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 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.

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.