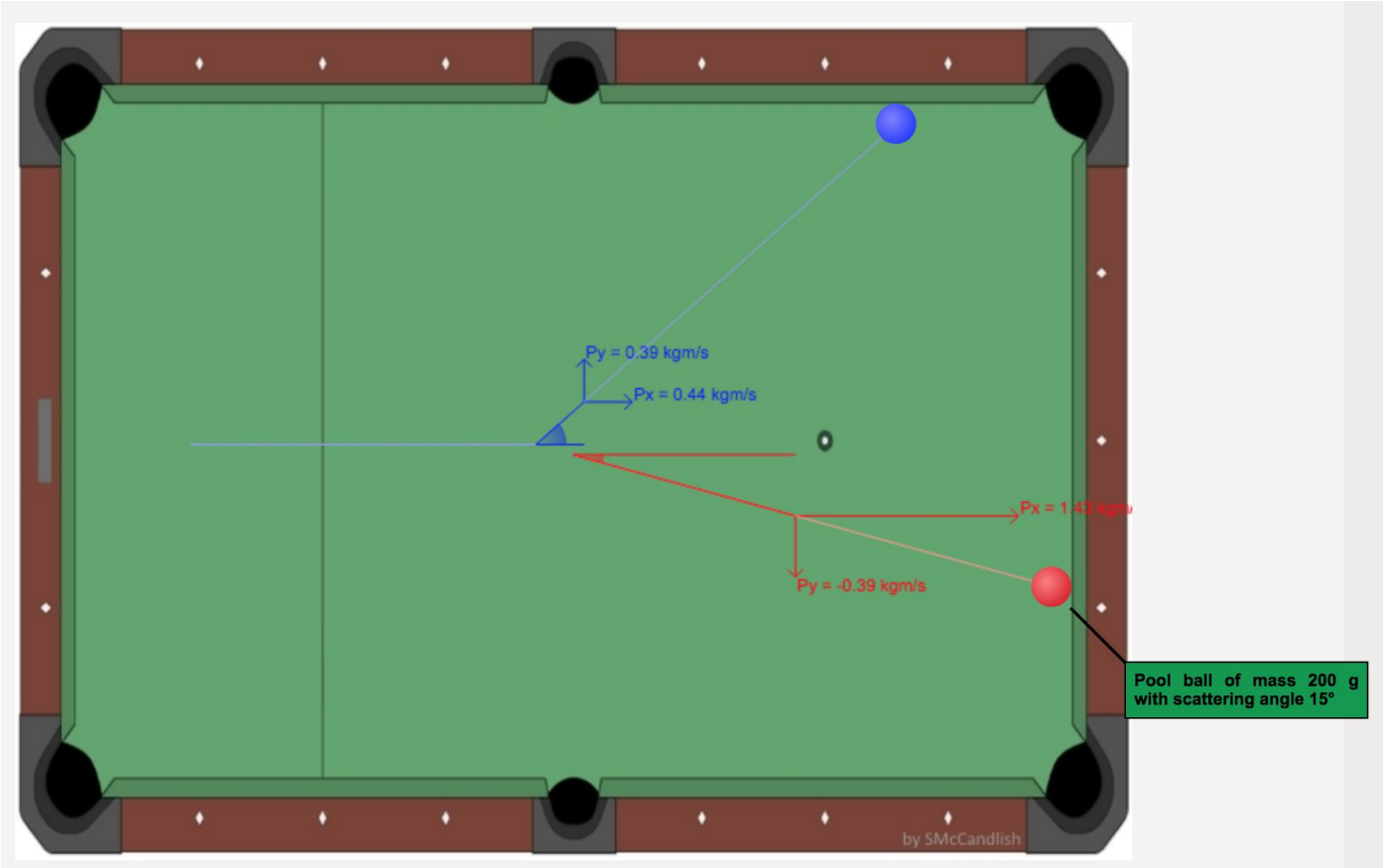
SG2 – Particle Accelerators

Adriano Donadoni Ben Simmons

Edite Briosa Maria La Gioia Francis Zong Lang

lancasteruniversity
particle physics package



Screenshot from Lancaster University Particle Physics Package

Kinetic Energy Conservation

- Conservation of Kinetic Energy

In a perfectly elastic collision no kinetic energy is lost.

m_1 = mass of incident (blue) ball.

m_2 = mass of target (red) ball.

u_1 = initial velocity of incident ball.

