

Description



The TimingPro™ Dynamics Cars and accessories are innovative tools for experimental studies involving the principles of motion in dynamics, momentum and energy, on level, inclined and curved tracks.

The Primary Car has built-in encoding and timing, with wireless transmission to a Windows PC.

Use the Primary Car alone to study motion on inclined and curved tracks.

The Primary Car receives motion data from the Secondary Car via IR. The cars can be used together on a linear track to capture data from a variety of collision experiments.

TimingPro™ software receives the data and has a range of tools for graphical display and data analysis.



TimingPro™ Dynamics Cars with accessories



The cars have spring loaded, low friction wheels.

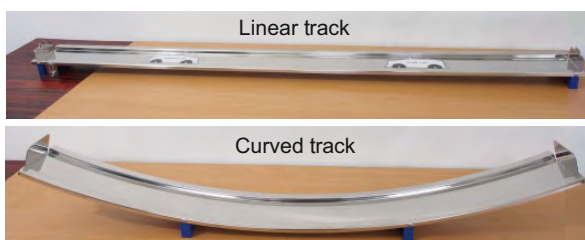
Up to four 150 g masses can be fitted to the pegs on top of either car.



Magnets on the front and back of each car provide attachment for accessories.



The pulley and large hooks attach to the endplates of the linear track.



INDOSAW

Primary Dynamics Car



The Primary Dynamics Car is marked with a red letter **P** on the top label and has a serial number on the base, in the format **Tcar_yy_nnnn**.
The Secondary Car is marked with a blue letter **S**.
These colours are also used to identify the Table headings and Graphs in the TimingPro™ software **.

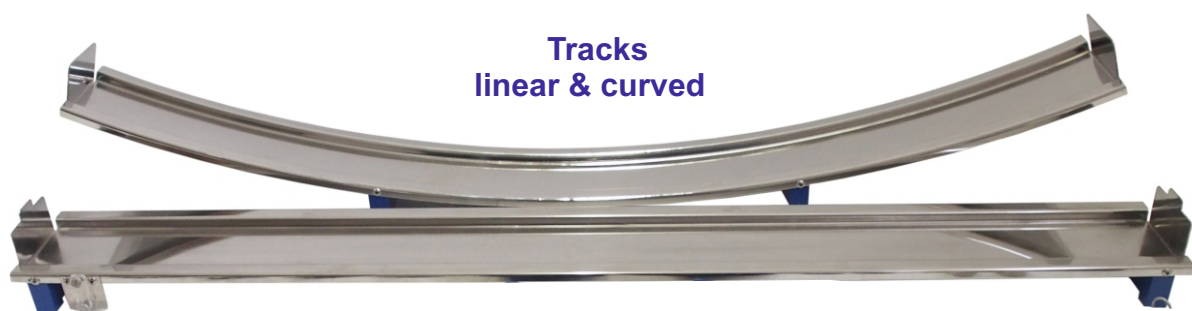


Both cars should be fully charged (about 8 hours) using the 9 V plugtop charger supplied, before attempting to use them in experiments.

If an extra charger is used, it must provide 9 V dc at 1.5 A (minimum) with the correct plug (ext 5.5 mm x 2.1 mm int) to fit the car sockets.

** TimingPro software can be downloaded using the link
<https://www.inspirephysics.com/downloads/>
then click on INSPIRE TIMING-PRO BLUETOOTH DYNAMICS CAR SI1047.
The software is downloaded as a .zip folder.

Track accessories



Tracks
linear & curved

Track accessories

Large hook attachments
(2) slot on to the endplates
of the track



The large hooks and pulley
have integral magnets for
attachment of bumpers



Pulley attachment (1) slots on
to either endplate of the track



Track support (1)
block for inclination
of the linear track

Masses

Additional 150 g
masses (4) for cars



Slotted masses
and hanger (100 g)



Bumper attachments

Small hooks (2)
attach to the cars



Velcro inelastic
bumpers (2)

Elastic bumpers (6)



Large rectangular
bumper attachment (1)



Explosion
bumper (1)

Miscellaneous accessories



Hammer



Elastic string and
elastic bands



Double-sided
adhesive tape



Thread

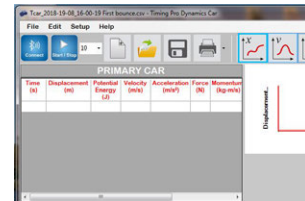
First time Bluetooth pairing



Switch on the Primary Dynamics Car.
The switch is on the bottom of the car.

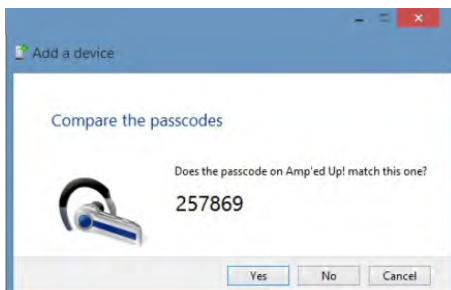


Launch the TimingPro™ application.



1. Click on Connect. Then click on Pair New Device.
A list of available Bluetooth devices will be displayed.
 - The name of the Dynamics Car will appear in this format: **TCar_yy_nnnn**
 - If the name of the car does not appear you may need to click on "Search again" to refresh the list.
2. Select the Dynamics Car.
Click OK.

The car is only identified as a "Bluetooth headset" when it is first paired. Subsequently, it is identified by its serial number



A Bluetooth pairing request will appear with a pairing code. Just click on the Yes button.

or

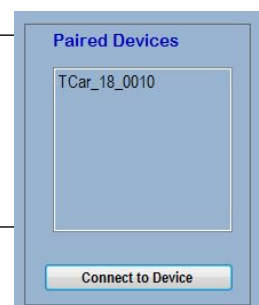


Alternatively you may need to enter 1234 as the pairing code.
Click on the Next button.

The Dynamics Car will be paired. Whether you are using one or both cars, data collection begins when you click on the Start/Stop button.



After pairing a Dynamics Car, you can perform your experiments.
If a car has been paired with a computer, you don't need to pair it again.
Next time it is used, just click on the Connect button, select the car and click on Connect to Device.



TimingPro™ software overview



The software is designed to collect data from any paired and connected Primary Dynamics Car. The screen is divided into the following areas, which are explained below.

Menu bar

File Edit Setup Help

Icon bar

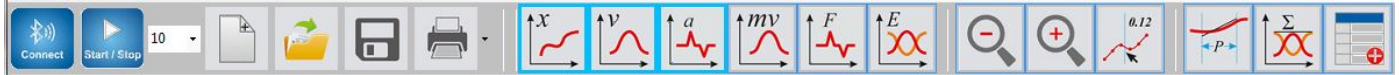
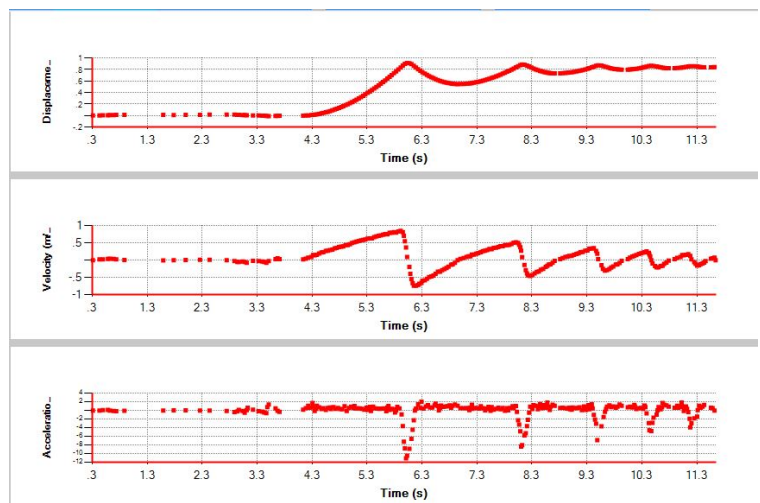


Table area with side bars

PRIMARY CAR					
Time (s)	Displacement (m)	Velocity (m/s)	Acceleration (m/s²)	Car Mass (kg)	Momentum (kg.m/s)
0.7342	-0.002	0	0		
0.8459	-0.004	-0.0289	0	0.6	-0.0173
0.896	-0.006	-0.0369	-0.1427	0.6	-0.0222
0.9549	-0.008	-0.0443	-0.0464	0.6	-0.0266
0.9915	-0.01	-0.0431	0.0875	0.6	-0.0259
1.0548	-0.012	-0.0341	0.202	0.6	-0.0205
1.1094	-0.014	-0.0198	0.1523	0.6	-0.0119
1.7627	-0.016	0.0081	0.0184	0.6	0.0049
1.866	-0.014	0.0075	-0.0478	0.6	0.0045

SECONDARY CAR					
Time (s)	Displacement (m)	Velocity (m/s)	Acceleration (m/s²)	Car Mass (kg)	Momentum (kg.m/s)

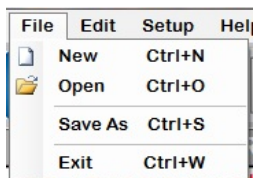
Graph area



Status bar

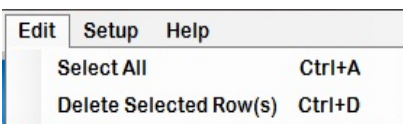
Track : Linear Type Track Angle 0° Primary Car Mass 0.600 kg Secondary Car Mass 0.600 kg

The **Menu bar** includes:



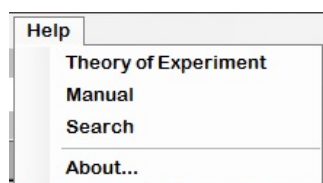
initialises the Table and Graph areas ready for a new experiment
gives a list of files which can be opened
saves the current experiment with a new name
exits TimingPro software

Edit operates on the data in the Table area.



selects all the data in the Primary or Secondary table
deletes any or all selected rows of data

Setup is described on the next page.



Opens a page explaining the current experiment
Opens the Dynamics Car manual
Not implemented
Reveals the software version date

Setup menu



To interpret the data received, TimingPro software needs to know the experimental conditions. The Setup menu options are illustrated below, with the default conditions and values:

☐ Curved Track
☒ Linear Track
☐ No Track

Select the track on which the cars will move. Default is Linear Track. "No Track" should be selected when the cars are used on a bench top or custom made track.

0.600

The default mass of the car is 0.600 kg. If you are using additional masses, the total mass should be entered here. You should also include the mass of any bumper attachments for accurate work.

1.390

1.39 is the default for the curved track. Enter the true radius (in metres) if a different curved track is used.

Setup Help

Select Track

Mass of Primary Car (kg)

Mass of Secondary Car (kg)

Curved Track Radius (m)

Linear Track Angle (Degree)

Wheel Diameter of Primary Car (mm)

Wheel Diameter of Secondary Car (mm)

43.20

When cars are used on the linear and curved tracks, the effective wheel diameter is 43.2 mm. When "No Track" is selected the correct wheel diameter is 45.8 mm.

0

The default angle is 0° for a horizontal linear track. Enter the appropriate angle for an inclined track.



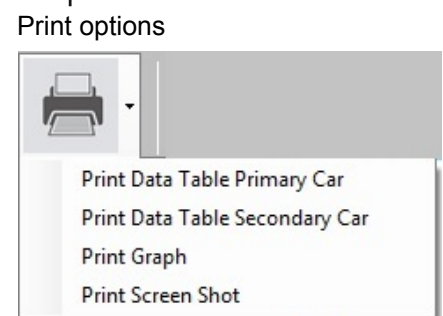
To reduce friction, the car wheels run between the sloping sides of the track.

Icon bar

The Icon bar is in three sections, with functions detailed below:

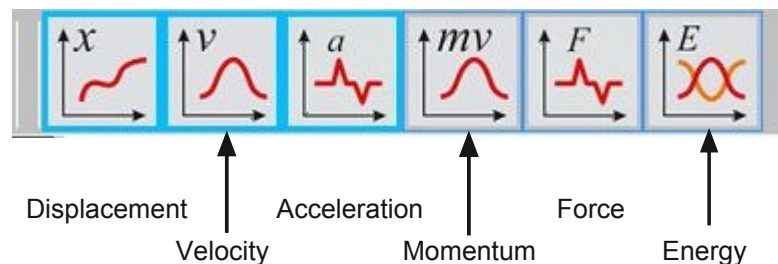


When Start is clicked, the icon changes to Stop for the chosen data collection time. The Primary car's indicators flash once, data collection begins and graphs are plotted in real time. At the end of the chosen time, the icon reverts to Start/Stop. Data collection can be stopped by clicking on Stop. During data collection, the car's blue LEDs are steady, instead of flashing.



