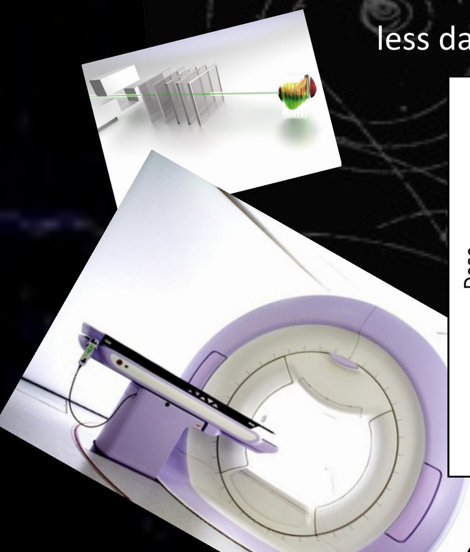
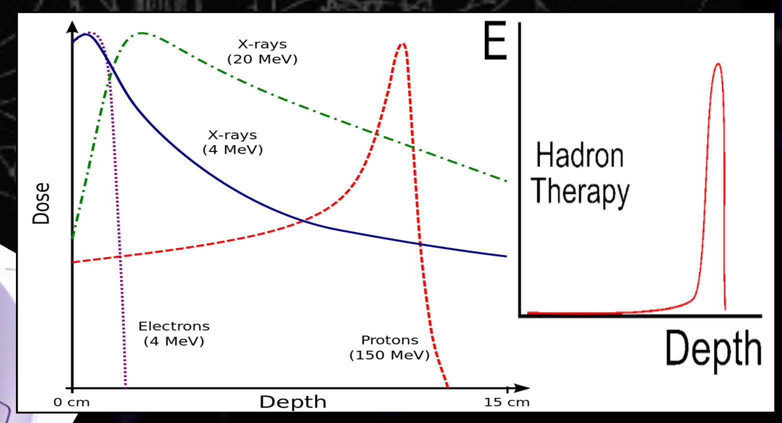
Particle Accelerators

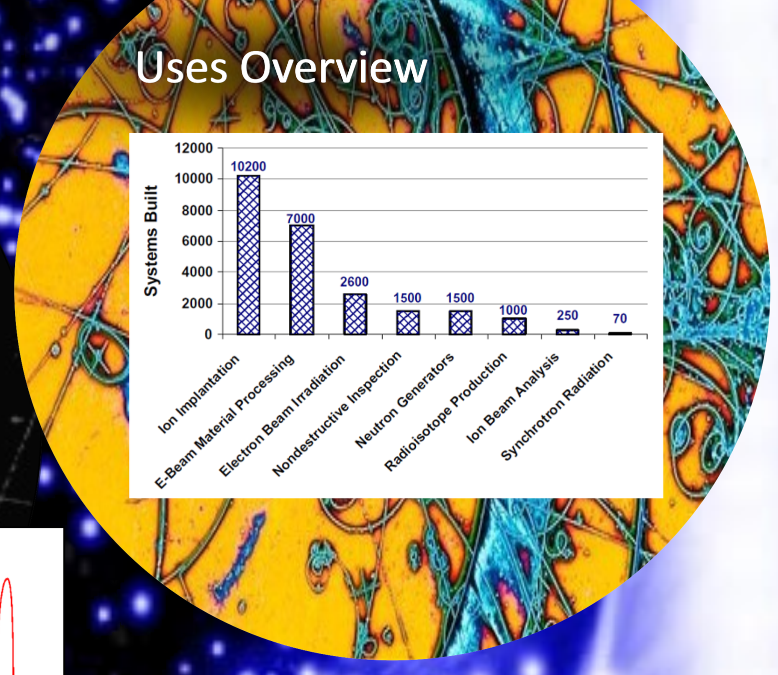
Uses: Hadron Therapy

- Ionising particles such as protons are fired into the body. They are aimed at cancerous tissue.
- Most methods like this irradiate the surrounding tissue too, but protons release most of their energy at the end of their travel. *(see graphs)*
- This allows the cancer cells to be targeted more precisely, with less damage to surrounding tissue.



