and weaken the conclusion.

Examiner Advice

High-value exam wording

State that the trolley is released without a push, the independent variable is changed in measured steps, control variables are kept constant, each reading is repeated, a mean is calculated, and the conclusion is based on the trend in the graph.

Troubleshooting Guide

Problem	Possible Cause	Solution
Trolley does not move at low angle	Driving component is smaller than static/rolling resistance	Increase the angle slightly; clean/check wheels; use a lower-friction track.
Trolley leaves the track or moves too fast	Ramp too steep or buffer inadequate	Reduce the angle; centre the trolley; add a secure buffer or catch tray.
Logger records no value	Beam not broken, cable loose or wrong mode selected	Check alignment, connections, sampling mode and card length; run a test pass.
Speeds are impossible or inconsistent	Card clips the gate or wrong card length entered	Realign the gate, secure the card vertically and remeasure the card length.
Repeated accelerations are widely scattered	Inconsistent release or apparatus movement	Use a release gate; mark positions; clamp the ramp; repeat the setting.
Acceleration appears smaller on a steeper ramp	Gate moved, angle measured wrongly, or one run anomalous	Check controls and raw data before accepting the result.
Hanging mass hits the floor	String too long or measurement region too long	Shorten the string, raise the bench pulley safely, or move the measurement interval.
Force-acceleration graph has a positive force intercept	Friction and pulley resistance must be overcome	Discuss the intercept rather than forcing the line through the origin.

Quick Examiner Tip
When results look unusual, check the release point, gate positions and raw speed readings before blaming the physics. Most poor data come from uncontrolled setup changes.

Common Exam Questions

1. Why must the trolley be released rather than pushed?
A push would add an uncontrolled force and change the initial velocity, reducing validity and reliability.

2. A trolley changes speed from 0.35 m/s to 0.95 m/s in 0.40 s. Calculate its acceleration.
$a = (0.95 - 0.35) / 0.40 = 1.5\ m/s^2$.

3. Why are light gates usually more accurate than a stopwatch?
They detect beam interruption electronically and remove human reaction time from the timing measurement.

4. Why are repeat readings important?
They reveal random variation, help identify anomalies, improve reliability and allow calculation of a mean.

5. What should be plotted to test the effect of ramp angle on acceleration?
Ramp angle on the x-axis and mean acceleration on the y-axis, with units.

6. How can force be increased while total mass stays constant in a trolley-pulley system?
Transfer masses from the trolley to the hanger. The driving weight increases but the same masses remain part of the moving system.

7. Why might a force-acceleration graph not pass through the origin?
Friction, pulley resistance and other systematic effects mean some force is needed before the system accelerates as predicted.

8. State one control variable in the ramp investigation.
Acceptable answers include trolley mass, release point, gate positions, ramp surface, card length or logger settings.

Advanced Evaluation Points (Grade 8–9)

Extension investigations

• How does acceleration vary with ramp angle rather than ramp height?
• Is acceleration proportional to sin(angle) for a trolley on a low-friction ramp?
• How does resultant force affect acceleration when total moving mass is constant?
• How does total mass affect acceleration when the driving force is constant?
• How does ramp surface or wheel condition affect acceleration?
• How closely do stopwatch, light-gate, motion-sensor and video-tracking methods agree?
• How does interrupt-card length affect the measured velocity at a light gate?

Force investigation - constant total mass

1. Set up a trolley on a level runway attached by string over a pulley to a mass hanger.
2. Place several slotted masses on the trolley and a small mass on the hanger.
3. Transfer one mass at a time from the trolley to the hanger. This increases the driving force while keeping total moving mass approximately constant.
4. Measure acceleration for each force using light gates. Repeat and calculate means.
5. Plot mean acceleration against driving force.

Mass investigation - constant force

1. Keep the hanging mass fixed so the driving force remains approximately constant.
2. Add measured masses to the trolley to increase total moving mass.
3. Measure, repeat and calculate mean acceleration for each total mass.
4. Plot acceleration against total mass, and optionally against 1 / total mass.