Graph selection icons

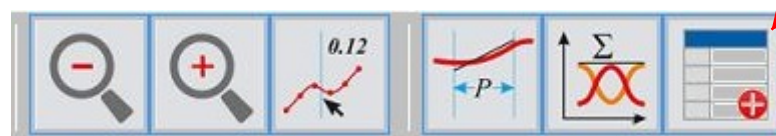
Clicking on any icon, either adds that graph to the display if it is not already shown, or removes that graph from the Graph area.



Graph tools

These tools operate on any displayed graph.

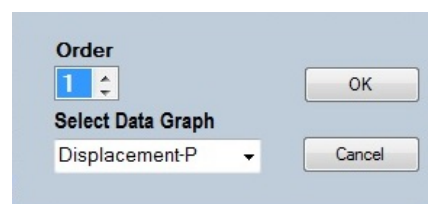
To Zoom in, click on the icon, then click, drag and release to highlight a section of a graph. All active graphs are zoomed in over the same range. To Zoom out, click on the icon. The full period of the experiment is displayed once more.



Cursor
Click on the icon to display the cursor. Move the cursor within the displayed graphs to highlight corresponding rows in the Primary and Secondary data tables, and to display the individual values at the cursor's location.

Polynomial Fit
Click on the icon, then click, drag and release to select a region of a graph. A pop-up window asks for the order of equation, and whether to use Primary or Secondary data.

Summation
Click on the icon to plot an extra line in the momentum and energy graphs, indicating the total momentum and energy for the cars. Click on the icon again and the line is removed.



Order of equation:
1 = linear x^1
2 = quadratic x^2
3 = cubic x^3

The Dynamics Cars, together with the linear track, curved track and accessories provide support for a wide range of experiments in dynamics, momentum and energy, including simple harmonic motion.

Specific practical activities and syllabus references are given below:

EDEXCEL Core practical 9: Investigate the relationship between the force exerted on an object and its change of momentum (Newton's second law).

EDEXCEL Topic 2: Mechanics

- 10. be able to draw and interpret displacement-time, velocity-time and acceleration-time graphs.
- 22. know the principle of conservation of linear momentum, understand how to relate this to Newton's laws of motion and understand how to apply this to problems in one dimension.
- 28. know, and understand how to apply, the principle of conservation of energy including use of work done, gravitational potential energy and kinetic energy.

Topic 6: Further Mechanics

- 97. understand how to use the equation, impulse = $F\Delta t = \Delta p$ (Newton's second law of motion).
- 99. understand how to apply conservation of linear momentum to problems in two dimensions.
- 101. understand how to determine whether a collision is elastic or inelastic.

Topic 13: Oscillations

- 181. understand that the condition for simple harmonic motion is $F = -kx$, and hence understand how to identify situations in which simple harmonic motion will occur.
- 184. be able to draw and interpret a displacement-time graph for an object oscillating and know that the gradient at a point gives the velocity at that point.
- 185. be able to draw and interpret a velocity-time graph for an oscillating object and know that the gradient at a point gives the acceleration at that point

AQA Required practical 7: Investigation into simple harmonic motion using a mass-spring system and a simple pendulum.

AQA 3.4.1.5 Newton's laws of motion. Students can verify Newton's second law of motion.

3.4.1.6 Momentum. Conservation of linear momentum. Applied quantitatively to problems in one dimension. Elastic and inelastic collisions; explosions. Impact forces are related to contact times (eg kicking a football, crumple zones, packaging).

Apply conservation of momentum and rate of change of momentum to a range of examples.

3.4.1.8 Conservation of energy. Quantitative and qualitative application of energy conservation to examples involving gravitational potential energy, kinetic energy, work done against resistive forces.

3.6.1.2 Simple harmonic motion. Analysis of characteristics of simple harmonic motion (SHM).

Graphical representations linking the variations of displacement, velocity and acceleration with time.

OCR Practical activity 10: Simple harmonic motion.

Investigating the factors affecting the period of a simple harmonic oscillator.

OCR 3.5.1 Newton's laws of motion

3.5.2 Collisions: the principle of conservation of momentum

Techniques and procedures used to investigate the motion and collisions of objects.

5.3.1 Simple harmonic oscillations: graphical methods to relate the changes in displacement, velocity and acceleration during simple harmonic motion.

5.3.2 Energy of a simple harmonic oscillator: interchange between kinetic and potential energy during simple harmonic motion

TEACHING NOTES

In any experiment, it is instructive to display only the Displacement graph and invite students to interpret it. In this way, they become familiar with the characteristic shapes of displacement graphs indicating constant velocity and acceleration. At any time, the other graphs can be displayed as a check on their interpretation.

Similarly, they could study and interpret the velocity graphs for the two cars during a collisions experiment, before viewing the momentum graph.

For consistency with physics texts and common practice, we have adopted the convention that the positive direction of motion, velocity and acceleration in dynamics experiments is from left to right.

Using TimingPro software



Getting to know TimingPro software

Place the linear track on a level surface - check using a spirit level if possible.
Fit an elastic bumper to the front of the Primary car and switch it on.

Launch the TimingPro application. Click Connect  to establish Bluetooth connection.

With the car at the left end of the track, facing forwards, give it a short push and observe its motion. Practise making the car travel the full length of the track and just reach the endplate, until you can do it reliably.

Go to the text box next to the Start/Stop icon and select 10 seconds for the experiment time.

Go to the Graph selection icons and hide the Displacement and Acceleration graphs. Leave only the Velocity graph displayed.

Be ready to push the car.
Click Start/Stop and push the car.



Your graph probably looks like this:

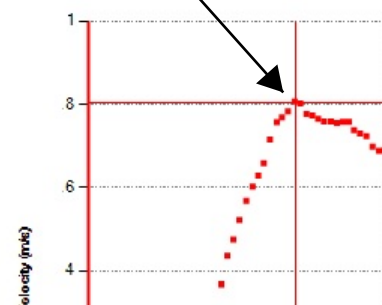
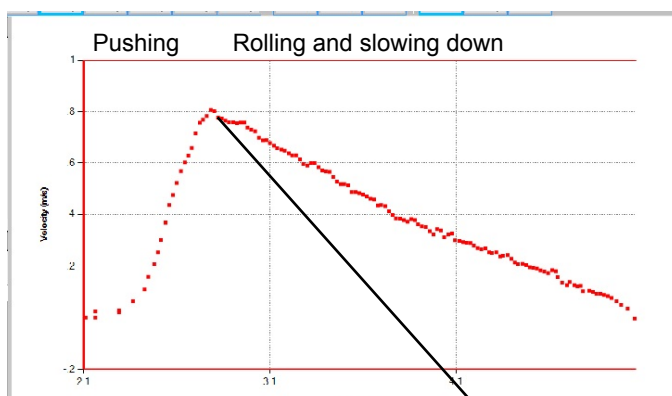
Click on the Cursor icon and find the start of the slowing down section.



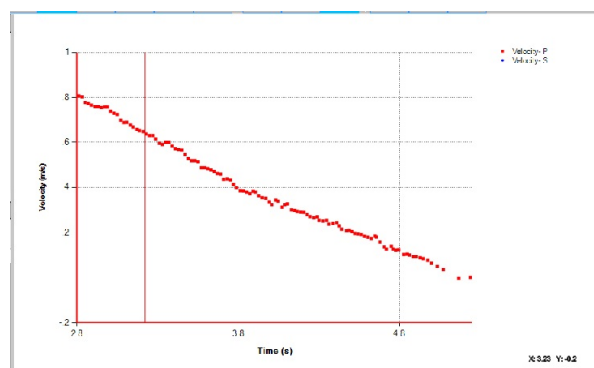
In our example, it was at 2.81 seconds - your time will be different.

In the Primary car data table, highlight all the data BEFORE that time, then go to the Edit icon and Delete Selected Row(s).

Time (s)	Displacement (m)	Potential Energy (J)	Velocity (m/s)	Acceleration (m/s ²)	Force (N)	Momentum (kg-m/s)
2.3163	0.1866880476	0	0.30693	0.337575783	0.32	0.4841590
2.338	0.2036575065	0	0.30279	-0.75318869	-0.4	0.1816778
2.3502	0.2167432477	0	0.77769	-0.00776394	-0.4	0.4006130
2.3778	0.2338239689	0	0.77165	-0.30836565	-0.4	0.4629925
2.3973	0.248914302	0	0.76564	0.3273535	0.7	0.4553846
2.4157	0.2658851690	0	0.75786	-0.12015910	-0.0	0.4547195
2.4356	0.2809719303	0	0.75999	-0.08374031	-0.0	0.1559950
2.4504	0.2900570715	0	0.75436	-0.07302515	-0.0	0.4526174
2.4756	0.3111434127	0	0.75713	0.068523569	0.04	0.4542736

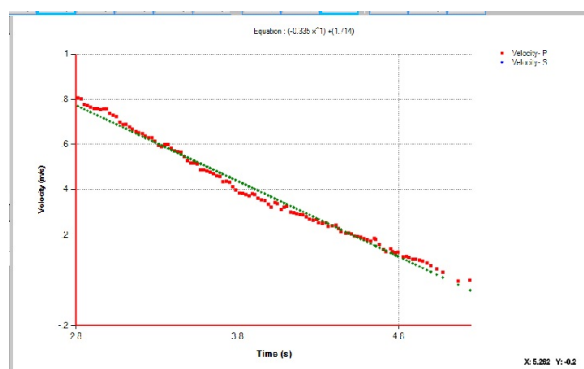


You now have a graph showing only the rolling and slowing down section.



The velocity appears to decrease steadily, in a linear fashion. Suggest reasons for this.

Click on the Polynomial Fit icon, then click at the start of the graph, drag to the end, then release. Click OK in the pop-up window to show the best fit line - the dotted green line.



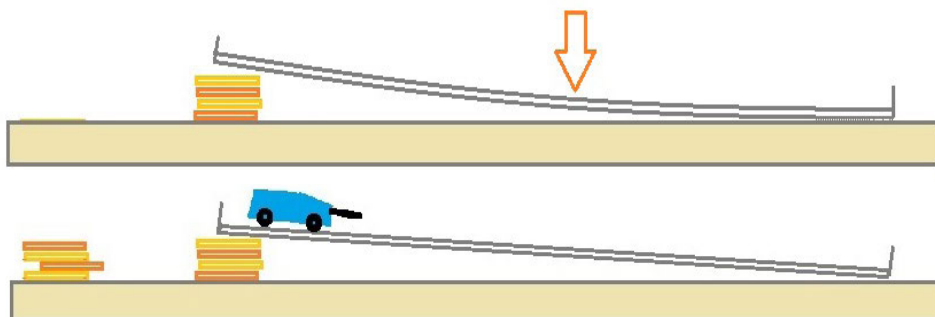
Exploring friction

You will use the Primary car on the linear track, together with some thin objects - exercise books or pieces of plywood - to raise the left end creating a slope at various angles.

Check that the linear track does not sag. If it does, add some support at the centre.

For protection (of the car), fit an elastic bumper to the front of the Primary car.

Switch the car on.



Launch the TimingPro application. Click Connect to establish Bluetooth connection.

Go to the text box next to the Start/Stop icon and select 20 seconds for the experiment time. Go to the Graph icons and hide the Displacement and Acceleration graphs. Leave only the Velocity graph.

Hold the car at the top of the track, facing forwards. Click Start/Stop, release the car and observe its motion.

Depending on the angle of the track, the car will accelerate, roll steadily down the slope, or not move at all.

Look at the velocity graph. You can easily see whether it was accelerating or moving steadily or stopped.