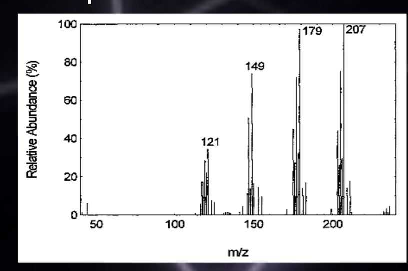


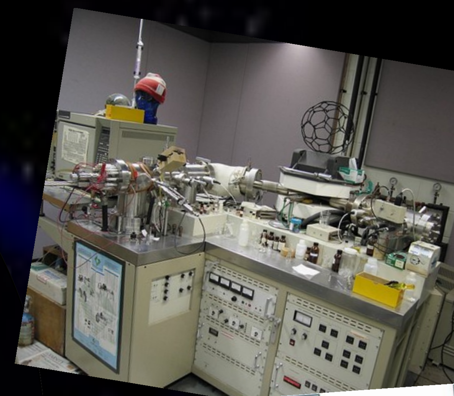
Uses Overview

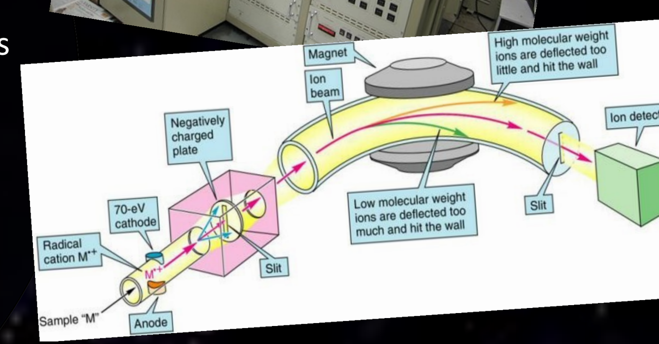


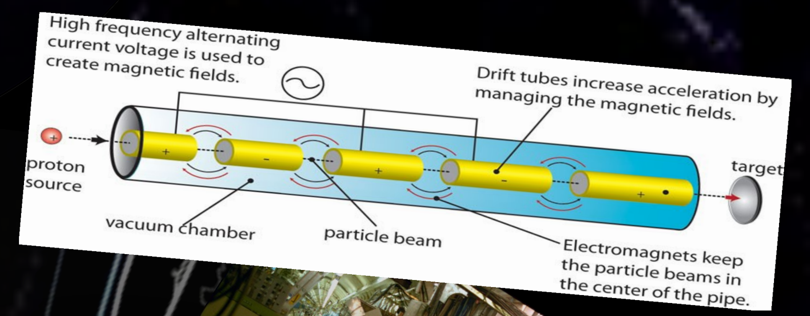
Uses: Mass Spectrometry

- This is a technique in analytical chemistry.
- It allows the identification of chemicals by ionising them and measuring the mass to charge ratio of each ion type against relative abundance.
- It also allows the relative atomic mass of different elements be measured by comparing the relative abundance of the ions of different isotopes of the element.
- An example mass spectrum is shown below:



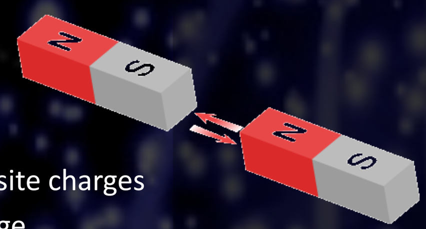


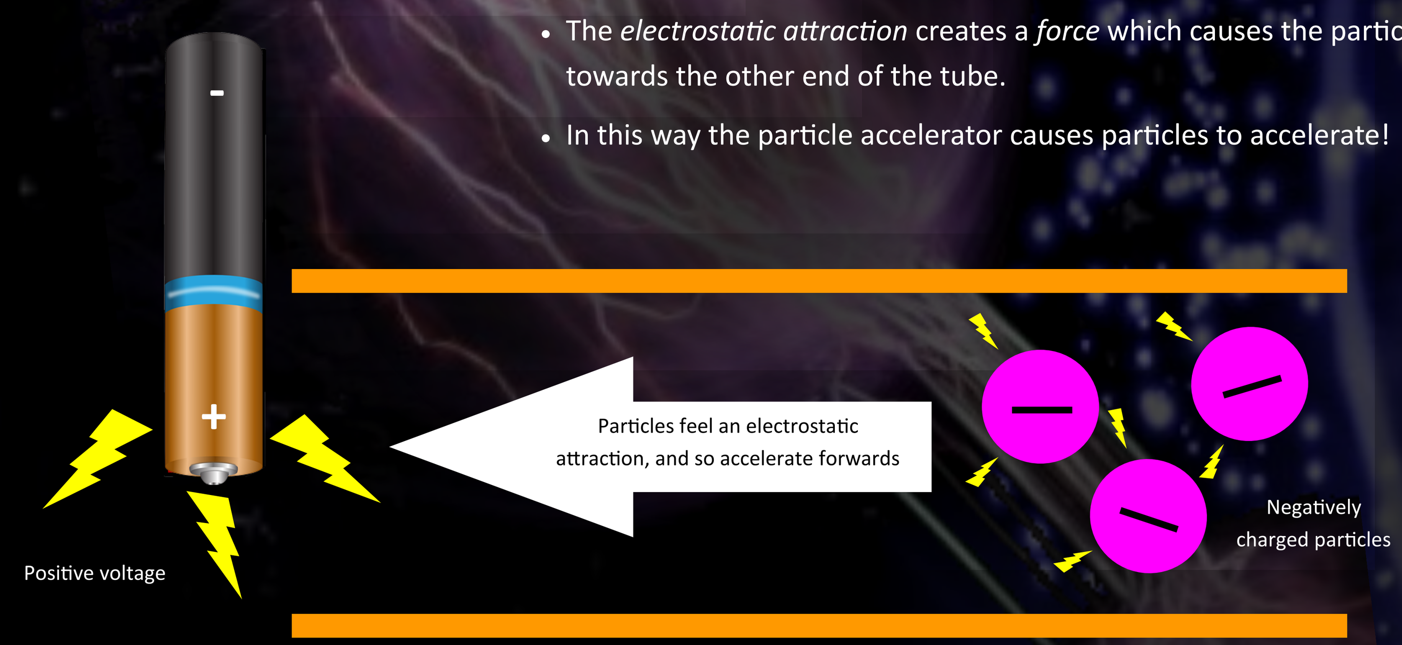




Electrostatic Particle Accelerators

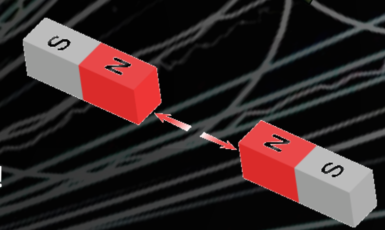
- An *electrostatic voltage* is provided at one end of a vacuum tube.
- This is like the charge on a magnet.
- At the other end of the tube, there are *particles* with the opposite charge.
- Like north and south poles on a magnet, the opposite charges attract and the particle is pulled towards the voltage.
- The *electrostatic attraction* creates a *force* which causes the particle to *accelerate* towards the other end of the tube.
- In this way the particle accelerator causes particles to accelerate!

