Technical Notes
Energy and Projectile Track

The Energy and Projectile Track is supplied with a chrome steel ball bearing of diameter 25.4 mm (i.e. 1 inch).

The Energy and ProjectileTrack allows you to study

- potential to kinetic energy conversions
- projectile motion
- linear collisions

The apparatus associated with the Energy Track is

- Light Gate Source, B1-1000.25
- Light Gate Receiver, B1-1000.35
- Light Bridge, B1-1000.07
- TSA (Time, Speed and Acceleration), B1-1000.01
- ALBA Interface and Logger, S1-1000.01
- Fast Timer software on Disk 2
- Timing Plate, B1-1000.16
- Sensor Extension Lead, G1-1000.10

Users may be able to adapt their own light gates to run with the Energy Track. In addition, their own data logger could be used with suitable Timing software. The Timing software should have a resolution of 0.1ms or better.

Comment on using the Energy Track

Place a clear plastic ruler place at the 10cm mark on the scale. Now place the ball directly behind it. Lift the ruler to release the ball. The ball will roll down the slope and along the flat section of the track. The vertical height between the top of the flat section of the track and the release point is 10cm.
If you wish to stop the ball at the end of the track use a piece of appropriate material for the ball to collide with. Take care to avoid loose ball bearings running around the floor.

If you are using the djb microtech Light Gate Source and Receiver then place them on their side on the flat section of the track. The centre of the ball bearing will coincide with the centre of the light gate. This makes the setup procedure very straightforward.

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Ideas for Energy Experiments

1) Using the straight track, release the ball from different heights and measure the speed at the bottom of the track. Now determine the relationship between height and speed.
2) Compare potential and kinetic energies – for both tracks. Does the energy lost vary with final speed along the track? Ignore the rotational energy of the ball bearing.
3) Repeat (2) but take account of rotational energy (see Appendix 1).
4) Measure the speed on the flat section of the track as close as possible to the bottom of the slope. Compare this with the speed at the end of the track. How much energy is lost per centimetre of track? Does this loss/cm depend on release height?
5) Compare the speed of the ball when released from 28cm on both tracks. Account for any differences. Note that at a release height of 28cm the ball will loop the loop.
6) For a ball to loop the loop without leaving the track theory shows that the minimum vertical height from which the ball is released should be 2.7 times the loop radius (see Appendix 2). Determine this minimum height and explain any divergence from the theoretical value. Does this height vary with different masses of ball?

Ideas for Projectile Experiments

1) Position the track at the end of a bench and, using the Timing plate along with TSA or the ALBA Data Logger, find the time of flight. Now using $s = ½ at^2$, calculate the release and compare this with the measured value.
2) Position the track at different heights (taking care to ensure that it is level) and determine the relationship between release height and range.
3) Do different sizes of ball affect the range?
4) How does the release height of the ball up the track affect the range?
5) For a measured launch speed at a known bench height, calculate the range and compare it with the measured value.

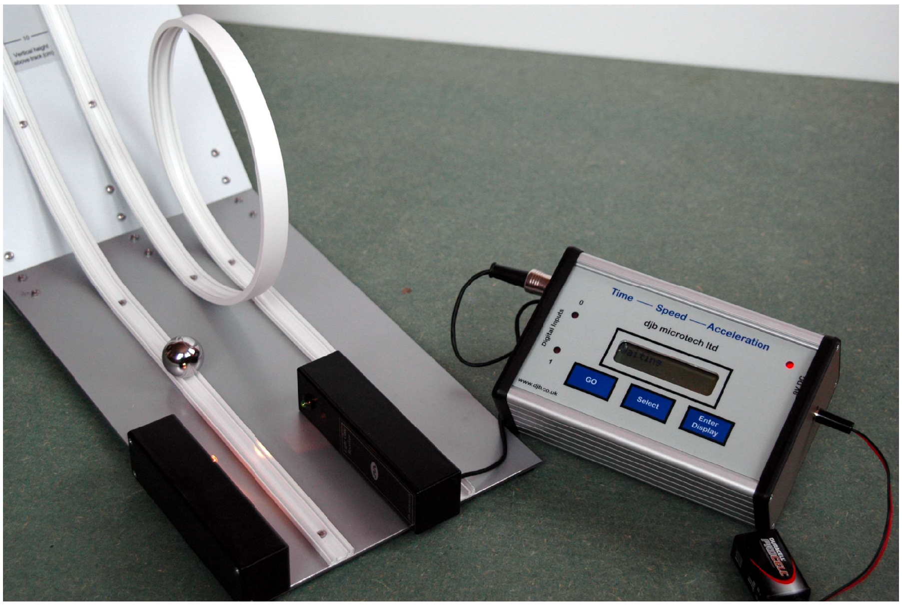
Ideas for Collision Experiments

1) If a ball bearing collides inelastically with an identical stationary ball bearing then the moving one should stop and the stationary one should move off at the incident speed. Release a ball bearing from say 20cm and allow it to collide with a stationary ball bearing. Explain your observations.
2) Repeat the experiment above but this time release a smaller ball bearing.

