Work and Kinetic Energy: Impulse and Momentum

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Demonstrations

A five kilogram bottle of water rests on a free-running cart. When the water bottle is pulled for a short time by hand with a force probe the cart and bottle accelerate and then roll across a level floor. (The bottle could be *pushed* with the force probe but it is then difficult to maintain the alignment of the probe). A trailing weight adds friction.

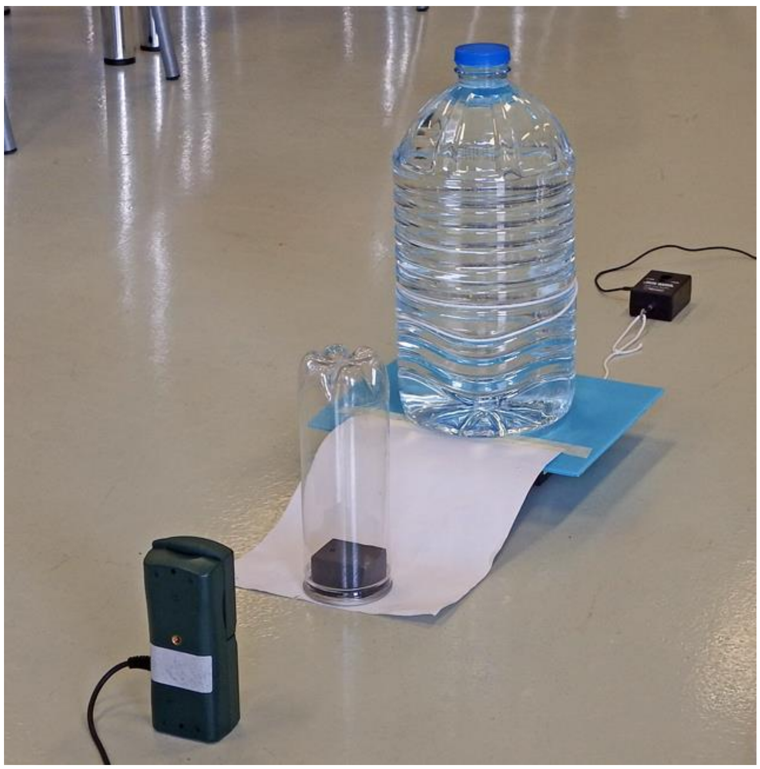


Fig 1 - water-bottle, cart, string, force probe and brake. The plastic container over the weight acts as an ultrasound reflector.

The displacement of the cart is recorded as a function of time with the motion detector.

The total moving mass was 7.5 kg. The mass of the steel block resting on the paper was 0.52 kg. Three graphs were plotted. Velocity/time, applied-force/time, and applied-force/position.

The velocity-time graph was **autoscaled** and the region of interest positioned on the graph by entering the scale end-points manually.

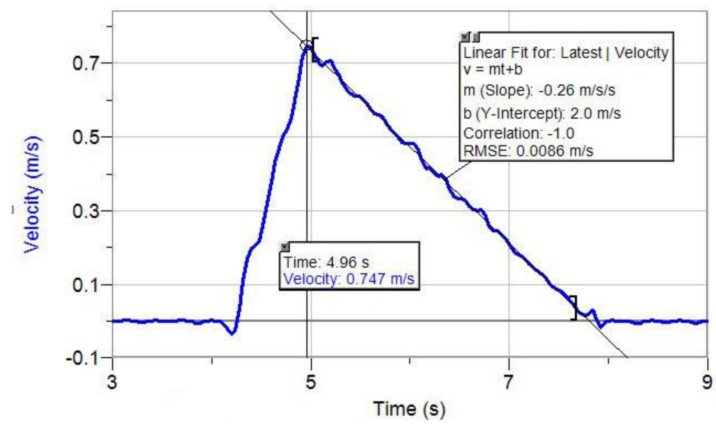


Fig 2 - The velocity of the cart as a function of time.

The line fit shows that the acceleration across the floor is constant at -0.26 m/s^2.
Since $f = ma$ and the acceleration is constant the retarding force due to friction is -1.88 N.
The maximum velocity, required for calculating the maximum KE, was 0.75 m/s.

Work and energy

The bottle and cart and trailing weight are accelerated by applying a force that acts through a distance. The accelerating force is the *net-force*": the applied force measured with the force probe, less the friction force which has been found above.

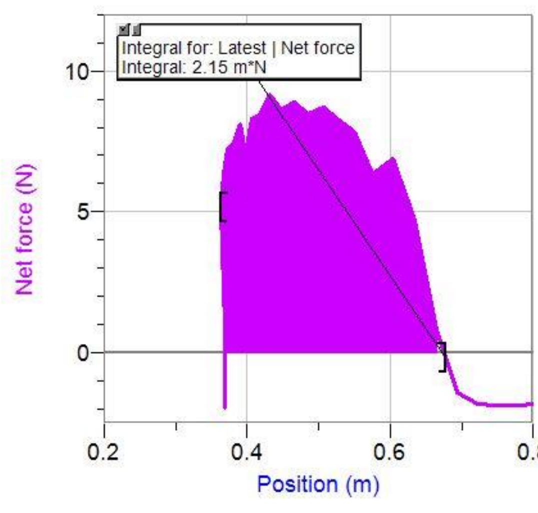


Fig 3 – the net force applied to the cart as a function of position.