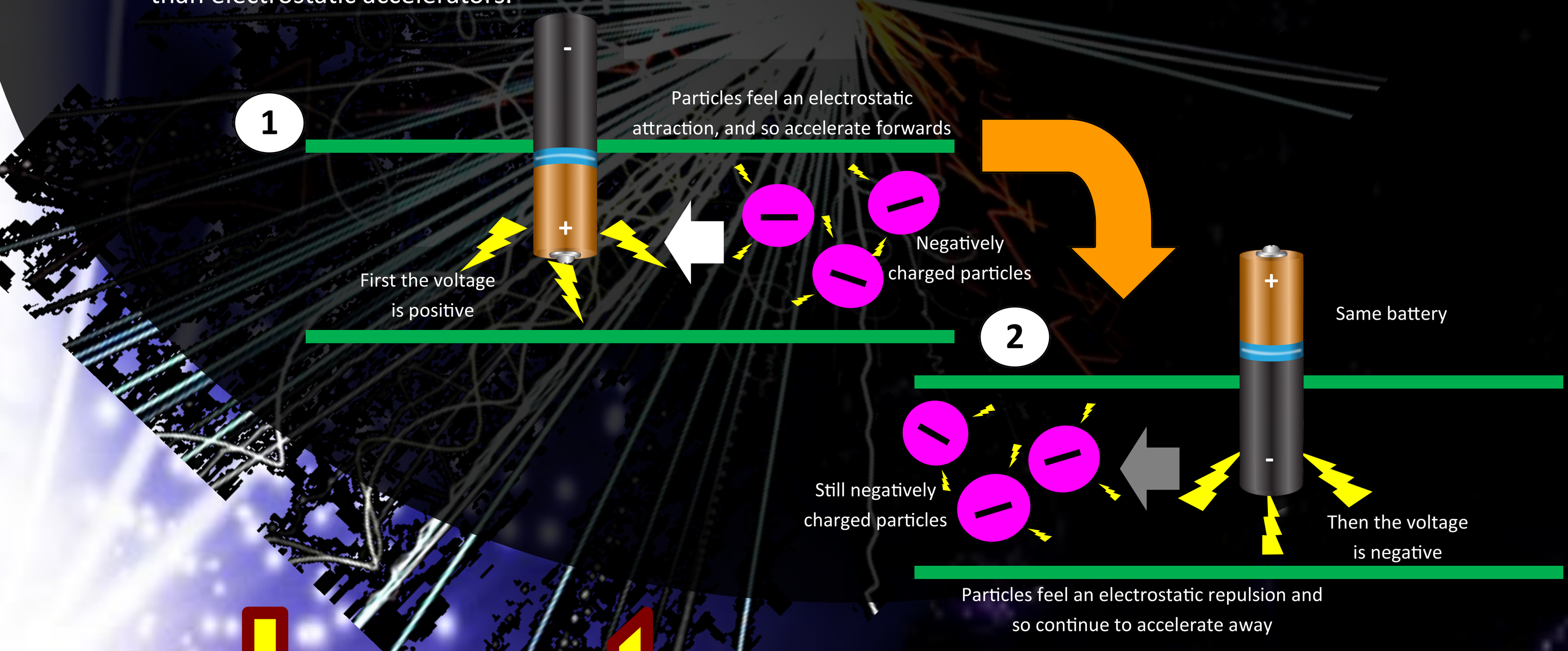




Linear Particle Accelerators

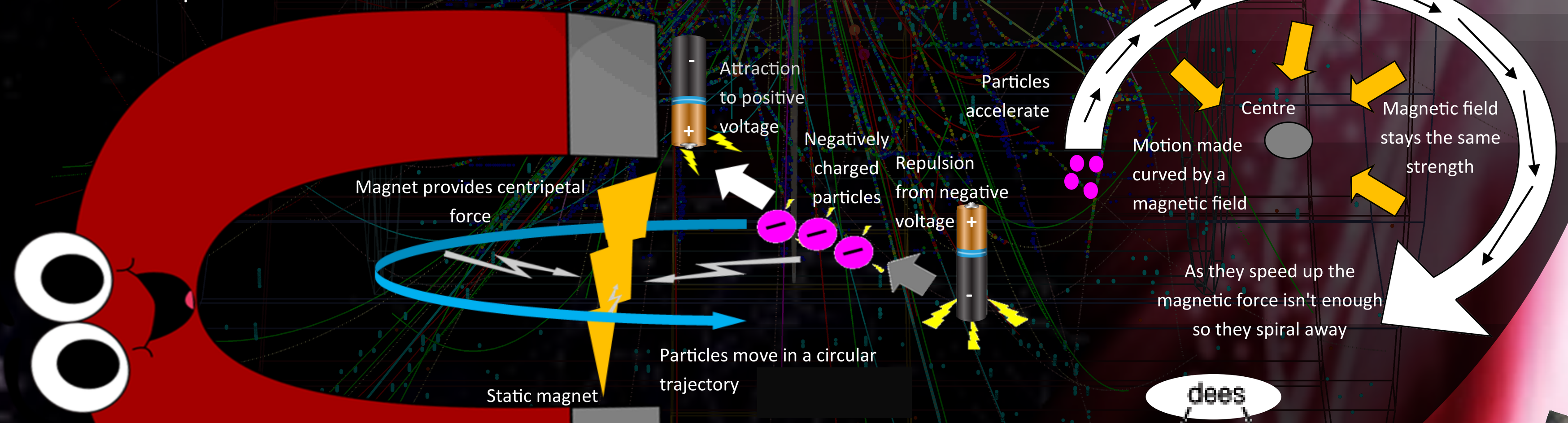
- These are still in a straight line, but now the voltage is no longer static - it is *oscillating*.
- This means the voltage is changing - so if it were a magnet, it would be first positive, then negative.
- Like the electrostatic accelerator, a charged particle is attracted to it as the charges are opposite, but just as the particle goes past the voltage changes, and the charge of the plate swaps (so it is now the same charge as the particle).
- Again like magnets - the same charges *repel* (eg north repels north).
- This means the particle receives a force away from the voltage too, so at first it is accelerating towards the voltage, then as it goes past it continues to accelerate away!
- This allows the particle to be accelerated for longer - so it can get to higher speeds.
- There may be many such voltages in a row, with each causing more acceleration, making linacs much more powerful than electrostatic accelerators.