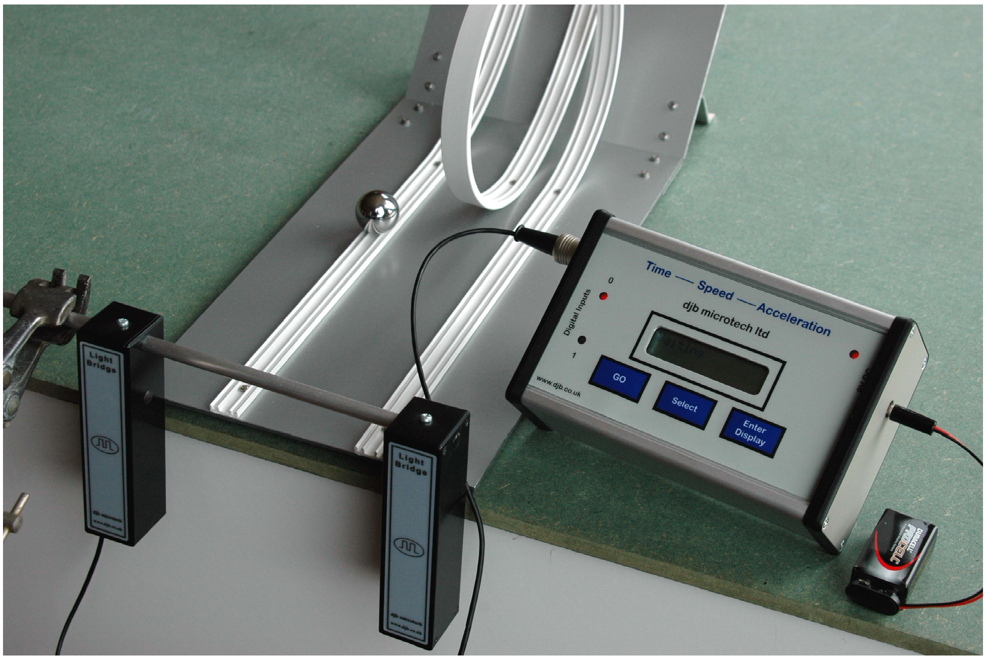
Various Apparatus Setups

Measuring Speed with TSA and Light Gate

Connect your Light Gate Receiver to TSA (or the ALBA Interface and Logger). Note that TSA can be powered by a plugtop power supply or a 9V battery. The Light Gate Transmitter should be positioned so that the lamp is not in the path of the ball bearing.



Measuring Speed with TSA and Light Bridge
Clamp the Light Bridge in a retort stand and position it at the the very end of the track so that the the height of the beam is the same as the middle of the ball bearing. Connect your Light Bridge to TSA (or the ALBA Interface and Logger).



Connecting the Timing Plate
Connect the Timing Plate to the second digital input on TSA (or the ALBA Interface and Logger). Position the Timing plate on the floor where the ball bearing is going to land - a dummy run will be necessary. When the ball hits the Timing Plate a timing event occurrs and TSA records the event time.

Note on Using TSA with the Timing Plate

Let's assume that you want to release a ball bearing on the slope and measure the time of flight from the end of the track until it hits the Timing Plate. The Light Gate (or Light Bridge) should be positioned at the very end of the track. There will be three Event Times

- the leading edge of the ball cutting the beam; this starts the timing – t_1
- the trailing edge of the ball re-establishing the beam – t_2
- the ball hitting the Timing Plate – t_3.

If you only wanted to measure the launch velocity then two event times would be required. However we require three event times for this experiment and using TSA + GM Counter it is very straight forward to set it to measure the three Fast Timer event times. The launch speed of the ball can be found using (t2-t1) and the time of flight from (t3-t2).

