PhysicsFactsheet

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Practical Investigation of Conservation of Momentum

Introduction

Momentum is a topic which many pupils find a little confusing, but the basic ideas are not too difficult to grasp. This Factsheet aims to approach the topic of Conservation of Momentum using practical investigation and examples of calculation.

Basic Ideas

1. **Momentum** for an object of mass M travelling at velocity v, is defined as **Mv.**
2. **Momentum** is a **vector** – the direction matters and momenta must be added **vectorially**. For collisions in the same straight line, for instance right as positive and left as negative.
3. **Principle of Conservation of Momentum:** In an event, ***providing there are no external forces acting,*** the **total** momentum is conserved. In practice, there usually are external forces acting, e.g. friction, but these are ignored for the purposes of calculation at A Level.
4. Note that it is only the **total momentum** which is conserved. **During** the collision, there will be forces acting on each of the vehicles in the collision and that will change the individual momenta of the vehicles.
5. The force occurring during the collision is given by the rate of change of momentum of that object.

> ***Exam Hint:*** *Some pupils lose marks by being too superficial when asked to quote the Principle of Conservation of Momentum. For example, not referring to the point that there must be no external forces acting and/or not stating TOTAL momentum.*

> ***Exam Hint:*** *For A Level you will only be asked to do calculations on collisions in the same straight line.*

Practical arrangements

There are several different arrangements for practical investigations of the Principle of Conservation of Momentum, but all have in common:

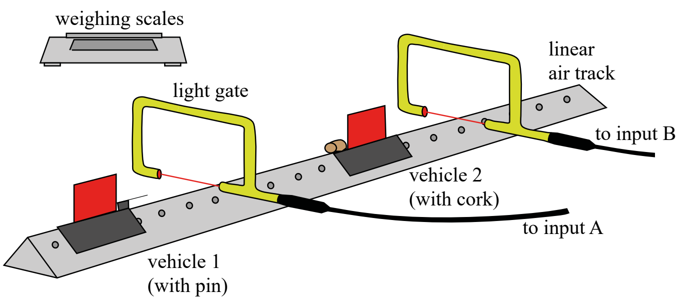
(a) the attempt to reduce or compensate for any external forces acting, e.g. friction, air resistance.

(b) some mechanism for measuring the speeds before and after a collision or separation event.

> *Any attempt to investigate the Law of Conservation of Momentum must aim to reduce or compensate for the effect of external forces such as friction.*

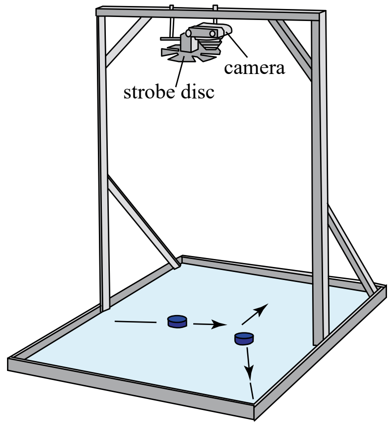
1. Reducing friction

(a) An air track.



Air blown continuously through the holes in the track reduces friction dramatically. The light gates are connected to software to calculate the speeds of the gliders.

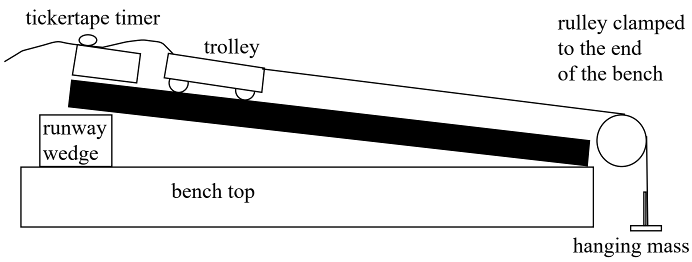
(a) Carbon Dioxide pucks on a glass plate.



The carbon dioxide being emitted from the pucks reduces the friction of the glass plate.

The camera gives pictures of the positions of the pucks before and after a collision and knowing the strobe-rate allows the speeds to be calculated.

2. Compensating for friction



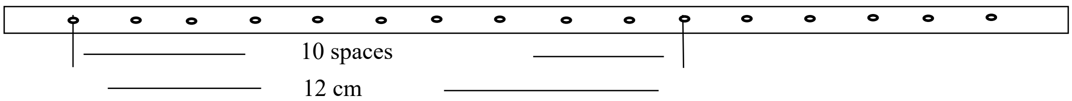
By trial and error, the height of the slope is adjusted until a trolley, started by a gentle push, will then travel at steady speed. The ticker-timer allows the speed to be checked. Thus the component of weight down the slope is just compensating for friction up the slope. Experiments carried out on the slope are effectively free of friction.