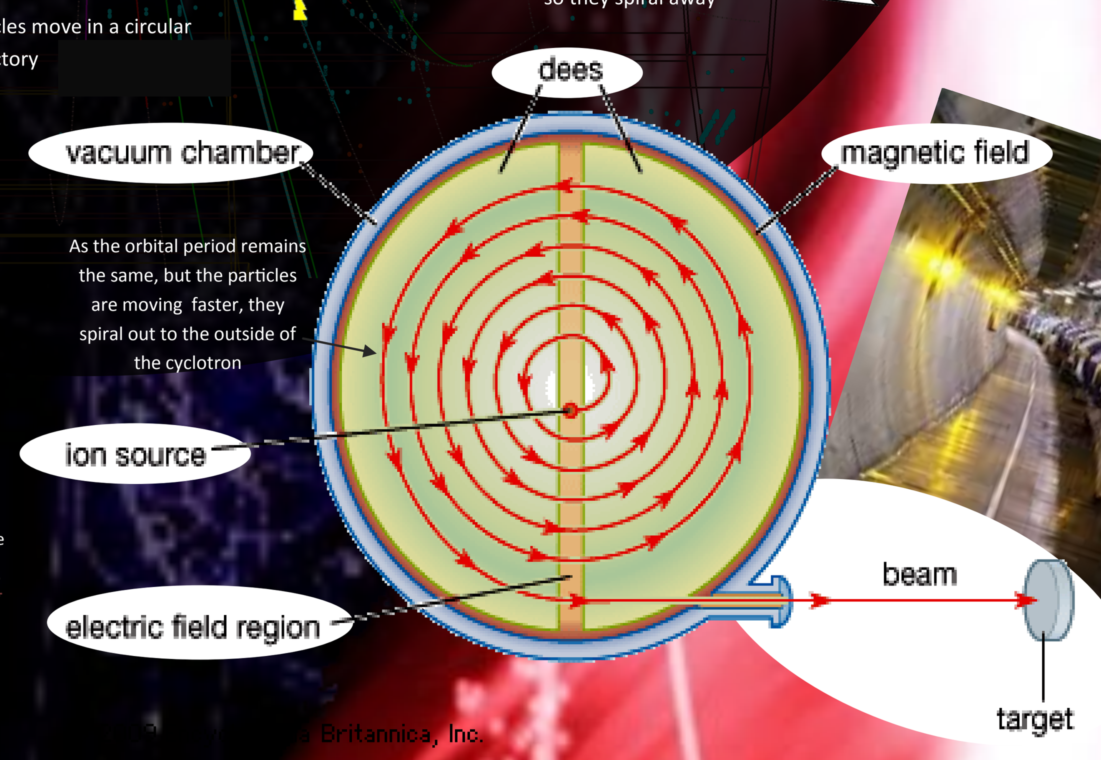


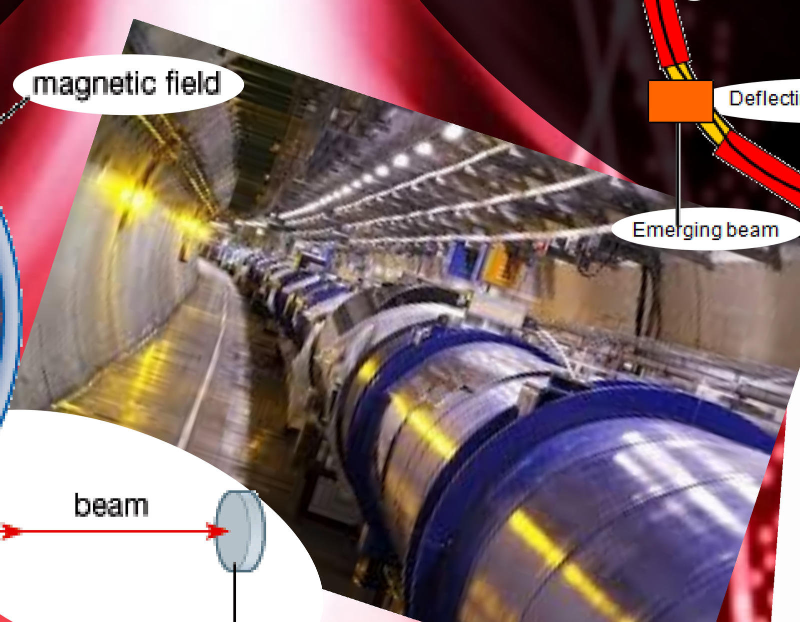


The Cyclotron

- This was the first type of *circular particle accelerator.*
- The particles move around in a *spiral* shaped path. The *force* which keeps them moving this way is provided by a *static magnetic field*. This is the *Centripetal Force* (a force that causes circular motion).
- As they *orbit* (move around the centre) they pass through an *alternating electric field* which speeds them up in the same way as in the *linac*.
- But as the particles are moving circularly, they can pass through the same field many times, and thus can be accelerated more, by fewer magnets than a linac (there are normally two - called *"dees".)*
- As the magnetic field does not change (it's *static*) the particles have to take the same time to complete one orbit (see the maths below). As they are speeding up, this means they have to travel further each time, and so move out in a *spiral trajectory*.