Adjust the angle and repeat the experiment, until the car runs steadily down the slope at approximately constant velocity. You can judge this from the graph. Measure the angle of inclination of the track. **

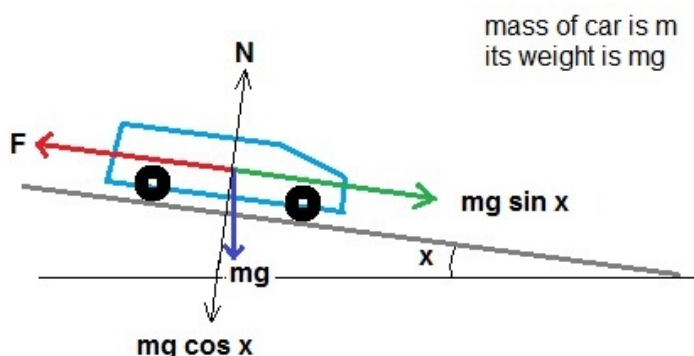
Gravity provides the force that pulls the car down the slope. Friction resists the car's motion. If these forces are balanced the car will either remain at rest or move at constant velocity (Newton's first law).

The car's weight, $mg \cos x$, acts at right angles to the slope, and there is an equal and opposite reaction force, N (Newton's third law).

$$N = mg \cos x$$

The force pulling the car down the slope, $mg \sin x$, is opposed by the force of friction, F .

$$F = mg \sin x$$



The ratio $\frac{F}{N} = \mu$ is the coefficient of friction between the car and the track.

The track has a simple clinometer. Knowing the angle x for your experiment, you can calculate μ . You should find that the value of μ for the linear track is quite small. The track and cars are designed to have minimal friction so that friction has only a minor effect on the results of your experiments.

** A slope adjusted in this way is a "friction compensated" slope.

However, it is advisable to keep friction in mind, when you are interpreting the graphs of your experiments.

Motion on an inclined plane

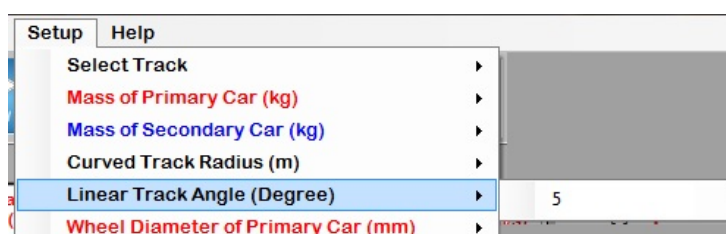
You will use the Primary car, the linear track, the track support block and other objects, to create an inclined track at various angles. For protection, fit an elastic bumper to the front of the Primary car.

Check that the linear track does not sag. If it does, add some support at the centre.



Switch the car on. Launch TimingPro software. Click Connect to establish Bluetooth connection.

Go to the text box next to the Start/Stop icon and select 10 seconds for the experiment time.

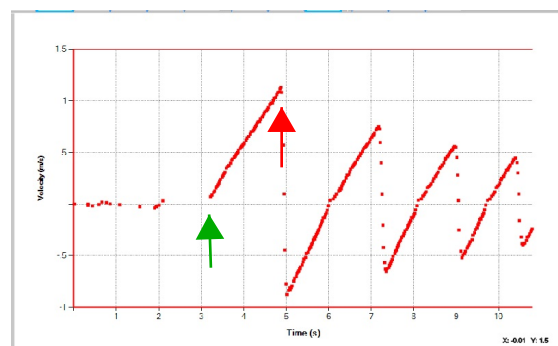


Click on Setup in the Menu bar and set Linear Track Angle to 5 degrees. Notice that it changes in the Status bar.

Use the Graph icons to display **only** the Velocity graph.

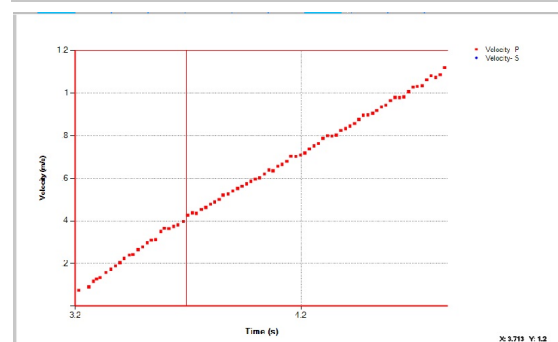
Click Start/Stop and follow the on-screen prompts.

Put the car at the right hand end of the track facing forwards. We will look at energy in a later experiment.



The car should accelerate and bounce off the endplate.

Use the Cursor to find time values at the **start** and **end** of the **first** velocity curve, then use these values in the data table to delete everything before and after the first velocity curve.



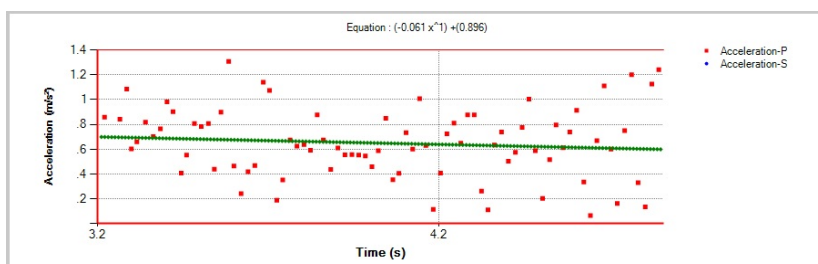
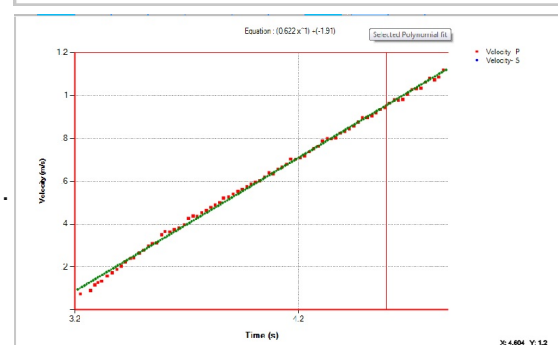
Click on the Polynomial fit icon, then click and drag the cursor over the velocity curve. In the pop-up window, select Order 1, i.e. a linear best-fit line. Click OK.

The best fit line is added and the equation of the line is displayed, in the format:

$$\text{Equation : } (0.622 x^1) + (-1.91)$$

In this example, the car's average acceleration was 0.622 m/s²

Click on the Acceleration icon to display the Acceleration graph.



Polynomial fit can create a best fit line (order 1), even though the graph is a scatter of points. The best fit line shows clearly that the acceleration was decreasing, but was nearly constant.

Galileo's experiment

Galileo was fascinated with the movement of objects, especially falling objects. His timing devices were his own pulse, a pendulum and an ingenious water clock, which served him well for many experiments. However, when objects fall they move too quickly to be timed using a pendulum.

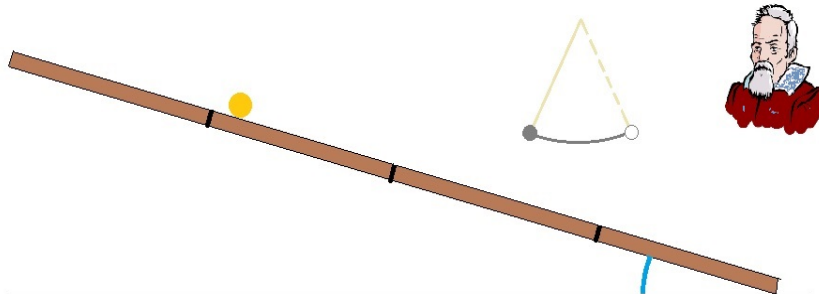
He set up a long, straight piece of wood with a groove in the top surface.

He rolled a bronze ball down slopes of different angles, over different distances.

The ball was not travelling so quickly, so he could time its descent more precisely.

He reasoned that measuring the acceleration of the ball on slopes of 5, 10, 15 and 20 degrees (and so on)

would enable him to calculate the acceleration when the slope was at 90 degrees, i.e. vertical!



Use the Inclined plane setup, capture the data and graphs for the Primary car rolling down 5, 10, 15 and 20 degree slopes. The car will move very quickly, so add some soft material at the end of the linear track!

Measure the angles and make a note of them, but do not enter them in the Setup menu.

Use Polynomial fit to find the acceleration from the Velocity graph.

Use the Acceleration graph to check whether the acceleration was constant.

Make a note of the angle and acceleration value for each run.

Between experiments, click on the New icon to clear the data table and graphs.

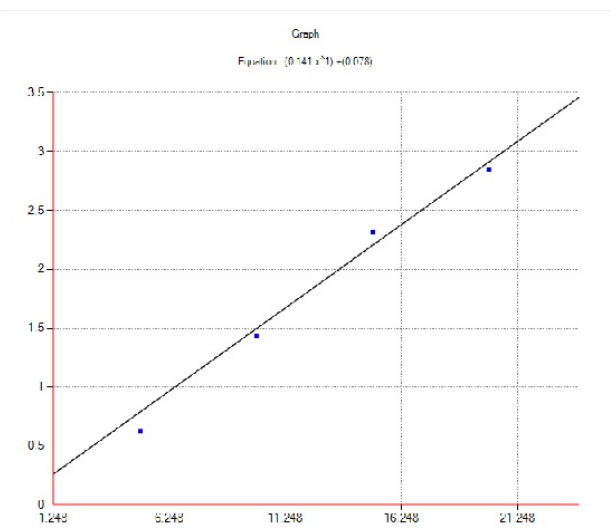


When your experiments are complete, use your data (X, the angle of the track and Y, the acceleration) to plot a graph as follows:

Click on the New Graph icon, enter your data in the table.



X	Y
5	0.522
10	1.435
15	2.315
20	2.05



Now estimate the acceleration if the track was inclined at 30, 60 and 90 degrees.

Enter angles and estimates in the table.

How does your estimate for 90 degrees compare with the accepted $g = 9.8 \text{ m/s}^2$?

The New Graph can be saved or printed.

Did you consider friction?

How is Galileo's rolling ball different from the car running down the track? How is a falling ball different?

The ball and the car at the top of the slope have potential energy, which is converted into kinetic energy as they accelerate down the slope. Does all their potential energy become kinetic energy?

You will deal with kinetic and potential energy next, using further facilities of the TimingPro software.

Inclined plane - energy



Potential and kinetic energy

From the data captured by the TimingPro software, we can also explore potential and kinetic energy.

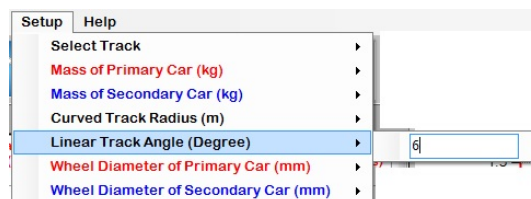
You will use the linear track, the track support block and other objects, to create an inclined track at various angles. Fit an elastic bumper to protect the front of the Primary car.

Switch on the Primary car. Launch the TimingPro software. Click Connect.

Set up the inclined plane at a known angle. It is important to enter the angle of the slope accurately. The clinometer is only approximate. It is better to measure the height by which the upper end is raised, H , and the track length, L .

$$\text{Then calculate } \text{angle} = \tan^{-1}\left(\frac{H}{L}\right)$$

Enter this angle in Linear Track Angle in the Setup menu.



Use the Graph selection icons to show only Velocity and Energy.

Click Start/Stop.

You are prompted to place the car at the bottom of the slope, facing forwards. Click **OK**

You are prompted to push the car up to the top of the slope.

A temporary graph is drawn, and removed when you click **OK**

Using the angle, the car's mass and distance travelled up the slope, the software calculates the initial potential energy, which is used as the starting value for the potential energy graph.

You are prompted to release the car. Click **OK** and release it.

From the velocity and mass, the software calculates the kinetic energy during the descent.

It also calculates the changing potential energy.

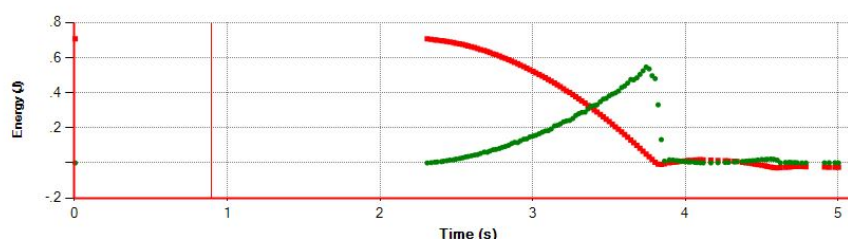
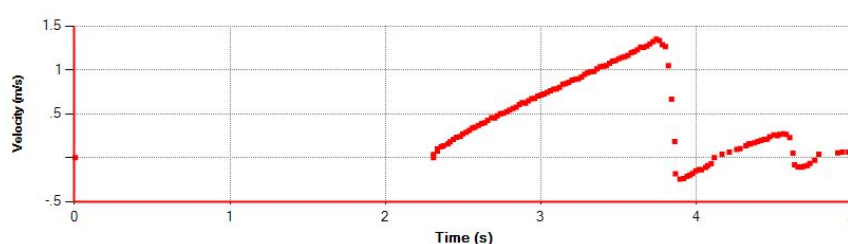
Look at the graphs.