Test your understanding

1. (a) Describe a practical arrangement which could be used to investigate the Law of Conservation of Momentum.
   (b) Outline how the apparatus reduces or compensates for friction.
   (c) Explain why it is important to do this.
   (d) Explain how the apparatus allows for the speeds of the incoming and outgoing elements of the collision to be calculated.
   {e) Momentum is a vector quantity. Explain why it is acceptable, here, to talk in terms of speeds and not velocities.

Test your understanding

2. Pupils use an air-track and light-gates to investigate conservation of momentum.
   a) The light-gates record the time taken for the card to pass through the gate. Explain how the speed can be derived from this.
   b) A 5cm card passing through the light-gate records 0.6s. What is the speed in cms^{-1}?
3. Pupils use a friction-compensated slope and ticker-timer to investigate conservation of momentum.
   (a) What will the ticker-timer trace look like if the trolley is travelling at steady speed?
   (b) The ticker-time puts a dot every 1/50 s. What is the speed if a "ten-tick" (ten gaps) is 12cm long?



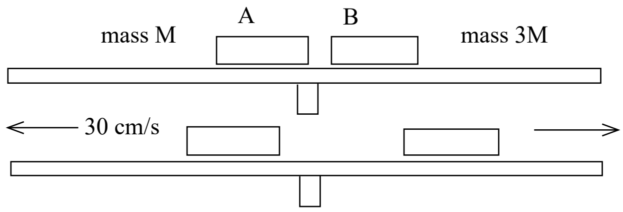
Some Investigations

Explosions

One option is to begin with the two vehicles joined together on the air-track and use a spring mechanism to separate them. The light-gates can be used to determine the speeds. Since the total momentum before the event is zero, the vehicles must go in different directions, which avoids the complication of needing to reset the light-gates between each vehicle´s passing.

Worked example

Pupils use an air-track and light-gates to investigate conservation of momentum. They begin with two stationary vehicles joined together, and then spring-release them.



(a) Explain why the vehicles must go in opposite directions.
(b) Vehicle A has a mass of M, and vehicle B a mass of 3M. When separated by the 'explosion', A goes left with a speed of $30cms^{-1}$. At what speed will B go right, if total momentum is conserved?
c) If M is actually 1kg and the collision took 0.01s, what was the force exerted on A during the collision?

Answers

(a) Total momentum is conserved, and since it was zero before the explosion, some must be positive and some negative after the collision – momentum is a vector quantity so if right is taken as positive, then left is negative.
(b) Vehicle A´s momentum after the event is $-30Mcm^{-1}$, so Vehicle B will move at $10cms^{-1}$, so that its momentum is $30M\ cms^{-1}$
(c) A´s momentum has gone from zero to $-30kg\ cms^{-1}$. $= 30/100\ kg\ ms^{-1}$ in 0.01s
Since Force = rate of change of momentum, the Force = $30/100 \times 0.01 = 30N$

Inelastic collisions

On the air-track or friction compensated slope, it is possible to make the vehicles stick together in the collision (note the spike and cork in the diagram of the air-track). This is called an **"inelastic"** collision. **Total energy** is conserved, but **total Kinetic Energy** is not. Thus a convenient arrangement is to have vehicle 2 initially stationary, and vehicle 1 given a push towards 2. Light-gate 1 records the initial speed of vehicle 1 and light-gate 2 records the speed of the outgoing combined vehicle 1+2. Again, this avoids the complication of having to have the light gates reset between the passage of one vehicle and the next.

(i) Let vehicles 1 and 2 have the same mass M.
(ii) Let vehicle 1 have mass M and vehicle 2 a mass of 2M.
(iii)Let vehicle 1 have a mass of 2M and vehicle 2 a mass of M.
(iv)Repeat with as many different values of mass as possible.
(v) Calculate the total momentum (mass x velocity) before and after the collision and show that in each case they are the same.
Record results in a table:

Before				**After**			
Time/s	**Speed/ cms^{-1}**	**Mass/kg**	**Momentum/ $kgcms^{-1}$**	**Time/ s**	**Speed/cms^{-1}**	**Mass/ kg**	**Momentum/ $kgcms^{-1}$**

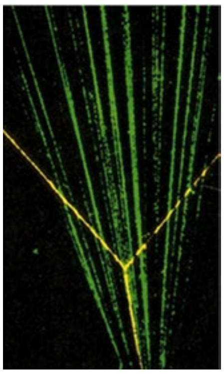
Elastic collisions

It is possible to do a series of investigations using different mass vehicles that do not stick together on impact. However, this is more complicated from a practical point of view, because, with the possibility of the two vehicles travelling in the same direction after the collision, it would need the light-gate to be able to be reset between the first vehicle going through it and the second. Also, if the first vehicle rebounded, then the first light-gate would need to be able to be reset.

