Core practical 9: Investigate the relationship between the force exerted on an object and its change of momentum

Objective

- To determine the momentum change of a trolley when a force acts on it, as a function of time

Safety	Specification links
• There are trolleys and masses in motion so students should produce a risk assessment for this work.	• Practical techniques 1, 2, 3, 4 • CPAC 2c, 3a, 4b

Procedure

1. Secure the bench pulley to one end of the runway. This end of the runway should project over the end of a bench, so that the string connecting the mass hanger and the trolley passes over the pulley. The mass hanger will fall to the floor as the trolley moves along the runway. The runway should be tilted to compensate for friction.
2. Place the slotted mass hanger on the floor and move the trolley backwards along the runway until the string becomes tight, with the mass on the floor. Place the light gate so it is positioned in the middle of the interrupt card on the trolley. There should be enough space on the ramp to allow the trolley to continue so that it clears the light gate before hitting the pulley.
3. Move the trolley further backwards until the mass hanger is touching the pulley. Put the five 10 g masses on the trolley so that they will not slide off. This is the start position for the experiment.
4. Record the total hanging mass m. Release the trolley and use the stop clock to measure the time T it takes for the trolley to move from the start position to the light gate – this should be when the mass hanger hits the floor. Record the time reading t on the light gate. Repeat your measurements twice more and calculate mean values for T and t and estimate δT and δt, the uncertainties in these values.
5. Move one 10 g mass from the trolley to the hanger and repeat step 4. Repeat this process, moving one 10 g mass at a time and recording your readings until all of the masses are on the hanger.
6. Measure the combined mass M of the trolley, string, slotted masses and hanger. Measure the distance d travelled by the trolley. This should be the same as the distance fallen by the mass hanger. Record the length L of the card.
7. You can develop the investigation further by taking more readings after adding an additional mass, for example 200 g, to the mass of the trolley.

Notes on procedure

- As the title suggests, this is an investigation. You will probably do this early in the year so students are likely to need some help recalling what they did in Year 12 and developing their own way of conducting an investigation. Some students will need more training but you might find that some are ready for assessment. To make this an investigation, students being assessed for CPAC 2c should draw attention to the control of variables not under investigation at that stage.
- This work can be carried out using an air track or dynamics trolleys. It may be interesting to have some students use different methods, so that they can compare outcomes. It is more appropriate for an investigation if the students write a plan, as they can then choose methods and apparatus.
- This is a good experiment in which to use uncertainties in support of the conclusion. This involves drawing error bars on the graph and two further lines of fit. These are then used to calculate the uncertainty in the gradient value.
- This experiment has been designed to use the minimum of apparatus. You can make the following amendments to the design:
  - Use two light gates and measure two velocities.
  - Use two light gates, one to measure the two times and one the time elapsed travelling from one gate to the other.
  - Use a linear air track.

Answers to questions

1. Use the gradients of the lines of fit and calculate the difference between them. Divide the difference by the gradient of the line of best fit and express the answer as a percentage. The computed value for $\frac{M}{g}$ should lie within the uncertainty.
2. Friction will oppose the motion with the result that the force acting will be reduced, and so the velocity at the light gate will be reduced. This will make the gradient smaller.
3. By using the air track, where there is no contact but considerable air resistance. Or, trolleys can be friction compensated by giving them a downward slope. The slope should be adjusted so that the trolley, when pushed, runs at a constant speed. The success can be judged in part by the percentage uncertainty in Q1.
4. Students should consider how to use the centre's apparatus more effectively. For example, they could discuss the use of a datalogger and multiple light gates.
5. Students may consider the kinetic energy and calculate the transfer from gravitational potential energy as the mass falls.

Sample data

Mass of trolley, all masses (constant total), string etc. = 0.717 kg

m/kg	T/s	v/m s^{-1}	mT/kg s
0.010	3.80	0.340	0.0380
0.015	2.90	0.455	0.0435
0.020	2.44	0.532	0.0488
0.025	2.17	0.579	0.0543
0.030	1.98	0.644	0.0594
0.035	1.79	0.704	0.0627

The graph of mT against v gives a gradient of 0.0713

Calculated value of $\frac{M}{g}$ = 0.0731

% difference = 2.5%

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All the maths you need

- Recognise and make use of appropriate units in calculations.
- Use ratios, fractions and percentages.
- Use an appropriate number of significant figures.
- Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers.
- Translate information between graphical, numerical and algebraic forms.
- Plot two variables from experimental or other data.
- Understand that $y = mx + c$ represents a linear relationship.
- Determine the slope and intercept of a linear graph.

Useful equations:

- $F\,\Delta t = m\,\Delta v$ shows the impulse of a force is equal to the change in momentum.
- $y = mx + c$ shows why the intercept should be zero.

Equipment

- dynamics trolley or air track vehicle
- runway or air track
- bench pulley
- string
- 5 slotted masses (10 g) and hanger
- light gate and recorder
- stop clock
- metre ruler

Procedure

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Analysis of results

1. The force acting on the trolley is mg and this acts for a time T. The momentum of the trolley increases from zero to Mv where v is velocity of the trolley as it passes through the light gate.
2. Theory suggests that $mgT = Mv$.
3. Calculate $v = \frac{L}{t}$ and plot a graph of mT against v for a straight line that passes through the origin. Measure the gradient and compare it with your value for M/g.
4. You can take the uncertainty in T and t as half the range of repeated readings. You need not do it for each value of T and t, but take typical values, neither the largest nor the smallest.

   Calculate δv, the actual uncertainty in v, from the equation $\delta v = v\left(\frac{\delta t}{t}\right)$, using a mid-range value for v. Calculate $\delta(mT)$ by multiplying a mid-range value for m (for example, 30 g) and δT. Use these actual uncertainties to draw error bars in both directions to form error boxes. Draw a line steeper than the line of best fit (LoBF) and one less steep than the LoBF. Both of these lines should pass through the error boxes. The difference between the two gradients of the lines gives you the uncertainty in your gradient and this uncertainty is based on your readings. Your value for M/g should lie between these two values if Newton's second law is operating.

Learning tip

- Use an A4 sheet of graph paper, and make sure the scale you choose stretches your plots over the whole page – you need not include the origin. This will make it easier to draw the last two gradient lines.

Questions
1. Calculate the percentage uncertainty in your value for the gradient and comment on the validity of your result.
2. Explain what effect friction will have on your result.
3. Describe how you reduced the effect of friction in your experiment and use your result to comment on the success of your method.
4. Explain how you might develop the use of ICT in this experiment.
5. Describe how you might use your readings to investigate the law of conservation of energy.

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Equipment per student/group	**Notes on equipment**
dynamics trolley or air track vehicle	Vehicle must be fitted with interrupt card with card length written on the card. A length of 0.100 m is suitable.
runway or air track	A runway should be friction compensated.
bench pulley	
string	Sufficient string is needed to allow the slotted mass to fall to the floor and pull the trolley through the light gate.
5 slotted masses (10 g) and hanger	
light gate and recorder	The recorder might have two inputs. The light gate will require support from a retort stand.
stop clock	Resolution of at least 0.1 s
metre ruler	
Notes	