Important control
The hanger must not reach the floor and the trolley must not reach the buffer before the acceleration measurement is complete.

Advanced Evaluation Points (Grade 8–9)

1. Acceleration may not be perfectly uniform
Rolling resistance, small track irregularities and changing wheel friction can make acceleration vary during the run. A single value between two gates is an average over that interval.

2. Angle is more physically meaningful than height alone
For a ramp of fixed length, height determines angle. The ideal downhill component is mg sin(theta), so acceleration is expected to relate more directly to sin(theta) than to angle in degrees.

3. A light gate measures average speed over the card length
The recorded speed is card length divided by beam-blocking time. A shorter card gives a more local measurement but may make the percentage uncertainty in card length more important.

4. Repeats do not remove systematic error
A mean reduces the influence of random variation, but an incorrect card length or mis-calibrated inclinometer shifts every result. Calibration checks are therefore essential.

Useful higher-tier graph
For a fixed ramp length L, calculate sin(theta) = height / L. Plot mean acceleration against sin(theta). In an ideal low-friction model the relationship should be linear. A non-zero intercept or reduced gradient can be discussed in terms of resistance and measurement error.

Advanced Evaluation Points (Grade 8–9)

5. Use total moving mass correctly
In a trolley-pulley system, the accelerating mass includes the trolley, masses on the trolley, the hanger and the hanging masses. Omitting part of the system changes the interpretation of $F = ma$.

6. The driving force is only approximately the hanging weight
The hanging weight provides the driving force, but friction, pulley rotational inertia and unequal string tensions mean the resultant force on the whole system is smaller than the simple value $m_h g$.

7. Do not force a graph through the origin without justification
A best-fit line should represent the data. A force intercept can represent resistance that must be overcome before the ideal relationship is observed.

8. Compare model and evidence
Students should state the ideal prediction, identify where the data agree, quantify departures using gradients or intercepts, and explain plausible physical or measurement causes.

Grade 8-9: Thinking Like a Scientist
Scientists do not judge a motion model from one run. They define the system, control variables, inspect raw data, quantify uncertainty, repeat measurements, test alternative graphs and distinguish random variation from systematic effects before accepting a relationship.

Teacher / Technician Preparation Notes

Risk Assessment

Overall Risk Level: Low

This practical presents a low level of risk when standard laboratory procedures are followed. Schools should complete their own risk assessment in accordance with local procedures.

Hazard	Risk	Control Measures
Moving trolley	Impact with hands, equipment or floor	Use a buffer/catch tray; keep hands and faces clear; use modest ramp angles.
Raised ramp	Ramp slips or falls	Use stable blocks or a lab jack; add non-slip matting; clamp where appropriate.
Hanging masses	Masses fall onto feet or strike the floor	Use low masses, closed shoes, a short drop, secure slotted masses and keep feet clear.
Trailing leads and string	Trip or entanglement hazard	Route leads along the bench; keep aisles clear; use the shortest practical string.
Pulley and clamps	Pinch points or unstable fixing	Check clamps before use and keep fingers away from moving pulley parts.
Fast trolley	Trolley leaves track or damages gates	Limit ramp angle; centre the trolley; ensure card clears the gates; supervise test runs.
Electrical equipment	Damage from incorrect connections or falling apparatus	Use manufacturer-approved low-voltage interfaces and keep equipment away from bench edges.

Teacher / Technician Preparation Notes

Technician Tips for High Success Rates

- Select trolleys with straight, free-running wheels and label each trolley so groups keep the same one.
- Wipe the tracks and test every trolley on its assigned ramp before the lesson.
- Cut identical interrupt cards, measure their lengths and write the value clearly on each card.
- Charge or power all data loggers and verify the light-gate mode with a test run.
- Pre-mark suggested release and gate positions on the ramps using removable tape.
- Provide stable ramp supports at several known heights.
- Prepare foam buffers or trays so trolleys cannot roll off the bench.
- Sort slotted masses into labelled sets and check that hangers are secure.
- Cut string to a length that keeps the hanger above the floor throughout the measurement interval.
- Provide spare leads, cards, string, stopwatches and one replacement trolley per class.
- Keep an example data set available in case one group experiences equipment failure.
- If groups share loggers, stagger the practical so setup time is used productively.