- The circular motion and fewer required magnets mean that cyclotrons are much smaller, more cost effective, and more powerful than linacs.







$$Lorentz\ Force:\ F = q(E + Bv)$$

$$Centripetal\ Force:\ F = \frac{mv^2}{r}$$

$$\frac{mv^2}{r} = qBv$$

The distance is the circumference of the circle

$$Circulation\ Frequency = \frac{speed}{distance} \quad \therefore\ f = \frac{v}{2\pi r}$$

$$v = 2\pi rf$$

Here we equate these equations. As the Lorentz force is providing the centripetal force, we can put them equal to each other.

$$\frac{mv^2}{r} = qBv$$

$$\frac{mv}{r} = qB$$

$$v = \frac{qBr}{m}$$

$$2\pi rf = \frac{qBr}{m}$$

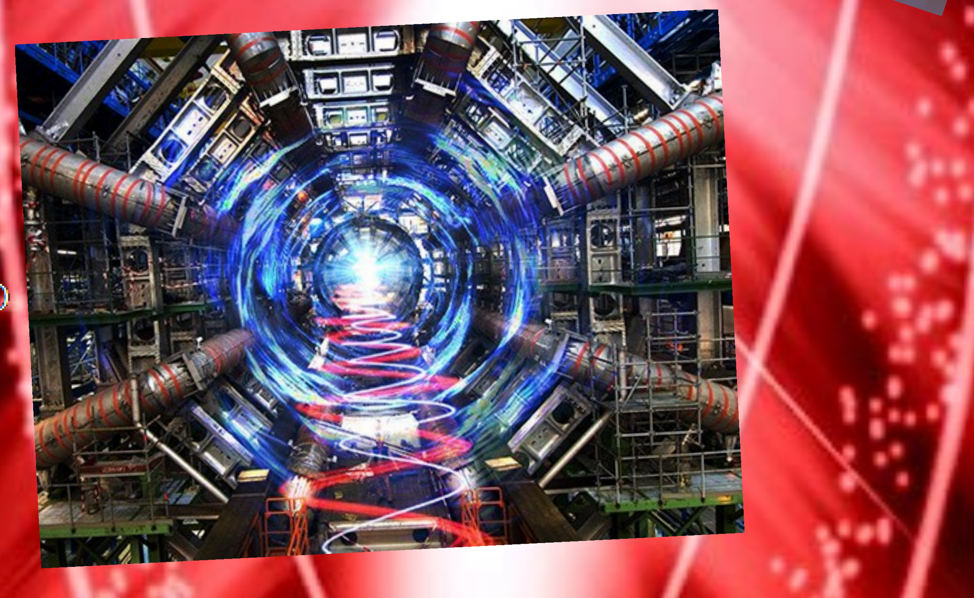
$$f = \frac{qB\not{r}}{2\pi m\not{r}}$$

$$f = \frac{qB}{2\pi m}$$

Neither *r* nor *v* appear in this equation

This shows that the circulation frequency is independent of the speed the particle is going, or the distance it is orbiting at! This tells us the frequency will stay constant!