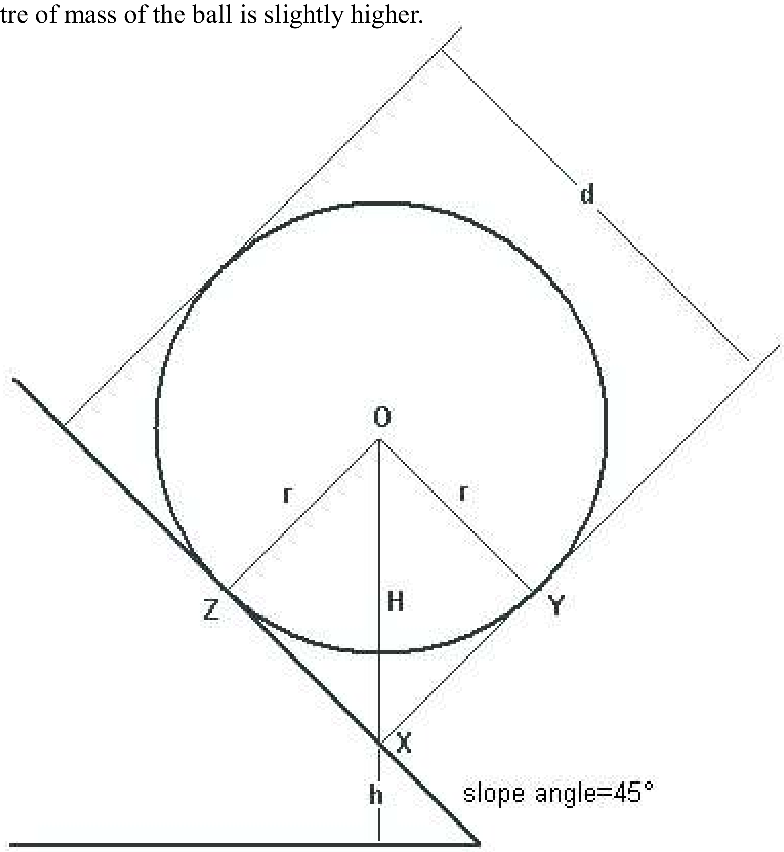
Users with older versions of TSA can only measure two event times using the Fast Timer. To circumvent this problem the ball is released twice from the same height. The first time it is released the Fast Timer should be used to find the launch velocity. The ball is released again from the same starting height but this time the Event Timer, set to three event times, is used. The Event Timer mode permits up to eight times to be measured. However the resolution of this timer is less than the Fast Timer but in this case it does not matter as the time of flight (t_3-t_2) is very long compared to the time (t_2-t_1).
Once the technique for measuring the launch velocity and time of flight are achieved lots of interesting Physics can be done.

Because of the lower resolution, the Event Timer should not be used to calculate the speed of the ball.
Note that with the Fast Timer software for the ALBA Interface and Logger you are not restricted to two times.

Some Thoughts

1) Release Height Adjustment

If, as suggested above, a clear plastic ruler is used to release the ball from position X which is has a vertical height h cm then the centre of mass of the ball is slightly higher.



d = diameter of ball
r = radius of ball
h = vertical height of X above top of rail on base board
H = vertical height of the centre of mass above release point X

If you wish to consider the centre of mass as the release height then the height h has to be increased:

height of centre of mass on slope = h + r/sin(45)
= h + 1.4 x r

height of centre of mass on flat = r
change in height = h + 1.4 x r – r
= h + r(1.4 – 1)
= h + 0.4 x r

if the diameter of the ball is 2.54cm then r = 1.27cm
hence change in height = h + 0.53cm

2) Track Levelling

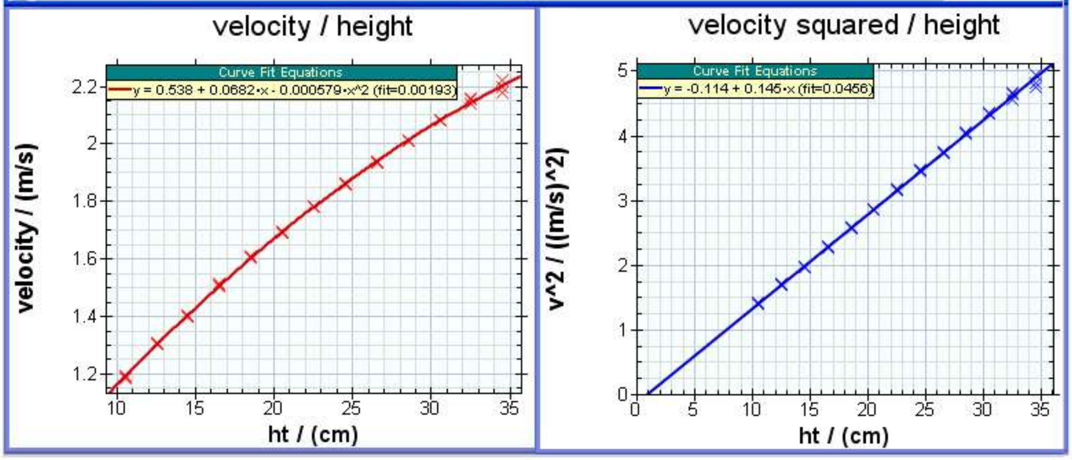
Use a spirit level to check that your track is level before you start. Use sheets of paper for fine adjustment of the levelling.

