Accelerator bowl

The 'accelerator bowl' is a model of a particle accelerator that can be used to explain the workings of real machines like Diamond, ISIS or even the Large Hadron Collider. Although it's a very simple model, by discussing the similarities and differences between this and a real accelerator we can understand a lot of the science involved.

It looks like a salad bowl connected up to a high voltage 'Van de Graaff' generator – and that's pretty much all it is! When a 'particle' is placed in there, it moves around and gets accelerated until it is circulating around the bowl. But how does it work?

The Van de Graaff generator builds up a high voltage by generating lots of *static electricity*. This means there is a high *voltage* of around 30,000 V but it is rather safe as even if it sparks, there is only a tiny *current*. Inside the bowl are two sets of metal conducting strips. One set crosses over in the centre of the bowl, and these are attached to the high voltage terminal of the Van de Graaff generator. The rest of the strips are connected to ground, or 0 V.

A ping pong ball coated in a conducting paint is placed in the bowl. When the voltage is switched on, the ball moves around a little because of *induced charges* on the ball. Soon it comes into contact with a charged strip and picks up that charge – so now it has a *like charge* to that of the strip. This causes *repulsion* and gives the ball a push along. When it rolls over a grounded strip, the ball becomes *neutralized* and loses its charge. But it doesn't lose its *momentum* and keeps rolling around the bowl. The next time it comes across a charged strip, it picks up the charge again, gets repelled in the same direction as before and once again gets a little kick along. Every time the ball crosses a charged strip it gets *accelerated.*

Give it a push…

In most real particle accelerators this is how *subatomic particles* such as *electrons, protons or ions* are given their energy; they see a voltage and get pushed along by it. In circular accelerators the beam of particles is bent around in a circle so voltage gets re-used again and again, with the particles gaining a little bit of energy each time. The difference is that in most modern accelerators the voltage isn't *static* like the one from a Van de Graaff generator. You might have noticed that in this demonstration the 'particle' is *changing* it's charge every time it gets a kick. But real particles have a fixed electric charge, so instead the *voltage* has to change very quickly from positive to negative and back again. That way, every time the particle goes past it will see an *accelerating voltage* rather than a *decelerating* one! To do this, we use *radiofrequency cavities*. These cavities *resonate* with *electromagnetic waves* and play the trick of providing a rapidly varying voltage. If the *frequency* of the wave is timed correctly, every time the particle goes through it will be accelerated.

The highest energy we've reached by accelerating particles this way is at the Large Hadron Collider (LHC) at CERN, where the protons are travelling at 99.999999% of the speed of light. At this speed they whizz around the 27km ring more than 11,000 times per second.

But that's not the only difference between this demonstration and a real accelerator. Real particles are much smaller than a ping-pong ball, it's hard to define a size of something as tiny as a particle, but the *classical radius* of a proton is around 200 trillion times smaller. To see the beam we have developed tools called *diagnostics*, which act like our eyes and ears when it comes to seeing the position of the beam, it's charge, current and size.

The accelerator bowl only uses one 'particle', but real accelerators have trillions or more of them at the same time, all with the same electric charge so they repel against one another. Controlling them at the same time is tricky, but it's very important that we don't accidentally lose the beam! Even though in the LHC each proton

only has as much energy as a fast-flying mosquito, the whole beam combined has enough energy to melt tonnes of solid metal!

Salad bowls…

Unfortunately we can't roll particles around in salad bowls either. They travel in a *beam pipe*, which has all the air taken out so it's under *ultra-high vacuum*. If there were any air left in there, the particles would scatter off it and get lost, which we want to avoid. To make the particles bend around a corner we use magnets. *Dipole magnets* do the bending, while more complicated magnets called *quadrupoles, sextupoles* and even *octupoles* do the job of beam focusing and other effects. The higher the energy of the beam, the stronger those magnets have to be. In the case of very high-energy machines like the LHC the magnets are often *superconducting*. This means that they can create very high magnetic fields, but it also means they have to be cooled down to *cryogenic* temperatures – in some cases just 1.8 K, that's -271° C!

A bendy problem…

In high-energy accelerators, bending a beam around a corner does something rather strange, it gives off *synchrotron radiation*. In an electron accelerator like Diamond this is exactly what they want to happen. The intense beams of radiation (mostly X-rays) are used to conduct experiments. They actually add in extra devices called *wigglers* and *undulators* in order to make as much *synchrotron radiation* as they can. But in an accelerator like the Large Hadron Collider this is an unwanted side effect, as it makes the beam lose energy. This energy loss can limit the maximum energy of a circular accelerator – we reach a point where the 'kick' from the radiofrequency cavities is just replacing the energy lost by synchrotron radiation.

The challenge of being able to do all these things at once means particle accelerators are always on the cutting-edge of technology. We're constantly seeking to go faster, higher and better than before!