TAP 603-2: One collision: many collisions

A few molecules: lots of molecules

To change the momentum of a single molecule in collision with the walls of a container requires a force acting for a short time. Many molecules colliding with a surface produce a continual force, interpreted as a steady pressure. This arises from a continual rate of change of momentum, happening over a fixed area.

You will need

- ✓ force sensor connected to a fast data capture display device
- ✓ flexible plastic track
- ✓ five tennis balls
- ✓ bucket
- ✓ rubber tubing
- ✓ Hoffman clip
- ✓ access to water
- ✓ access to a gas tap

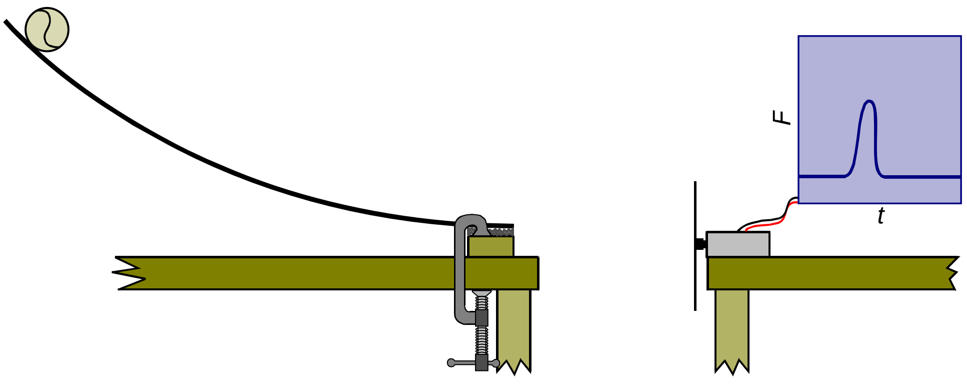
or

- ✓ access to pressurised air

Setting up

You will be looking at a force sensor linked up to a computer screen, recording the force exerted on a small plate about 5000 times a second. A variety of particles, from tennis balls to air molecules, will be fired at this plate in turn.

A single collision



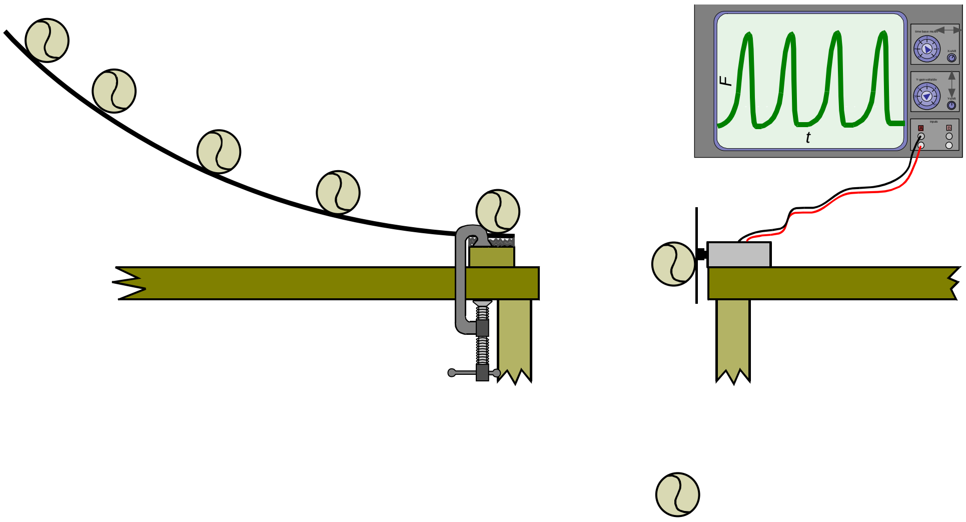
The ball trundles down the track into the force sensor. Here it needs to bounce, not to stick. Can you see why?

You can simulate 'warming the gas' by releasing the ball from further up the hill.