Velocity is increasing steadily, you can use Polynomial fit to find the acceleration, if you wish.

The Energy graph has two traces, one for Potential energy (in red),

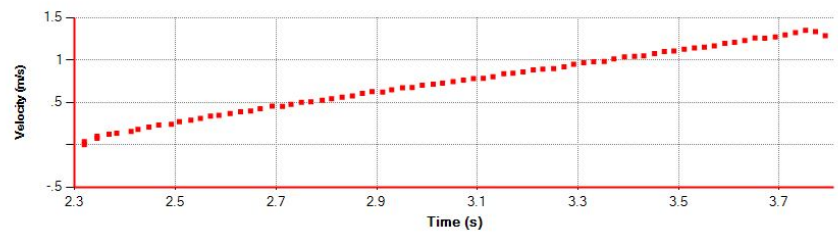
the other for Kinetic energy (in green). As one decreases, the other increases.

If there are no losses the total energy should remain the same, i.e. energy is conserved.



Inclined plane - energy continued

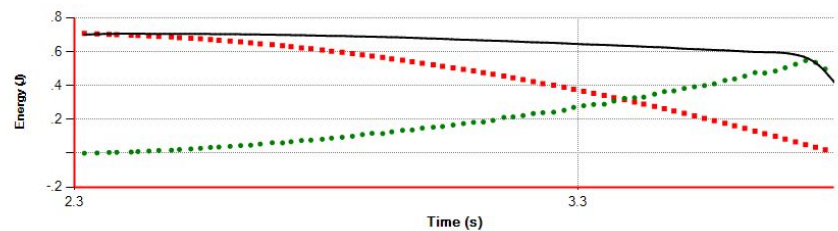
Zoom in on the first slope.
We can ignore the small rebounds



Click on the Summation icon.



A new curve is added to the energy graph, in black.



This is the sum of potential and kinetic energy at each point during the journey down the slope.

Is the total energy constant throughout the graph?

Use the Cursor to explore the energy graph, including the Summation plot of total energy.

What could have caused any changes?

The experiment should be repeated for different angles, and with the Primary car loaded with additional masses. Be sure to put extra cushioning material at the bottom of the slope, for steeper runs!

Identify any sources of error in your experiment and consider whether steeper slopes or additional masses help to reduce the effect of the errors.

We intuitively appreciate that pushing an object makes it move. If we push harder, it moves faster. If we keep on pushing, we can make it accelerate. We also know that heavier objects are harder to move. Testing our ideas and turning them into a useful formula is at the heart of good physics.

The GCSE examination boards take slightly different approaches to this topic:

AQA GCSE Physics required practical activity 8: Acceleration

Investigating acceleration using an air track and light gates. Students are expected to investigate the effect of varying the force on the acceleration of an object of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force.

A detailed method is provided.

Edexcel GCSE Physics Core Practical 1: Investigating force, mass and acceleration

Students are expected to investigate the relationship between force, mass and acceleration by varying the masses added to trolleys. Students are led through the investigation by a series of questions.

OCR GCSE 9-1 Physics PAG P3 and Combined Science PAG P3: Motion

Suggested activity 1: investigating acceleration of a trolley down a ramp

Suggested activity 2: using light gates and data loggers


Suggested activity 3: the effect of force on acceleration

Investigating acceleration down a slope - OCR suggested activity 1

The Primary Dynamics Car captures time, displacement (distance moved), velocity and acceleration every time it moves, while it is connected to TimingPro software.

In the simplest experiment, the car is allowed to roll down a ramp. A slope of 5 degrees is suitable. The Data table shows a lot of data, but in this experiment only Time and Displacement are needed.

Place the car at the top of the ramp, facing down the slope.

Click on Start/Stop  and release the car. Do not push it.

Look at the first two columns in the data table, Time (s) and Displacement (m).

Find the time when the displacement was 0 and the time when the displacement equals the full distance the car can travel down the slope. The difference is the travel time for the full slope. Repeat this twice and calculate the mean of the three travel times.

From the same data tables, you can find the time taken to travel the last 0.3 m (30 cm) of the slope.

Alternatively, you can allow the car to run down the ramp 3 times, looking only at the time taken to travel the last 0.3 m, and find the mean of the three times.


You now know the speed of the car in the last 0.3 m of the ramp, from **speed = distance ÷ time**

You can also calculate the car's acceleration starting from zero at the top of the ramp,
acceleration = change in speed ÷ time taken to change

Investigating acceleration down a slope - OCR suggested activity 2

The Primary Dynamics Car provides an alternative to the light gates with data logger approach.

The car captures time, displacement, velocity and acceleration as it runs down a slope, and is connected to TimingPro software.

Click on Start/Stop  and allow the car to run down the slope - 5 degrees is suitable.

In the data table, you have a continuous record of the time, displacement and velocity.

Choose two points in the car's journey and read the times and velocities at those points.

Acceleration can be calculated from **acceleration = change in velocity ÷ time taken to change**

Repeat the experiment twice and calculate the mean of the three values for acceleration.

The effect of force on acceleration - OCR suggested activity 3

In this activity, the car is accelerated by a falling mass, which provides a constant accelerating force.

The experimental set up is shown and described on page 19.

The car's journey is recorded in detail by the TimingPro software. Time, displacement, velocity and acceleration can all be found in the data table.

The acceleration values in the data table are calculated over very short distances, and could be thought of as "instantaneous" acceleration at any point in the car's journey.

A more suitable method for students is to look at the time and velocity values in the table. Choosing points near the start and end of the car's motion provides data to use in the equation:
acceleration = change in velocity ÷ time taken to change

For the first run, use a falling mass of 20 g, which gives a force of 0.2 N
Do three runs and calculate the mean acceleration for the three sets of data.

Change the falling mass to 40 g, giving a force of 0.4 N and do three runs.
Again calculate the mean for the three sets of data.

In the same way, use falling masses of 60, 80 and 100 g, giving forces of 0.6, 0.8 and 1 newton.

Plot a graph of force against acceleration and comment on the shape of the graph and the likely relationship between force and acceleration.

Alternatively, look at the Velocity graph for any run and use Polynomial fit to add a best fit line.
The gradient of this line is the acceleration.
Repeated runs provide more values from which a mean can be calculated.

Edexcel Practical 1: Investigating force, mass and acceleration

Investigate the relationship between force, mass and acceleration by varying the masses added to trolleys.

The experimental set up is the same as for Newton's 2nd Law on page 19.

Students are led through the investigation by a series of questions. Instead of using light gates, the Dynamics Car and TimingPro software capture and display all the necessary data.

They must consider "friction compensation" for the track - discussed on page 11.

They must explain how the accelerating force is calculated.

They must consider the effect of the falling mass on the total moving mass.

They are invited to list the main errors and suggest how the method might be improved.

Students are expected to use the same experimental set up to investigate the relationships:
between force and acceleration and
between mass and acceleration.

The Dynamics Car can be fitted with additional masses from the accessories kit, mounted on the pegs. If all the additional masses are used, the car's mass is doubled.

AQA required practical activity 8: Acceleration

In their Teachers' Notes, the AQA provides a detailed method for this investigation. It is very similar to the Advanced procedure on pages 19 to 21.

Instead of light gates and a linear air track, we recommend the use of our Linear Track with the Primary Dynamics Car and TimingPro software.

The car and software capture and display continuous data from the moving car, from which Time, Displacement, Velocity and Acceleration can be extracted.

Acceleration can be calculated from the velocities at two points in the car's journey, or can be found by applying Polynomial fit to find the gradient of a best fit line to the Velocity graph.

Whichever method is used, it is for students to discuss the sources and potential reduction of errors.

If friction compensation is required, this is discussed on page 11 and can be incorporated in the procedure.

Newton's 2nd law - A level

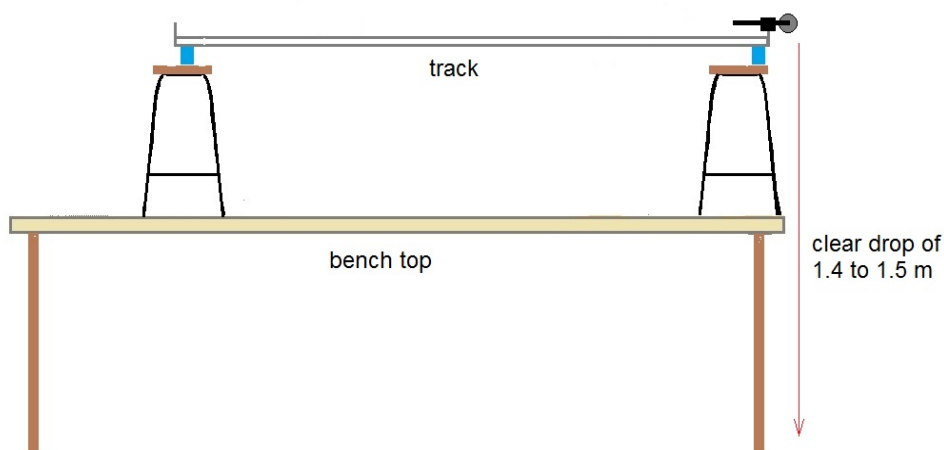
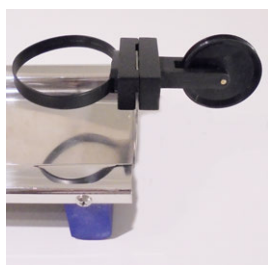
We intuitively appreciate that pushing an object makes it move. If we push harder, it moves faster. If we keep on pushing, we can make it accelerate. We also know that heavier objects are harder to move. Testing our ideas and turning them into a useful formula is at the heart of good physics.

You will use the linear track, the Primary car, a small hook attachment, the pulley attachment, an elastic bumper, some 10 g masses and some thread.

For the best range of data, the track should be securely supported about 1.5 metres above the floor. This could be achieved by standing two lab stools on a bench, then resting the track on top of the stools.

The track must be level.

Fit the large pulley attachment to one of the endplates and an elastic bumper to the pulley.



Fit the small hook attachment to the car. Fasten a length of thread to the small hook.

With the car resting against the bumper and the thread running over the pulley, fasten the thread to the mass hanger so that it is almost touching the floor.

When the accelerating mass falls, it pulls the car along the track.

The total mass that is accelerated, is the mass of the car and hook, **M**, plus the mass hanger and masses, **m**.

We can keep the total moving mass constant, by putting any spare masses NOT on the hanger on top of the car. So the total is always **M + m**

$$\text{car} + \text{hook} + \text{hanger} + \text{masses} \\ 0.585 + 0.015 + 0.010 + 0.090 = 0.700 \text{ kg}$$

In this way, we only need to concern ourselves with the acceleration and the force producing it.

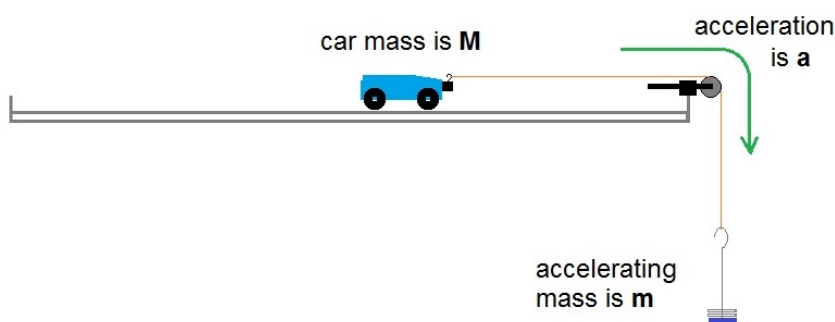
The accelerating force, **F**, is the mass of the hanger and masses, multiplied by **g** (9.8 m/s^2)

So with 2 masses on the hanger, **m** is 0.030 kg and **F = mg = 0.03 x 9.8 = 0.294 N**

The other 7 masses are on top of the car, keeping the total moving mass at 0.700 kg. To prevent the loose masses slipping off the car, they could be contained in a small polythene bag.