$F = Force$
$q = charge\ of\ particle$
$E = Electric\ Field\ Strength$
$B = Magnetic\ Field\ Strength$
$m = particle\ mass$
$v = particle\ velocity$
$r = distance\ from\ particle\ to\ centre$
$f = circulation\ frequency$
$(number\ of\ times\ the\ particle\ moves\ around\ per\ second)$
$\pi = pi = 3.14\ ...$



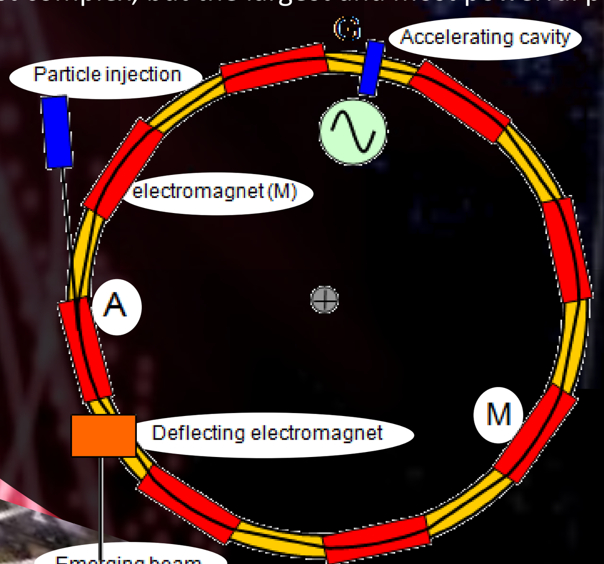
The Synchrotron

- The problem with cyclotrons is Einstein's relativity. As a particle speeds up, its mass increases. This limits the energy of the particles in a cyclotron. The equation for this is:

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$m = relativistic\ mass$
$m_o = rest\ mass$
$v = velocity$
$c = speed\ of\ light\ in\ a\ vacuum \approx 3 \times 10^8 ms^{-1}$

- To get around this, the strength of the magnetic field that keeps the particles in a circle can be varied. As the particles go faster, the magnetic field strength (B) can be changed, so even as they change in mass the accelerator can work. This is a synchrotron.
- The magnetic field can be adjusted so precisely, that the particles no longer spiral, but instead are held within a large thin torus (ring doughnut shape).
- This allows much larger, cheaper and more powerful accelerators (such as the LHC at CERN) as you only need the edge of a circle, you don't need to clear the inside (like you would for a cyclotron - where the particles spiral from the centre).
- However the synchrotron is a closed circle so there is nowhere for a particle emitter, therefore the synchrotron cannot accelerate particles from rest, and instead needs a linac or cyclotron to fire particles into it.
- These are the most complex, but the largest and most powerful particle accelerators there are.