3) Different Diameter Ball Bearings

The 1 inch diameter ball bearing has its centre at the same height as the djb microtech light gate (when the light gate is lying on its side). If you use a different diameter ball then the position of the light gate has to be adjusted. If smaller ball bearings are used then our Light Bridge should be used but it would have to be carefully aligned at the end of the track – see Photograph on page 3.

Typical Results

notes	ht cm h	time ms t	velocity m/s (A) v	v^2 (m/s)^2 (A) v2	Ep mJ (A) Ep	Ek mJ (A) Ek	Er mJ (A) Er	Etotal mJ (A) Et
1	10.5	21.44	1.18	1.40	69.2	47.0	18.8	65.8
2	10.5	21.33	1.19	1.42	69.2	47.5	19.0	66.5
3	10.5	21.27	1.19	1.43	69.2	47.8	19.1	66.9
4	12.5	19.38	1.31	1.72	82.4	57.5	23.0	80.6
5	12.5	19.50	1.30	1.70	82.4	56.8	22.7	79.6
6	12.5	19.48	1.30	1.70	82.4	57.0	22.8	79.7
7	14.5	18.11	1.40	1.97	95.5	65.9	26.4	92.3
8	14.5	18.12	1.40	1.96	95.5	65.8	26.3	92.2
9	14.5	18.07	1.41	1.98	95.5	66.2	26.5	92.7
10	16.5	16.77	1.51	2.29	108.6	76.9	30.7	107.6
11	16.5	16.80	1.51	2.29	108.6	76.6	30.6	107.2



Graphs drawn using the ALBA Data Logging software - demo version available free from www.djb.co.uk

The heights in the Table above have been adjusted. The plastic ruler was placed across the 10cm mark on the track with the ball resting against it. The point of contact of the ball with the track is 10.53cm – see calculation on page 4.
The velocity column is obtained by taking the diameter of the ball (2.54cm) and dividing it by the time.
The potential energy, Ep, was calculated using the mass of the ball as 67g and the acceleration due to gravity as 9.8 m/s^2.
The rotational energy, Er, of the ball was calculated using $½.I.v^2/r^2$ where $I = 2mr^2/5$. This simplifies to $I = m.v^2/5$.

The Technical Notes are available as a coloured pdf in the Teachers section of our website.

Appendix 1 - Calculation of the speed at the bottom of the ramp when the ball is released from a known height

A ball rolls down a slope without slipping. It starts at rest from a height h. No energy is lost to friction as it rolls. The initial potential energy is

$$PE_i = mgh$$

The initial kinetic energy is zero and the final potential energy is zero. The final kinetic energy is

$$KE_f = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

For an object rolling without slipping, v = ωr, so the final kinetic energy is

$$KE_f = \frac{1}{2}v^2(m + \frac{I}{r^2})$$

At the bottom of the slope, the potential energy is zero. Thus the final kinetic energy is the same as the initial potential energy:

$$KE_f = PE_i$$

$$\frac{1}{2}v^2(m + \frac{I}{r^2}) = mgh$$

Solving for v gives

$$v = \sqrt{\frac{2gh}{1 + I/(mr^2)}}$$

This equation is true for any object rolling down a slope. For a rolling ball, $I = 2mr^2/5$

$$v = \sqrt{\frac{10gh}{7}}$$

Appendix 2 - Calculation of minimum release height for ball to loop the loop without leaving the rail

At the highest point h of the loop the upward centrifugal force must be at least equal to the downward force of gravity acting on the ball to keep it on the rail so we must have:

$$mg = mv^2/R$$

so $v^2 = g R$ where R is radius of loop

note also we have h = 2R;

At this point the total Energy will be:

E_t = E(translational) + E(rotational) + Ep where E_t is the total energy

but E(translational) = $1/2mv^2 = 0.5mgR$,

Ep = mgh = mg.2R and

E(rotational) = $½.I\omega^2$

With the moment of inertia of the ball $I = 0.4mr^2$ and its angular speed ω = v/r with r being the radius of the ball.

Then E(rotational) = $0.5*(0.4mr^2) . (v^2/r^2) = 0.2$ mg R and

$$E_t = 0.5mgR + 0.2mgR + 2mgR$$
$$= 2.7mgR$$

Which must be equal to the initial energy mgH where H is the vertical height from which the ball is released, so

$$mgH = 2.7mgR$$
$$H = 2.7*R$$

ie the release height is 2.7 times the radius of the loop