When there are 3 masses on the hanger, **m** is 0.040 kg and **F = mg = 0.04 x 9.8 = 0.392 N**. The other 6 masses are on the car.

In the experiment, several runs will be done with a range of accelerating masses.



Newton's second law - continued

Launch TimingPro software. Set the experiment time to 5 seconds.
Use the Graph selection icons to show only the Velocity graph.

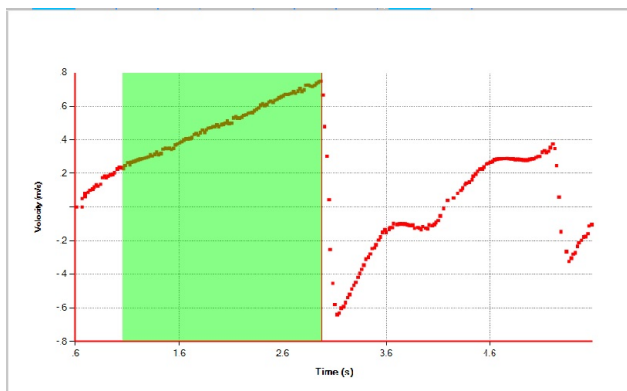
Switch on the Primary car and click Connect.

Put two 10 g masses on the mass hanger. Put the other seven masses on top of the car.

Move the car to the end of the track away from the pulley.
Click Start/Stop and release the car.

This graph was produced by a force of 0.294 N
i.e. a falling mass of 0.030 kg

Click on Polynomial fit then click and drag the cursor over the straight part of the velocity graph.



Select order 1 for a linear best fit line, which appears in green.

The equation includes the gradient of the velocity graph, and the value is 0.27 which is the "rate of change of velocity", better known as acceleration, in m/s^2 .

Click on the New Graph icon



You are presented with a two column table labelled X and Y and a blank graph.

Enter acceleration, 0.27 in the X column and force, 0.294 in the Y column. Press Return. A point is plotted.

Click on New Graph again, you are returned to the original velocity data and graph. The New graph is stored in the background.

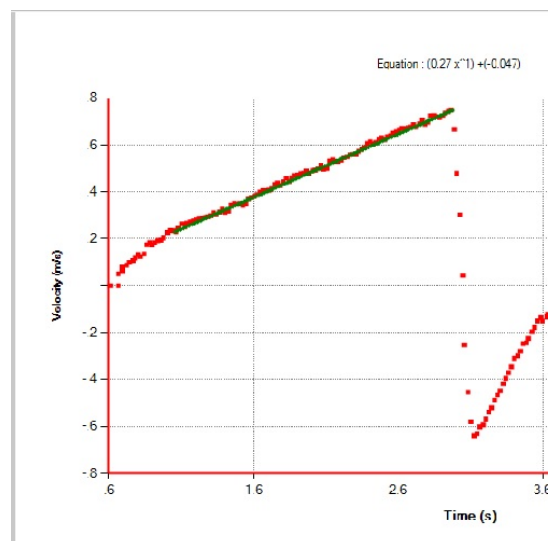
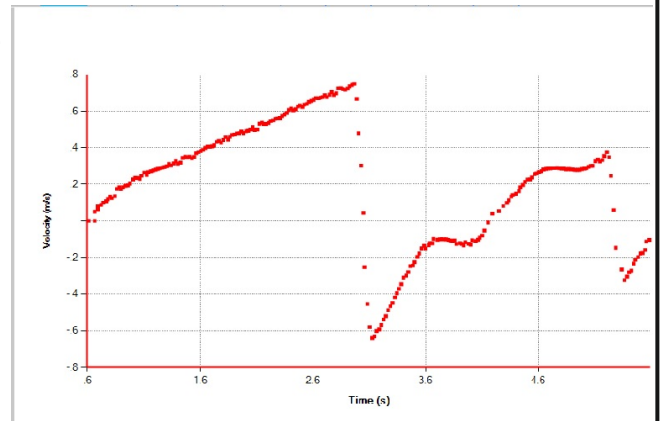
Click on the New icon



the velocity data and graph are cleared.

Remove one mass from the top of the car and add it to the mass hanger, the mass is now 0.040 kg, the accelerating force is 0.394 N. NOTE: this will change with each repetition.

Go back to the red arrow above and repeat the process, building up the data and New graph, with new values of acceleration and force, which are entered in the New Graph.



Newton's second law - continued

When you have six or seven rows in your table, use Polynomial fit in the New Graph. Note the gradient, which can be read from the equation of the best fit line.

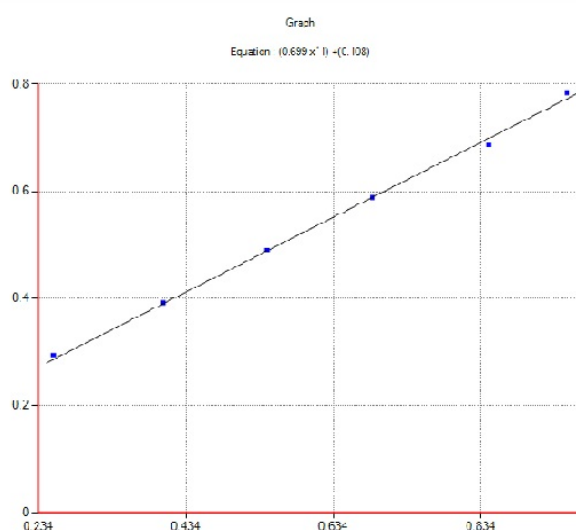
In this example, based on our experimental data, the gradient was 0.699

We know acceleration, $a \propto F$, the force, because the harder you push or pull, the faster the car goes.

We can write this as $F = k a$ where k is a constant of proportionality.

If there is a linear relationship between force and acceleration, then k will be the gradient of a graph of F against a

x	y
.254	.294
.403	.392
.544	0.45
.687	.588
.845	.686
.951	.784



We have the graph, it is clearly a linear relationship, and the gradient is 0.699

That is a very good match for the total mass that is accelerating, 0.700 kg

Therefore, the constant of proportionality is the mass.

We can say with confidence, that force = mass x acceleration which is $F = ma$

This is the mathematical statement of Newton's second law and also defines the unit of force, the newton.

$$\text{Force} = \text{mass} \times \text{acceleration, which is } \text{kg} \times \text{m/s}^2$$

A force of 1 newton is $1 \text{ kg} \cdot \text{m/s}^2$ that is the force required to make a mass of 1 kg accelerate at 1 m/s^2

Extension

You may wish to test the law by using a fixed force (say 0.49 N, which is produced by a falling mass of 50g) to accelerate the car with one or more additional masses attached to it.

At 150 g each, you can increase the mass of the car significantly and capture a range of accelerations.

What relationship are you expecting between mass and acceleration?

Newton's second law can also be written as: Force = mass x velocity/s, which is $\text{kg} \times \text{m/s/s}$ is mass x velocity, which is momentum, so it is also correct to say:

$$\text{Force} = \text{rate of change of momentum}$$

New Graph function

Clicking on New Graph switches between the normal graph display and the New Graph X Y data table and graph display. The New Graph display is stored in the background.

While the New Graph data table and graph are displayed, New Graph can be saved by clicking on Save, or cleared by clicking on New.

In the normal graph display, clicking New clears the original graph and data tables, without affecting the New Graph.

Elastic collisions

For consistency with physics texts and common practice, the positive direction of motion, velocity and acceleration in dynamics experiments is from left to right.

You will need the linear track, the Primary and Secondary cars, 4 elastic bumpers.

Primary car >>

Secondary car >>

Make sure the track is level.
Check with a spirit level if possible.

Place the cars on the linear track so they both face to the right. Attach bumpers to both cars.



Switch on both cars.
Launch the TimingPro application.
Click Connect to establish Bluetooth connection.


In the Setup menu check that "Linear Track" is ticked and Linear Track Angle is 0.

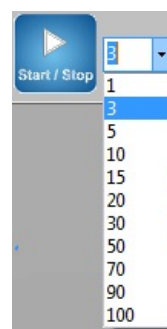


Use the Graph selection icons to display Displacement, Velocity and Momentum graphs.

Next to the Start/Stop icon, select 3 seconds for the experiment time.

Put the Primary car at the left end of the track and the Secondary car at the centre.

Click Start/Stop  and immediately push the Primary car towards the Secondary car.

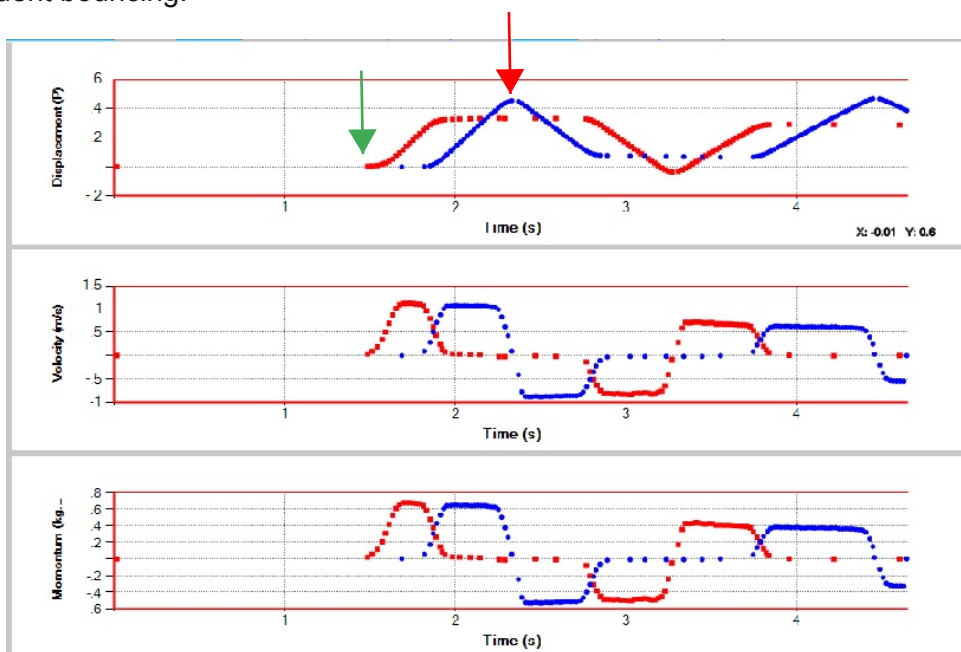


This is a typical set of results for an elastic collision, including the delay before the Primary car was pushed and some of the subsequent bouncing.

Look at the Displacement data, from the Primary car **starting** to move, to the point when the Secondary car bounced off the endplate - take this time as the **end** of the collision.

During the collision, the Primary car's velocity falls to zero and the Secondary car moves away at a velocity similar to the Primary car's approach velocity.

Look at the Momentum graphs for the two cars, the Primary car's momentum falls to zero as the Secondary car moves away, taking transferred momentum with it.