Pre-lesson trial
Run the practical at the minimum and maximum planned ramp settings. Check that the trolley passes both gates, stops safely, and produces acceleration values within the logger range.

Teacher / Technician Preparation Notes

Before the Lesson

- Assemble and test one complete demonstration setup.
- Check ramp stability, trolley condition and safe stopping arrangements.
- Measure and label every interrupt card.
- Confirm light-gate/data-logger settings and reset procedures.
- Prepare student results tables and graph axes guidance.
- Mark release and gate positions or provide measuring instructions.
- Set out eye protection and mass sets if the pulley extension will be used.
- Prepare a clear risk briefing and identify where trolleys will be caught.

Teacher Demonstration Point

Before students start, demonstrate:
1. how to secure the ramp and place a buffer at the lower end
2. how to attach and measure the interrupt card
3. how to align the card with both light gates
4. how to mark and keep a fixed release position
5. how to release the trolley without a push
6. how to read u, v and t from the logger and calculate acceleration
7. how to record repeats, calculate a mean and identify an anomaly
8. how to transfer masses between trolley and hanger to vary force at constant total mass
9. how to ensure the hanger does not hit the floor during the measurement interval.

Key explanation
Ask students what the logger measures directly and what it calculates. This prevents the common mistake of treating a displayed acceleration value as unexplained “magic”.

Teacher / Technician Preparation Notes

Suggested Lesson Timing

Core Ramp Investigation - 60 minutes

Activity	Time
Introduction and theory	10 min
Safety briefing and demonstration	7 min
Apparatus setup and test run	10 min
Data collection at five settings	20 min
Calculations and graph start	8 min
Plenary and equipment check-in	5 min

Force / Mass Extension - 50 to 60 minutes

Activity	Time
Modify setup and review controls	10 min
Force investigation data collection	20 min
Mass investigation or data-set analysis	15 min
Graphing and evaluation	15 min

Teacher Assessment Opportunities

Observe whether students:

- Can students identify the independent, dependent and control variables?
- Do students secure the ramp and use a safe stopping method?
- Can students align and configure light gates independently?
- Do students release the trolley without a push?
- Can students calculate acceleration with correct units?
- Do students repeat readings and investigate anomalies?
- Can students select suitable graph axes and scales?
- Can students link the trend to resultant force and F = ma?
- Can students distinguish reliability, validity and accuracy?

Suggested Plenary

Plenary Question	Expected Answer
Why does a steeper ramp usually produce a larger acceleration?	The component of weight down the ramp is larger, so the resultant force is larger. For the same trolley mass, a larger resultant force gives a larger acceleration.
Why must the release point stay fixed?	Changing it changes the speed at gate 1 and introduces another variable.
What does the gradient of a velocity-time graph represent?	Acceleration.
How can force be varied while total moving mass stays constant?	Transfer masses from the trolley to the hanger.
Why might a force-acceleration graph not pass through the origin?	Friction and pulley resistance mean some driving force is used to overcome resistance.
What is one reason light gates improve accuracy?	They remove human reaction time from the timing measurement.

Examiner Advice Summary

- Define acceleration as change in velocity divided by time and use m/s^2.
- State clearly what is changed, what is measured and what is controlled.
- Release the trolley without a push and keep release/gate positions fixed.
- Use repeats, calculate a mean and identify anomalous readings.
- Put the independent variable on the x-axis and include units.
- Explain the trend using resultant force and $F = ma$.
- For force/mass work, use total moving mass and state how force is kept constant or varied.
- Do not claim direct proportionality unless the graph supports it.