In figure 3 the force probe was recalibrated to show the integral of the *net-force* w.r.t. displacement in a *New Calculated Column* in Logger pro.

Analysis

From Fig 3 work done by the accelerating force was = 2.15 J.
The kinetic energy gained, $\frac{1}{2}mv_{max}^2 = 0.5 \times 7.5 \times 0.75^2 = 2.11$ J.

Since the values are accurate to no better than ±2% the agreement between the force/displacement integral and the KE is not expected to be better than ±6%. Within errors the two values are the same (as expected).

Momentum and impulse

Net-force, as a function of time is plotted in figure 4 below.

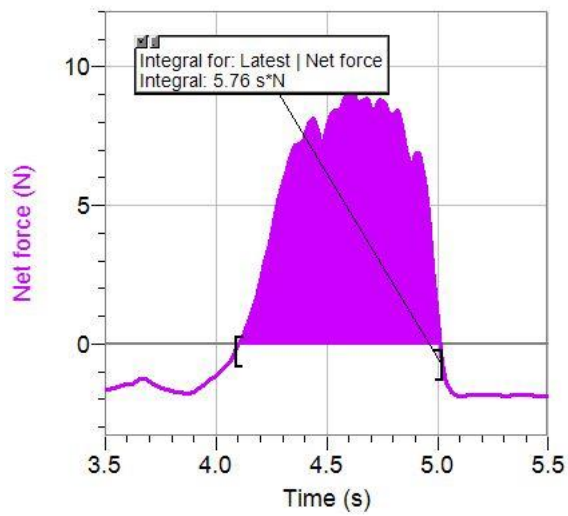


Fig 4 – net force applied to the cart as a function of time.

In figure 4 the force probe has been recalibrated to show the integral of the *net-force* w.r.t. time in a *New Calculated Column* in Logger pro.

Analysis

Impulse applied by the net accelerating force was 5.76 N s
The momentum gained … $mv_{max} = 7.5 \times 0.75 = 5.63$ kg m/s

Since the values are accurate to no better than ±2% the agreement between the force/displacement integral and the KE is not expected to be better than ±4%. Within errors the two values are the same (as expected).

Questions

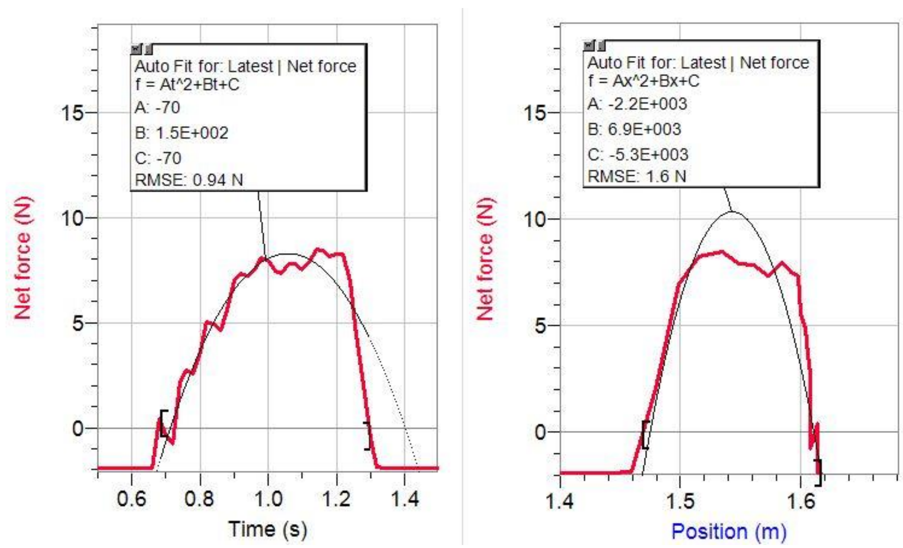
1 The trailing block had a mass of 0.52 kg.

a Find the coefficient of friction between the paper and the floor.

b What evidence do you see that this coefficient is independent of velocity?

c What happens to the "wasted" work done against friction?

2 An integration can be done analytically if relationships are approximated by known curves. The graphs below show parabola fits to work and impulse graphs in a similar situation.



Estimate the definite integrals analytically using the curves. *Can you suggest a less complicated method of estimating the size of these integrals*?

3 Scientists seek to reduce errors and improve the reliability of measurements by:-

i Repeating independent measurements several times and averaging the numerical results. (This approach reduces random errors but does not address systematic errors due to unknown constant factors that have the same effect on all measurements.)

ii Redesigning measurements in some way to make greater accuracy possible with reduced random and systematic errors.

How would you suggest improving the accuracy of measurements made here by an order of magnitude?