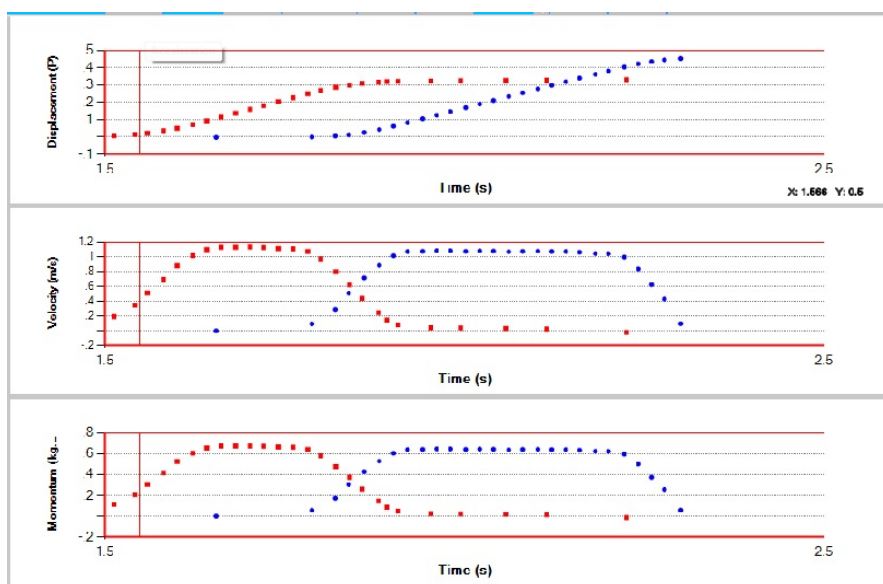


Elastic collisions - continued

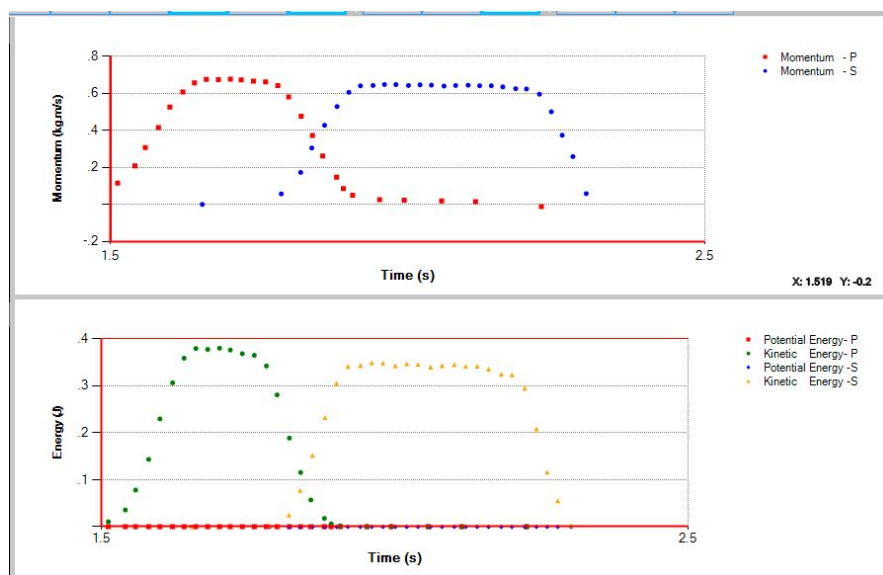
Use the cursor to find the **start** and **end** points described above.

Select and delete any data before the start time. Select and delete data that shows the bouncing after the end of the collision.

The cursor can be used to look at individual values for either car during the collision as velocity and momentum are exchanged.



Hide the Displacement and Velocity graphs, click to display the Energy graph.



Click the Summation icon

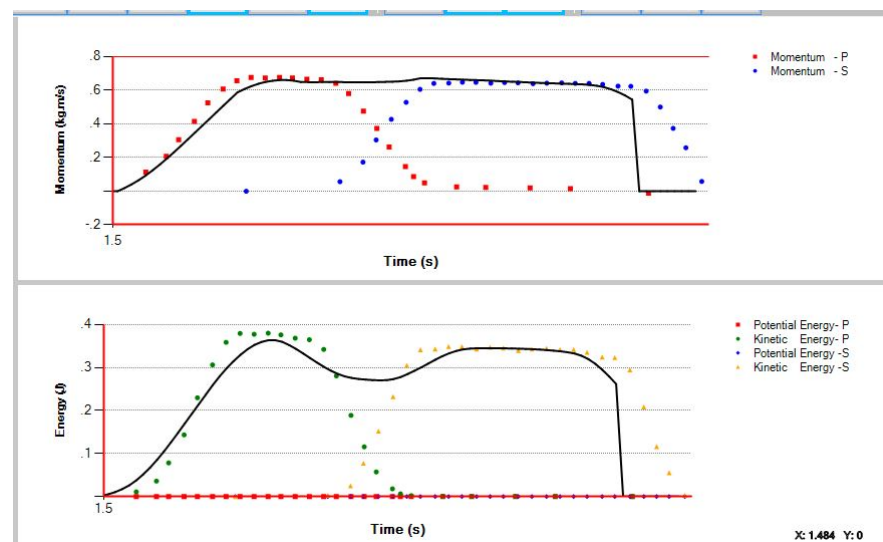


The black line shows the sum of the two cars' momentum. It is conserved.

Similarly, the black line in the energy graph is the sum of the energy of the two cars. Kinetic energy is conserved.

The red and blue dots along the x-axis are a plot of potential energy, which is zero throughout the collision.

Discuss and explain the dip in the energy curve. Was energy actually conserved?



Elastic collisions - continued

For consistency with physics texts and common practice in dynamics experiments, the positive direction of motion, velocity, acceleration and momentum is from left to right.
In all collision experiments, both cars must face to the right.

To extend students' experience, a range of elastic collisions should be explored to test conservation of momentum and energy in different situations.

1) The Primary car can be loaded with up to four 150 g masses, which doubles the mass of the car. Using the same method as above, collisions using the loaded Primary car can be performed and analysed.



2) Alternatively, the Secondary car can be loaded to study the effect of a lighter vehicle (the Primary car) colliding with a heavier one. Using the same method as above, collisions can be performed and analysed.

3) "Rear end shunt" - the Secondary car is moving slowly left to right and is hit from behind by the faster moving Primary car. The effect of loading either car should be investigated.

4) "Head on" collision - both cars move toward the centre of the track and rebound. The effect of loading either car should be investigated.

Note: both cars must still face to the right, so the Secondary car will be moving backwards toward the Primary car, its initial velocity and momentum will be negative.

Think about a passenger travelling in one of the cars above and experiencing a collision. Discuss whether it is better to be in a heavier or a lighter vehicle in a collision.

Elastic collisions

When objects collide and rebound, and there is no overall loss of kinetic energy, the collision is described as **elastic**. In the same collision, momentum is also conserved.

Total kinetic energy before = total kinetic energy after

Total momentum before = total momentum after (remember that momentum is a vector quantity, so direction must be taken into account).

But collisions in the real world are rarely truly elastic. When two cars collide, there is noise, the cars are bent by the force of the collision - some of their kinetic energy is converted to sound, some is used to bend, break and warm the damaged parts of the cars. The total amount of energy remains the same.

Inelastic collisions

You will need the linear track, the Primary and Secondary cars, 2 Velcro inelastic bumpers and 2 elastic bumpers.

Make sure the track is level. Check with a spirit level.

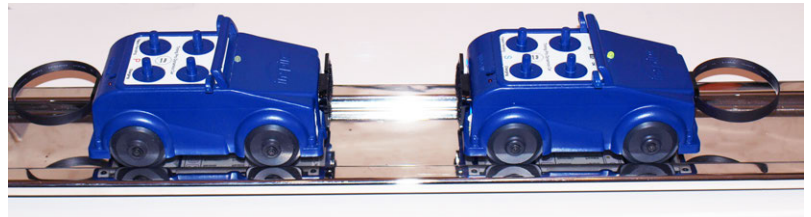
Fit the Velcro inelastic bumpers to the **front** of the Primary car and to the **back** of the Secondary car. Elastic bumpers are for protection, in case the cars hit the track endplates.



Primary car

Secondary car

For all collisions, the two cars must be placed on the linear track as shown.



The Velcro bumpers make the cars stick together when they collide.

Inelastic collisions can be done in various ways:

- the moving Primary car collides with the stationary Secondary car

- the same, but either car has its mass increased

- the slowly moving Secondary car is hit from behind by the faster Primary car

- the cars are both pushed toward the centre of the track and collide "head on", but one car is loaded

Both cars must face to the right as shown. Students can model and analyse real world incidents.

Decide which type of collision you are going to perform.

Switch on both cars. Launch the TimingPro application. Click Connect to establish Bluetooth connection.

In the Setup menu check that "Linear Track" is ticked and Linear Track Angle is 0. Set the experiment time to 5 seconds.

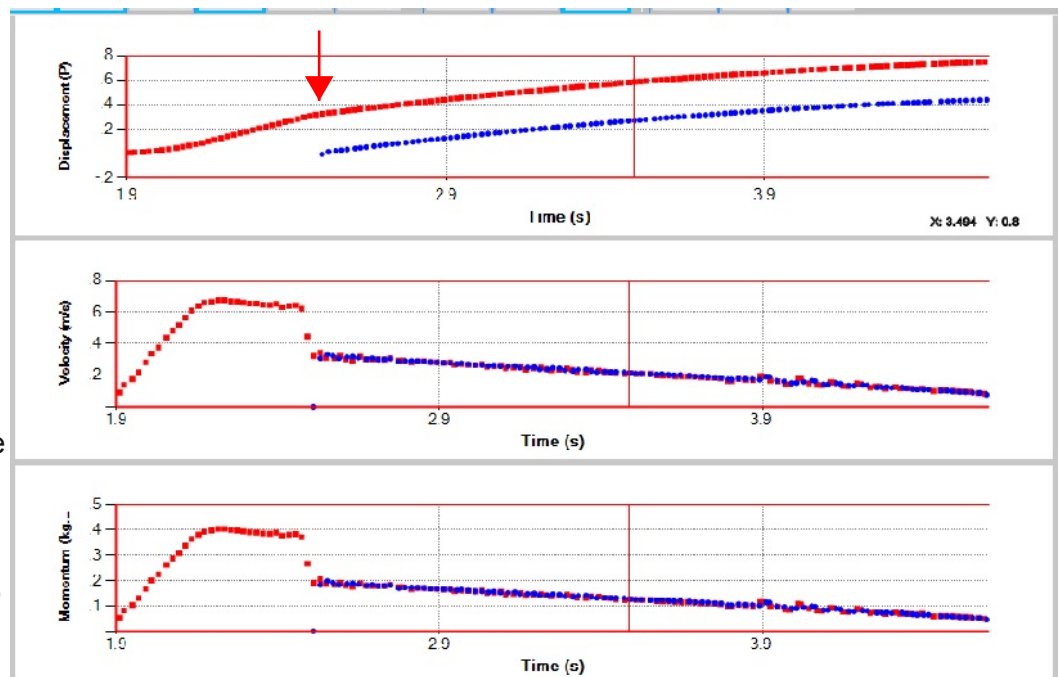
Click on the Graph icons to display Displacement, Velocity and Momentum.

Click Start/Stop and perform the collision.

Here is a typical result for cars of equal mass.

At the point of collision, the Primary car slows down and both cars move on at half the velocity.

The two cars share the Primary car's momentum, half each. Momentum is conserved.



Inelastic collisions - continued

Analysing the data from an inelastic collision

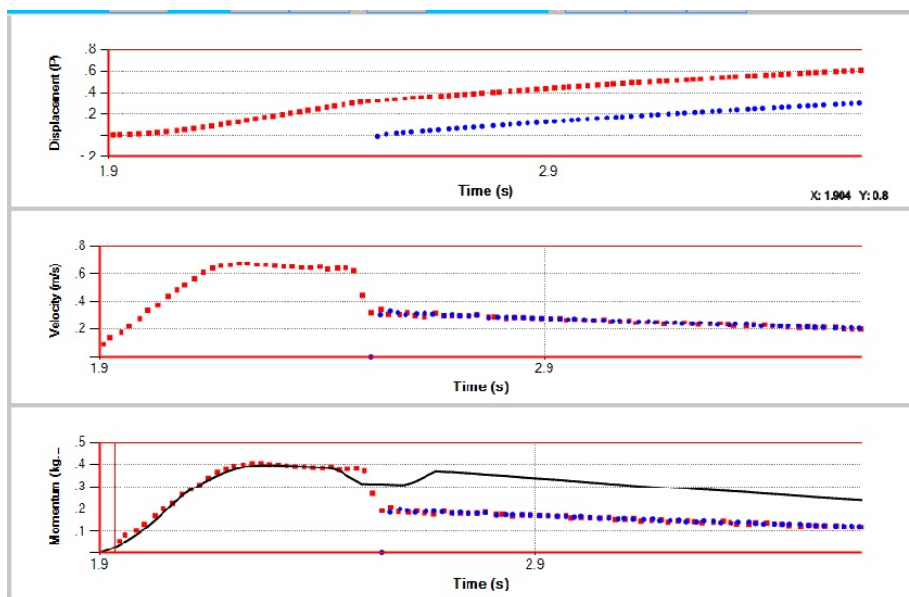
Use the cursor to find the start and end of the collision, then delete data before and after it.

You can now examine the collision in detail, using the cursor to check the cars' velocities, and to check the values of momentum in the instants before and after the cars joined.