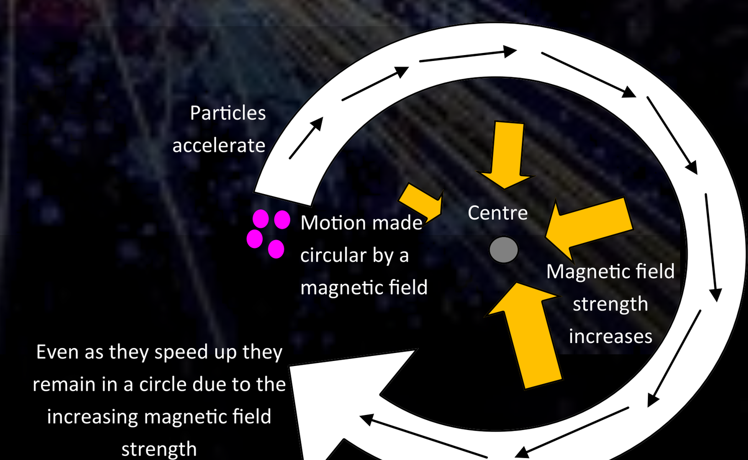
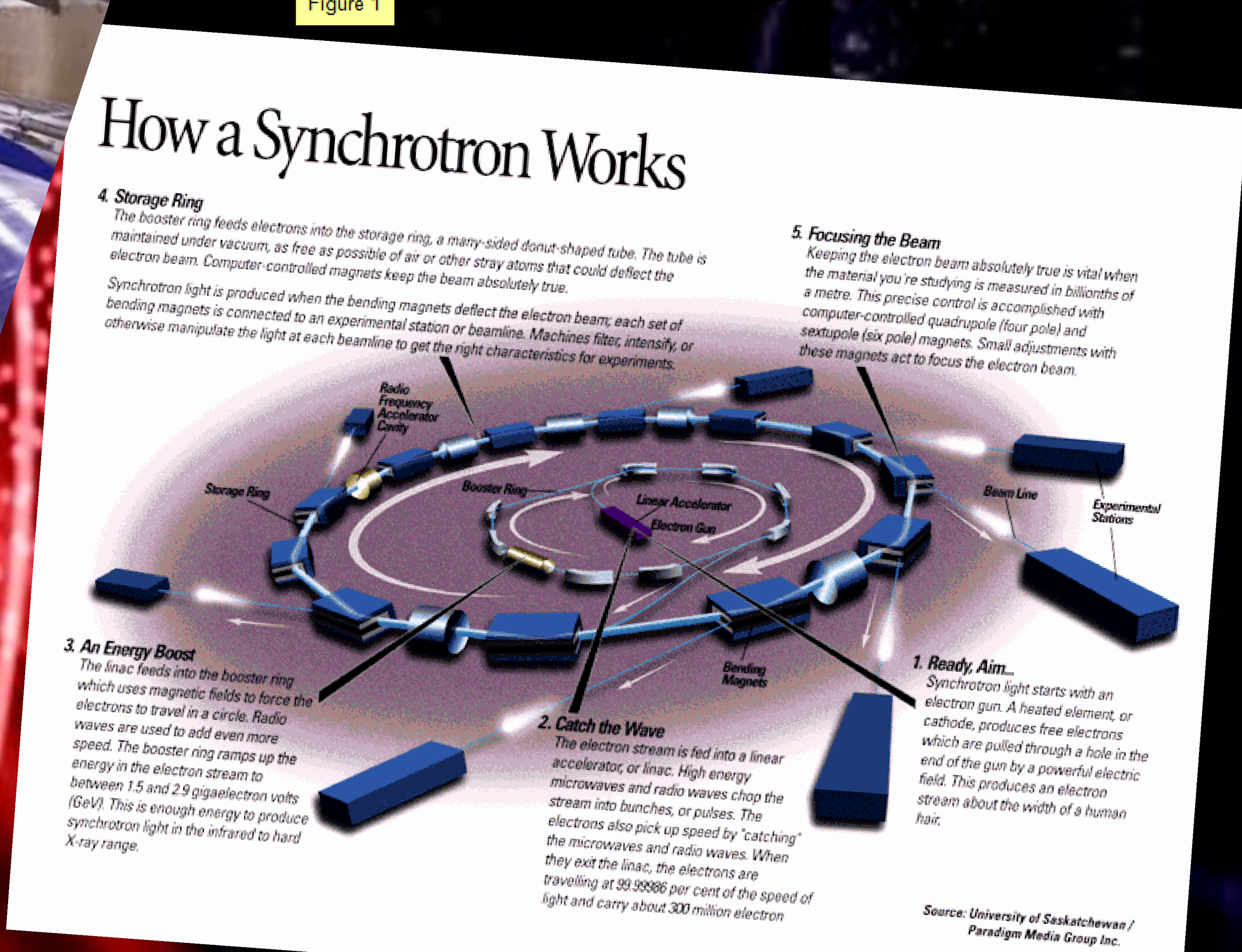


Figure 1


How a Synchrotron Works

4. Storage Ring

1. Ready, Aim...

2. Catch the Wave

3. An Energy Boost

5. Focusing the Beam

Source: University of Saskatchewan / Paradigm Media Group Inc.

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