

Cathode ray tube

The cathode ray tube was a scientific curiosity discovered in the late 19th century, and a mainstay of display technology in the late 20th. We now know that the mysterious ‘cathode rays’ are in fact electrons—and we can use magnets to bend their path.

Apparatus

This experiment obviously requires a cathode ray tube filled with gas which glows when electrons hit it. The ideal CRT is enclosed by Helmholtz coils to allow a varying magnetic field to be applied. In the absence of Helmholtz coils, a strong neodymium magnet should suffice to bend the electron beam.

In addition to a cathode ray tube, you’ll probably need a sensitive camera to show your audience the results of this experiment. The beams of electrons are too dim for anything except a very small audience to see directly, and are something of a challenge for video equipment too! A camera with a night mode, or manual control over gain (or ISO) and shutter speed will probably be necessary.

If you’ve not got a cathode ray tube, an old CRT TV or computer monitor and a strong magnet will provide a more qualitative version of this demo.

The demonstrations

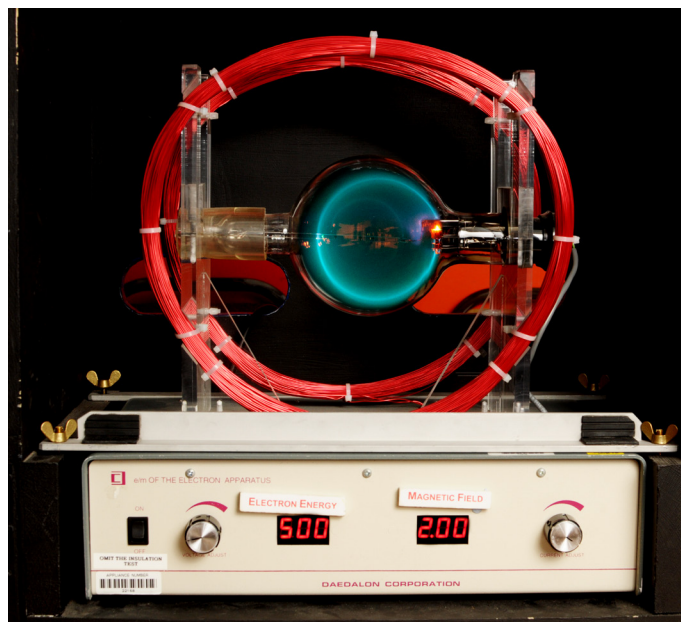
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1. Dim the lights and turn on the camera if you’re using one.
2. Turn up the energy of the electron beam until the gas inside the globe is clearly glowing.

Vital statistics

speed of an electron
accelerated through 1 V:
600 km/s

strength of LHC bending magnets:
8.36 T



A cathode-ray tube with controls for both the electron energy and the magnetic field applied. The blue-green glowing trail in the gas in the globe shows the path of the electrons.

3. If your CRT doesn’t have Helmholtz coils, simply wave the neodymium magnet near the CRT to show the beam bending. You may need to do this quite slowly if the camera is set to a low frame rate to increase its low light sensitivity.
4. If your CRT does have Helmholtz coils, turn up the current in them until the beam bends.
5. Having curved the path of the beam, turn up the energy further and show that the curvature decreases with increasing electron energy.
6. Apply a higher magnetic field to demonstrate that the curvature can again be increased by increasing the magnetic field strength.

CRT TV/monitor + magnet

1. Get an image on the television or computer screen. If it’s a computer screen simply plugging it into a laptop should work. For a TV, many

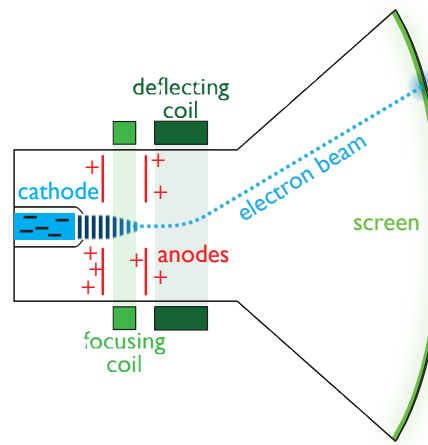
camcorders and digital stills cameras will have an S-video, component or composite connection; older camcorders may have these directly, but newer camcorders or digital cameras may have a bespoke cable which plugs into a mini-USB or similar jack on the camera and feeds out to multiple types of connector for insertion into the TV. A relatively still, bright image or video makes the effect we're about to observe easier to distinguish.

- Put the strong magnet near to the TV screen. The image will warp, and sweeping trails of colour will appear.
- If the distortion and colours remain after taking the magnet away from the TV, turning it off and on again should force the TV to 'degauss' which will fix the problem—this is signified by the distinctive clunk which often accompanies a CRT turning on. Sometimes, often after repeated cycling, the TV will fail to degauss. In this case, turn it off, leave it for a short period, and turn it on again.

How it works

The key here is that magnetic fields will bend the path of a moving charged particle, and we can make use of this effect to control a beam. Crucially for the Accelerate! recipe, you need a larger magnetic field to bend a faster-moving particle.

In the cathode ray tube, electrons are ejected from the cathode and accelerated through a voltage, gaining some 600 km/s for every volt they are accelerated through. Some of these fast-moving electrons crash into the gas inside the tube, causing it to glow, which allows us to see the path of the beam. Helmholtz coils can then be used to apply a quantifiable



A schematic cross-section of a cathode-ray tube television or computer monitor. The cathode creates the electrons, and anodes accelerate them, and the focusing and deflecting coils use magnetic fields to control the beam to the desired point on the screen, where electron impact causes coloured phosphors to glow and an image to form.

magnetic field by passing a known current through them.

A magnetic field will cause a force to act on the electrons which is perpendicular to both their direction of travel and the magnetic field. This causes a charged particle in a magnetic field to follow a circular path. The faster the motion of the particle, the larger the circle traced out for a given field or, conversely, the larger the field needed for a given radius of curvature of the beam. Making this quantitative point is impossible without control over both particle energy and magnetic field, so this will need to be stated if your demo doesn't have both of these.

In the case of the CRT TV, the paths of the electrons are distorted by the magnet being brought near the screen. The picture on the screen is dependent on the electrons precisely hitting phosphors on the back of the screen, which emit different colours of light when impacted. The electrons are thus forced to land in the wrong place, causing the distortion of the image and the psychedelic colours.

A CRT television first without and then with a magnet brought near to it. The patterns of colour are related to the magnetic field lines of the large circular magnet brought near to the TV: its poles are on its faces.