Use Summation to look at the total momentum



Because the two cars are joined together their mass, momentum and energy are combined.



Look at the Energy graph and discuss whether energy was conserved in the collision.

Use the same procedures to perform and analyse a range of inelastic collisions.

Momentum is conserved?

You will see that friction has a noticeable effect in the graphs of momentum and energy. In the case of the energy graph, it should be easy to account for the energy "lost" by the colliding cars.

But momentum also appears to be lost.

Imagine an ideal situation: two snooker balls collide in the vacuum of space, far away from any planet's gravity. There are no external forces acting on the colliding objects. In this situation, the conservation of momentum would be perfect. Even though you couldn't hear it, the snooker balls would make a sound as they collided, so a little energy would be lost as vibration.

So, it would be best to say that momentum is conserved, in the absence of external forces.

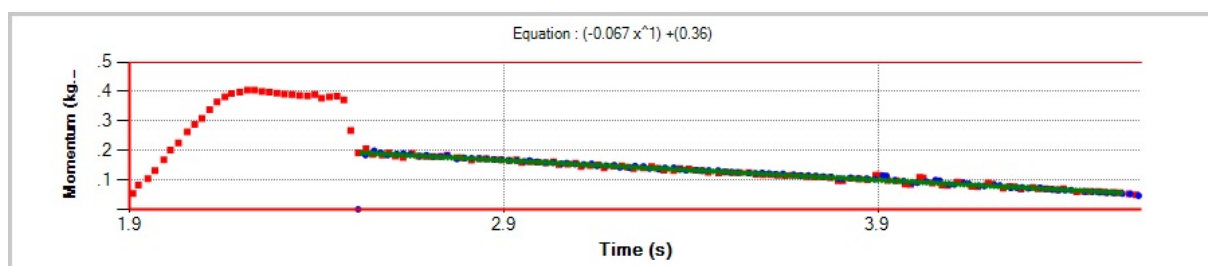
In our experiments, the force of friction acts on the cars. There must be a balancing force, opposing and overcoming the force of friction - otherwise the cars could not move. This force is provided by the changing momentum of the cars, as they slow down.

This is a practical example of the alternative statement of Newton's second law:

$$\text{Force} = \text{rate of change of momentum}$$



You can use Polynomial fit to find the rate of change of momentum. In this example, the gradient is 0.067 so the force of friction is 0.067 newton.



Real collisions are neither perfectly elastic, nor completely inelastic - they are somewhere between.

Crumple zones

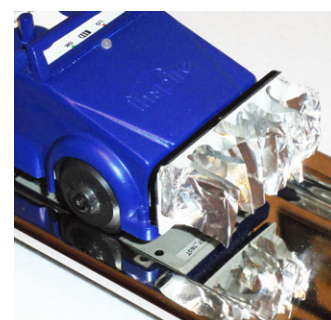
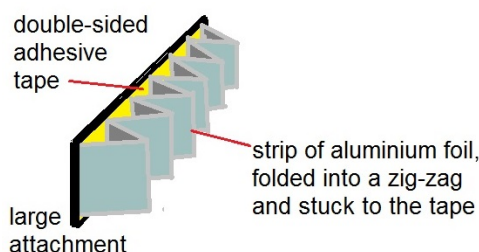
Inelastic collisions put to use

Modern cars are designed to keep their occupants safe from injury. It is also desirable to prevent cars rebounding after a collision. Clearly, inelastic behaviour could be useful in the real world!

To help minimise injury, modern cars have "crumple zones" at the front and back. These are intended to absorb kinetic energy by crumpling or squashing, leaving the passenger compartment of the car undistorted.

You will need the linear track, the Primary car, the large rectangular bumper attachment, one elastic bumper, double sided sticky tape, some aluminium foil.

Prepare the large rectangular bumper by cutting and fitting lengths of double-sided sticky tape to it. Peel off the backing tape then attach a some folded or shaped aluminium foil to the adhesive tape.



This is a simple example. Many other shapes could be tried - remember that the purpose of the crumple zone is to absorb energy by crumpling, so it must not be too rigid.

Make sure the track is level. Check with a spirit level if possible. Place the car on the track.

Attach the elastic bumper to the rear of the car, and fit the large bumper with foil to the front.

Switch on the car. Launch the TimingPro application. Click Connect to establish Bluetooth connection.

In the Setup menu check that "Linear Track" is ticked and Linear Track Angle is 0.

Click Start/stop and roll the car towards the endplate of the track. Not too quickly!

From your graphs, find the velocity of the car immediately before impact.
Zoom in on the section where it is slowing down and the aluminium is crumpling.

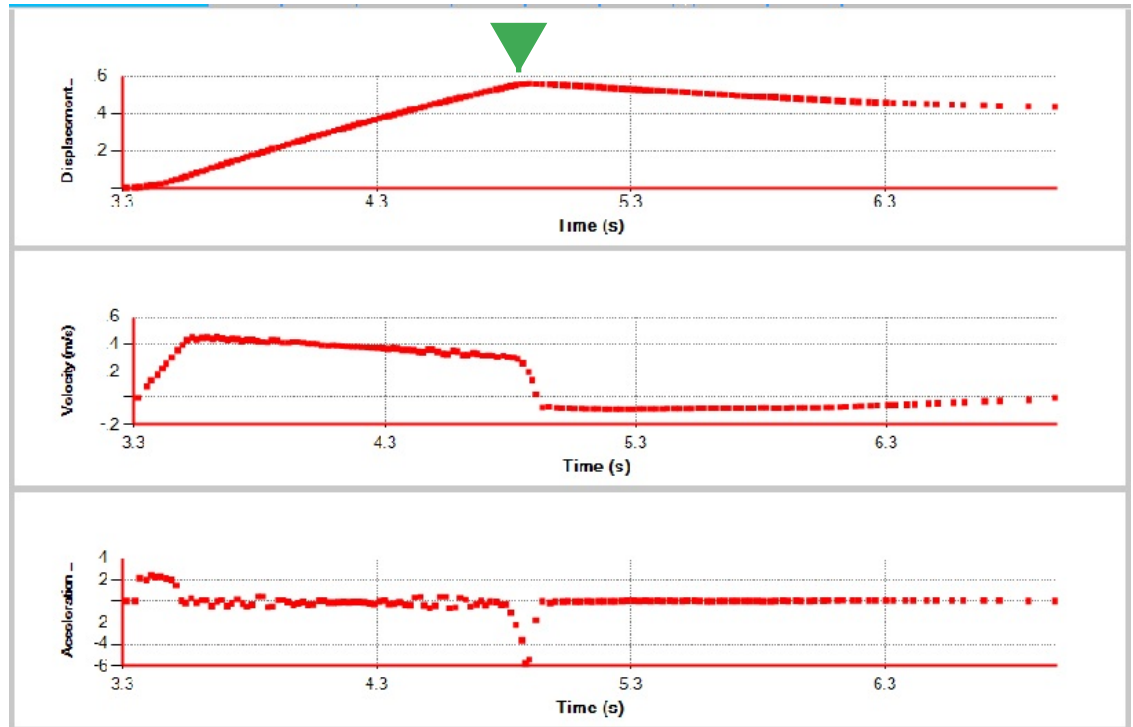
How long did the car take to stop? Use the cursor.
Can you measure the deceleration during that time? Use Polynomial fit.

Look back to the elastic collisions you performed.
How is the change of momentum different when a crumple zone is involved?
Is energy conserved when the crumple zone does its job? Explain your answer.

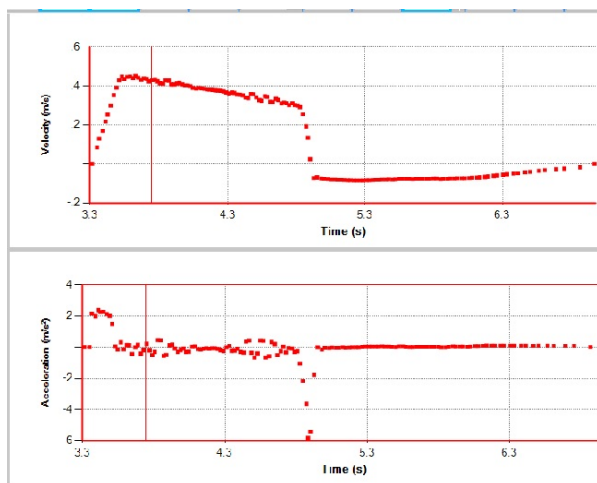
Analysis of a sample collision follows on the next page.

Crumple zone - analysis

The graphs show that the car comes to a stop and moves very little after the impact.



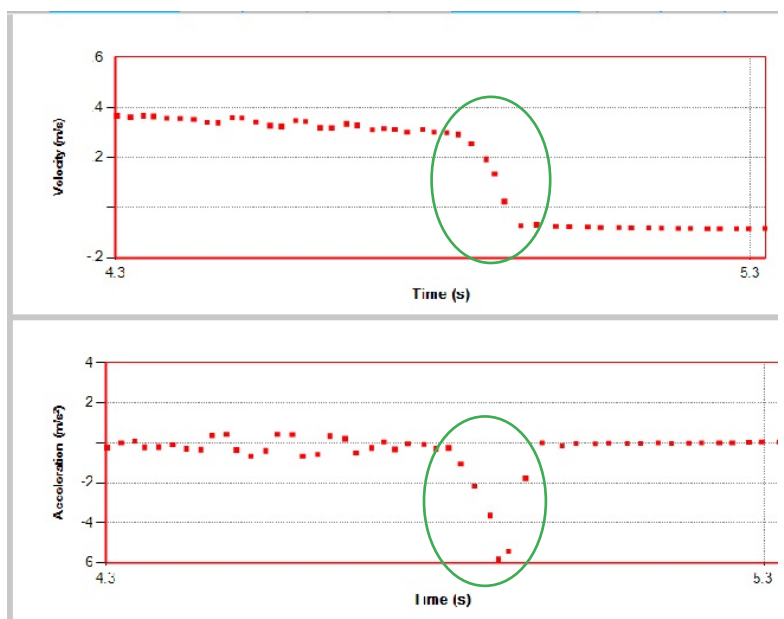
Hide the Displacement graph to view the Velocity and Acceleration graphs in greater detail.



Then zoom in on the interesting part, in this case, somewhere between 4.3 and 5.3 seconds.

Exploring with the cursor shows that the velocity falls from 0.3 to 0 m/s and deceleration peaks at -6 m/s^2

All that happened in 0.1 second.



Try different shapes of crumple zone attached to the car.

How can you ensure that you are testing the crumple zones fairly?

Can you describe a "good" crumple zone in terms of velocity and deceleration?

Your data will include momentum and energy. Can they provide a better measure of the crumple zone's behaviour?

Explosions

You will need the linear track, the Primary and Secondary cars, the explosion bumper, 3 elastic bumpers and the wooden hammer.

Make sure the track is level. Check with a spirit level if possible.

Attach the explosion bumper to the back of the Secondary car.

Attach elastic bumpers to the front and rear of the Primary car, and to the front of the Secondary car.

For accurate work, check the mass of both cars with their attachments, then use Setup to enter the masses. The Status bar confirms the masses.

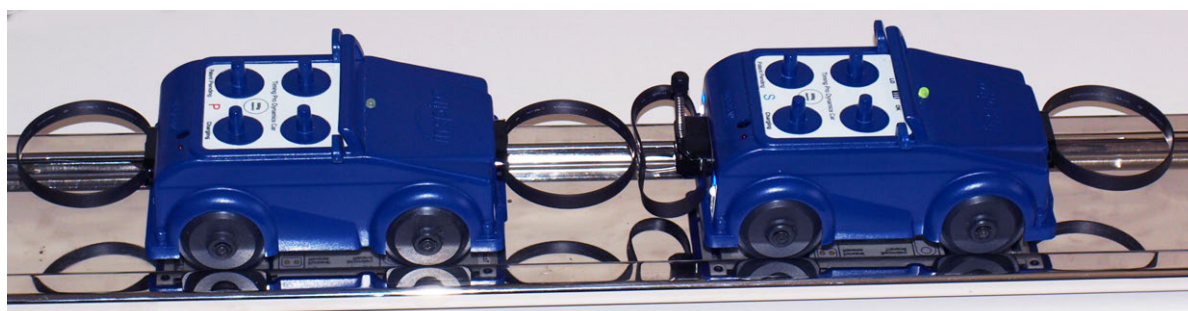
Switch on both cars. Launch the TimingPro application.