Some things to try:

1. Measuring the peak force.
2. Relating the peak force to the speed of the ball.

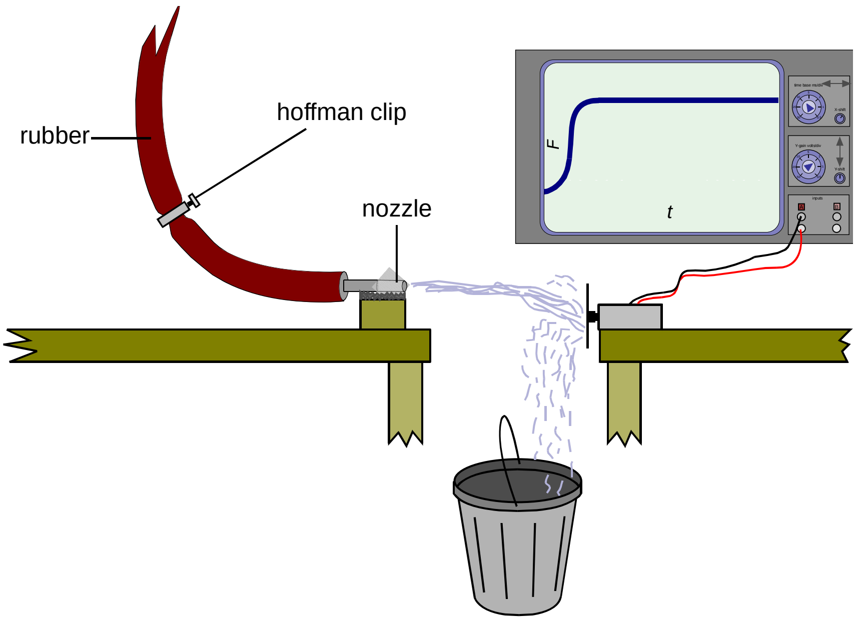
3. Relating the momentum before the collision to the area under the force / time curve.
4. Many collisions. Now look at streams of balls, the number arriving per second gradually increasing.



Look out for the blips of force smearing out into a steady value, as you look over time scales that are long compared with the interval between collisions.

Fluid streams

Now look at streams of molecules producing forces that seem to be completely steady.



Things to think about and perhaps try:

1. Calculating the number of molecules hitting the force sensor per second.

2. Calculating the average interval between these collisions.
3. Comparing the rate of change of momentum with the force exerted.

You have seen

1. How many collisions a second produce a steady force.
2. How to relate the rate of change of momentum of the colliding particles to the force exerted.

Practical advice

You will need a force sensor capable of taking 5000 or so readings a second, and able to discriminate to 1N or so, in order to make this experiment work as written. A cheap substitute is to mount an old spring-calibrated set of kitchen scales horizontally, so as to measure forces in the horizontal plane, in place of the force sensor. This is unlikely to produce a discernible reading for the stream of air.

Tennis balls are preferred to harder balls, such a marbles or ball bearings, as they confer a degree of damping on the collision with the force sensor.

A single collision: Try to get a well defined F / t plot generated from a single collision with the force sensor. You might like to relate increasing velocity of impact to the changes in the F / t plot.

Many collisions: Now release a well spaced stream of tennis balls down the ramp, performing several runs, gradually reducing the interval between releasing the balls on each run, each time looking at the pulses of force. As the interval is reduced, encourage students to see an increasing smoothing of the force over time. You might rig up a vibration generator to release the balls at regular intervals, or try changing the mass or velocity of the balls. There are plenty of discussions that can arise from this experiment, all assisting with the fundamentals of the kinetic theory of gases.

Fluid streams: Here the bucket will be needed. You might carefully direct a stream of water at a plate connected to the force sensor (not over the force sensor!) and use the bucket to collect the water – so giving a mass per second. Knowing the diameter of the jet enables you to calculate the impact velocity – or constant-head apparatus and conservation of energy might give you a value. What happens here is open to development, according to the aptitude and interest of the class. Measuring these quantities should be an exercise in skilful manipulation of apparatus, and might be set as a challenge to the more able to pursue further and then present to the class. Or it might provide a starting point for an investigation.

A stream of air will also provide a measurable force on some force sensors (try it first!). Adapt the means of providing a controlled flow of air to suit local circumstances.

You might ask students to recall listening to rain on a roof, particularly a glass roof, and ask the following question: ‘How does this phenomenon illustrate these ideas?’.

Alternative approaches

You can replace all the high-tech measurements with a jug full of marbles poured over a top pan spring balance. There are advantages to seeing pulses of force smeared out by the averaging action of the spring in the balance. These approaches are supplementary.

Social and human context

An imaginative leap similar to this one is necessary to see smooth macroscopic effects emerging from discrete microscopic events.

External reference

This activity is taken from Advancing Physics chapter 13, 90P