However, a particular example is worth investigating.

Test your understanding

4. An air-track is used with two sliders of the same mass m. Vehicle 2 is stationary, vehicle 1 is sent towards it with speed v. After the collision, assume vehicle 2 goes off with speed v_2 and vehicle 1 continues with a speed v_1.
(a) Write the equation for conservation of momentum for this event.
(b) Write the equation for conservation of kinetic energy.
(c) Show that these two equations can be satisfied, in the same straight line, ONLY if $v_1 = 0$ and $v_2 = v$.
5. In a cloud chamber (used for detecting collisions between particles) an alpha particle enters helium gas and collides with a helium nucleus. The picture below is obtained and shows that the two particles go off at right angles to each other.



Explain how this shows that an alpha particle is a helium nucleus (hint: think about conservation of momentum and conservation of KE and remember that they are vectors.)

Vehicles of the same mass. Vehicle 2 stationary, vehicle 1 sent towards it with speed v.

If this investigation is carried out, it is found that vehicle 1 comes to a stop and vehicle 2 moves at the same speed that vehicle 1 approached.

Test your understanding:

6.. The picture shows two ice-skaters gliding across the ice. One skater then pushes the other and they separate, travelling in the same straight line.
(a) State why it is reasonable to assert that total momentum is conserved in this event.

(b) The heavier skater has a mass of 80kg and the lighter one 50kg and they are initially skating together at $4ms^{-1}$. What is the total momentum before they separate?
(c) The lighter skater then continues with a speed of $5ms^{-1}$. What speed will the heavier skater have?
(d) If the separation occurred in 1.5s, what will have been the force exerted on the lighter skater by the heavier skater?
(e) Without doing any more calculation, how can you demonstrate that Newton´s Third Law holds in this example?

Answers to "Test your understanding"

1. (a), (b), and (d): See text.
   (c) Conservation of momentum holds only if there are no external forces acting.
   (e) Since the movements are all in the same straight line the velocities are the same as the speeds except + or -.

2. (a) The card is of known length (say 5cm) so the light-gate records the time taken for the vehicle to travel 5cm, allowing the speed to be calculated.
   (b) 5cm in 0.6s, gives 5/0.6 = $8.3cms^{-1}$
3. (a) For steady speed the trace will be equally spaced dots.
   (b) Since the dots are every 1/50s a "ten-tick" represents 1/5 s. So 12cm in 1/5 s gives 60cm in 1s. $60cms^{-1}$.

4. (a) $mv = mv_1 + mv_2$
   (b) $\frac{1}{2} mv^2 = \frac{1}{2} mv_1^2 + \frac{1}{2}mv_2^2$
   (c) From a) $v = v_1 + v_2$, so substituting in b) gives:
   $(v_1 + v_2)^2 = v_1^2 + v_2^2$
   $v_1^2 + 2v_1v_2 + v_2^2 = v_1^2 + v_2^2$
   So $v_1v_2 = 0$,

v_2 cannot be 0 unless v_1 is also 0 (or vehicle 1 would overtake vehicle 2) and they cannot both be 0 if momentum is conserved,
so v_1 is 0 and $v_2 = v$

5. The vector triangle for the momenta before and after the event form a right-angled triangle, thus the magnitudes of the vectors follow Pythagoras. This can only happen if the mass cancels out, leaving:
$\overline{v} = \overline{v_a} + \overline{v_{He}}$
$v^2 = v_a^2 + v_{He}^2$

6. (a) It is reasonable to state that total momentum is conserved because the ice gives very low friction.
   (b) Total momentum = $(80 + 50) \times 4 = 520kgms^{-1}$
   (c) Let the speed of the heavier skater be v after the event.
   Momentum after the event = $80v + 50 \times 5$
   So $80v + 250 = 520$
   $v = 270/80 = 3.4ms^{-1}$
   (d) Increase in momentum for lighter skater
   $= 50 \times 5 - 50 \times 4 = 50kgms^{-1}$ and this occurred in 1.5s, so rate of change = 50/1.5 = $33.3kgms^{-2}$, so force = 33.3N
   (e) Since total momentum is conserved, the gain in momentum of the lighter skater must be balanced by an equal loss of momentum of the heavier skater, and since the change for each of them occurs in the same time, the rates of change must be the same. Therefore, the forces are equal and opposite.

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