Click Connect to establish Bluetooth connection.

In the Setup menu check that "Linear Track" is ticked and Linear Track Angle is 0.

Place the cars on the linear track so that they face to the right, as shown.

Set the explosion bumper by squeezing the elastic loop on to the hook.



Display Displacement, Velocity and Momentum graphs.

Set the experiment time to 5 seconds.

Click on Start/ Stop.



Being careful not to hit the car, use the wooden hammer to smartly hit the black tip of the explosion bumper.

The cars will fly apart and rebound from the endplates.



When you have studied the results, try repeating the experiment with one of the cars loaded with extra masses.

Remember to enter the new mass of the car in Setup.

Some typical results and analysis are presented on the next page.

Explosions - continued

Analysis of an explosion

This example of an "explosion" had cars of equal mass.

The displacement graph shows that they moved apart quite symmetrically, the Primary car went backwards, the Secondary car forwards.

It is easy to see that their velocities were equal and opposite.

The cars were at rest, i.e. they had NO initial momentum.

The explosion gave them equal and opposite momentum, so momentum was conserved.

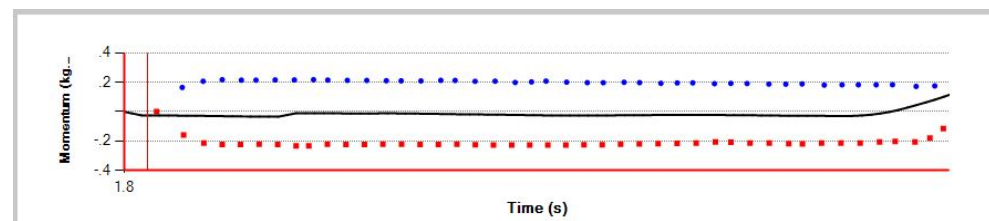
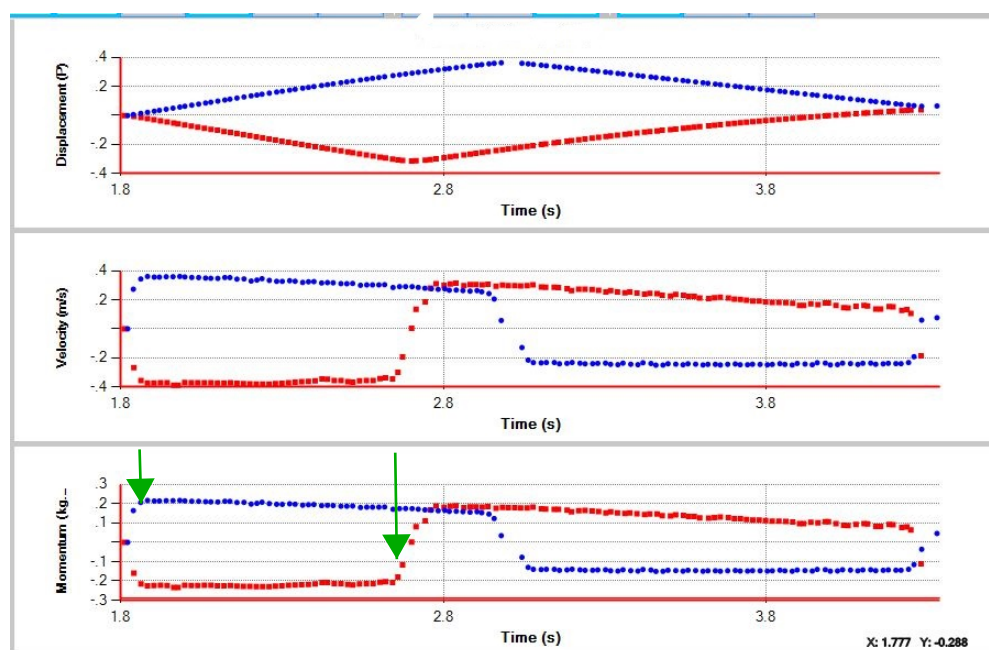
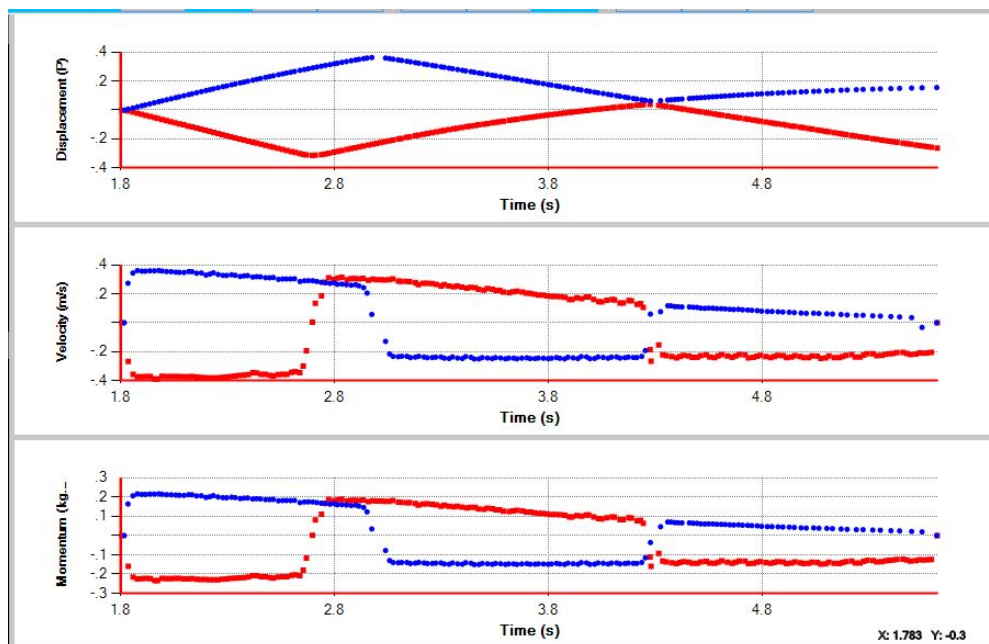
Using Edit, the unwanted data can be deleted, leaving a graph that can be explored with the cursor, to reveal the detail of the explosion.

The graphs here include the data from the explosion and the cars' first bounce off the track endplates.

Zooming in and using Summation gives a detailed view of the time between the green arrows.



The black line shows that the total momentum is very close to zero.



Setup an new explosion, doubling the mass of the Primary car. Remember to enter the new mass in Setup.

Predict and sketch the shape of the graph, before you perform the experiment.
How good was your prediction?

Oscillations 1 - inertia

Oscillations - inertial mass

You will need the linear track, the Primary car, 2 large hooks, plus a number of elastic bands.

Make sure the track is level. Check with a spirit level if possible. Fit the two large hooks to the endplates.

Place the Primary car on the track near the centre.

Make two chains of elastic bands, long enough to fasten to the two hooks, and stretch to attach to the car, as shown.

The elastic bands should be tight enough to stay close to horizontal.

Test the arrangement by pushing the car forwards or backwards and releasing it. The car should oscillate for several seconds.

Switch the car on. Launch the TimingPro application. Click Connect to establish Bluetooth connection.

In the Setup menu check that "Linear Track" is ticked and Linear Track Angle is 0. Set the experiment time to 10 seconds.

Use the Graph selection icons to display Displacement, Velocity and Acceleration.

Move the car by at least its own length from the centre position.

Click Start/Stop and release the car.

Study the graphs and discuss the following questions:

1) Does the oscillation have a regular period, like a pendulum?
Use the cursor to make measurements.

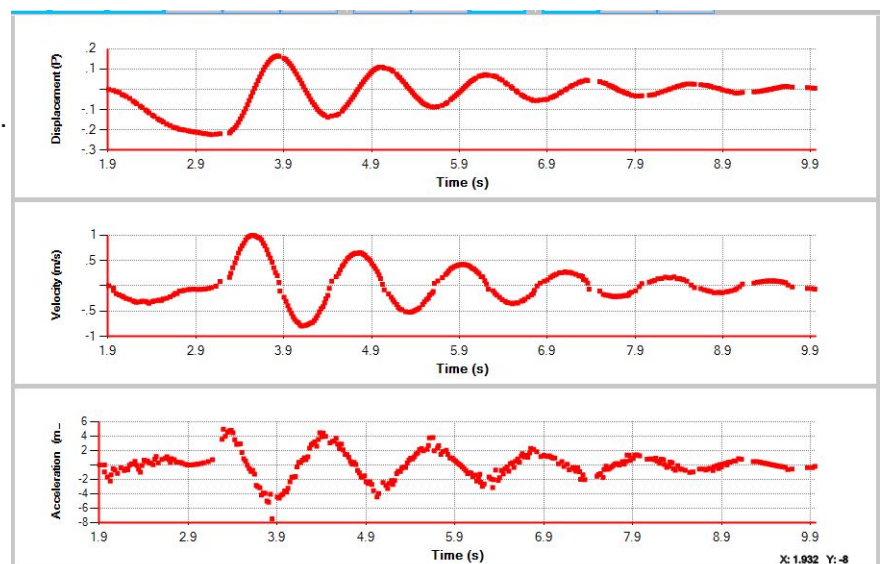
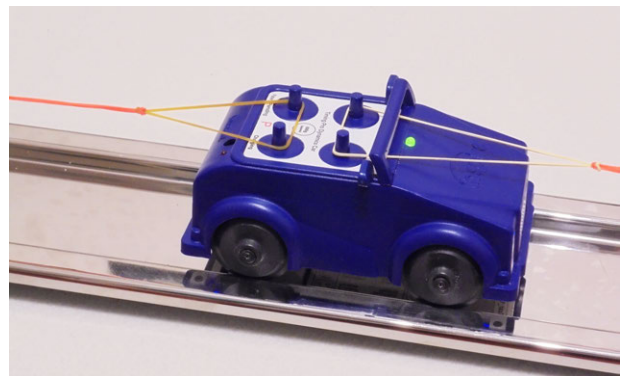
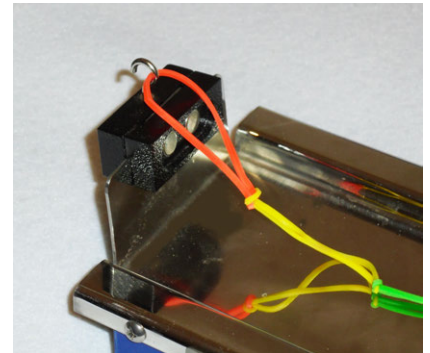
2) Look at the displacement graph. When the displacement is zero, what do you notice about the velocity?

3) When velocity is zero, what do you notice about the car's acceleration?

Repeat the experiment but load the car with additional masses - you can add up to 600 g.

Observe how the oscillation changes and make measurements to investigate the changes.

The elastic band chains provide the forces that cause the car's motion. Does gravity play any part in this experiment? Explain your answer.



Oscillations 2 - the curved track

Oscillations - using the curved track

You will need the curved track, the Primary car, no elastic bumpers.

Make sure the track is on a level bench.

Switch the car on. Place the car on the track.



Launch the TimingPro application.

Click Connect to establish Bluetooth connection.

In the Setup menu check that "Curved Track" is ticked and Linear Track Angle is 0.

Set experiment time to 20 seconds.

Click Start/Stop.

Move the car to one end of the curved track and release it.

Use the cursor to find the period of the oscillation. Is the period regular?

The Velocity and Acceleration graphs are "out of step" with the Displacement graph. Comment on this and explain how velocity and acceleration are related to the displacement.

It is helpful to look at points where one of the quantities is zero. Use the cursor to find these points.

Hide the Velocity and Acceleration graphs, then add the Energy graph.

The red line is the potential energy, the green line is the kinetic energy.

Look at points where displacement is zero and where it is a maximum.

Zoom in and try to describe the relationship between the two types of energy and displacement.

Click on Summation. The black line shows the sum of kinetic and potential energy. Energy is conserved by continuously exchanging potential energy and kinetic energy. Total energy decreases due to friction.

Repeat the experiment, doubling the mass of the car by adding the extra masses. Compare the results. Explain your results, making reference to a pendulum, and the effect of changing the mass of the bob.