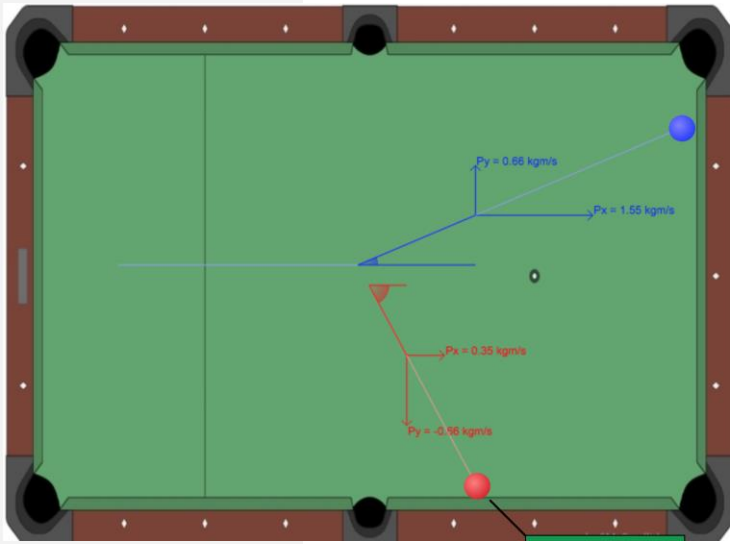
v_1 = final velocity of incident ball.

v_2 = final velocity of target ball.

Conservation of kinetic energy gives,

$$\frac{1}{2} m_1 u_1^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \quad (1)$$

Remember that the target (red) ball is stationary at first and so has zero initial velocity.



Screenshot from Lancaster University Particle Physics Package

ComPADRE - OSP

Cyclotron in 3D Model

https://www.compadre.org/osp/items/detail.cfm?ID=10527

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Science

Science SPORE Prize
November 2011

The Open Source Physics Project is supported by NSF DUE 0442581

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Computer Program Detail Page

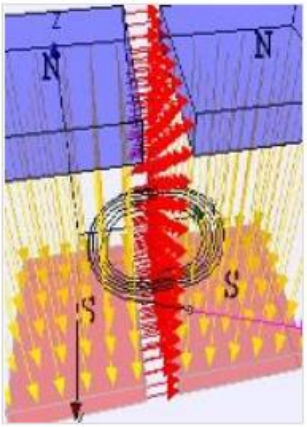
Cyclotron in 3D Model

written by Fu-Kwun Hwang and Loo Kang Wee

This simulation illustrates the operation of a cyclotron, showing a charged particle moving through combined magnetic and electric fields. The particle, started near the center of the cyclotron, accelerates when passing through the gap between the electric electrodes and is turned by a perpendicular magnetic field. The geometry of the cyclotron, the magnitude of the electric and magnetic fields, and the properties of the charge are all adjustable. This page includes links to information on the operation of cyclotrons.

Please note that this resource requires Java Applet Plug-in.

http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=2021.0



1 supplemental document is available

1 source code document is available

Subjects	Levels	Resource Types
Electricity & Magnetism - Electric Fields and Potential = Electric Field - Magnetic Fields and Forces = Force on Moving Charges = Magnetic Fields	- Lower Undergraduate - High School - Informal Education - Upper Undergraduate	- Instructional Material = Activity = Demonstration = Interactive Simulation = Model = Simulation

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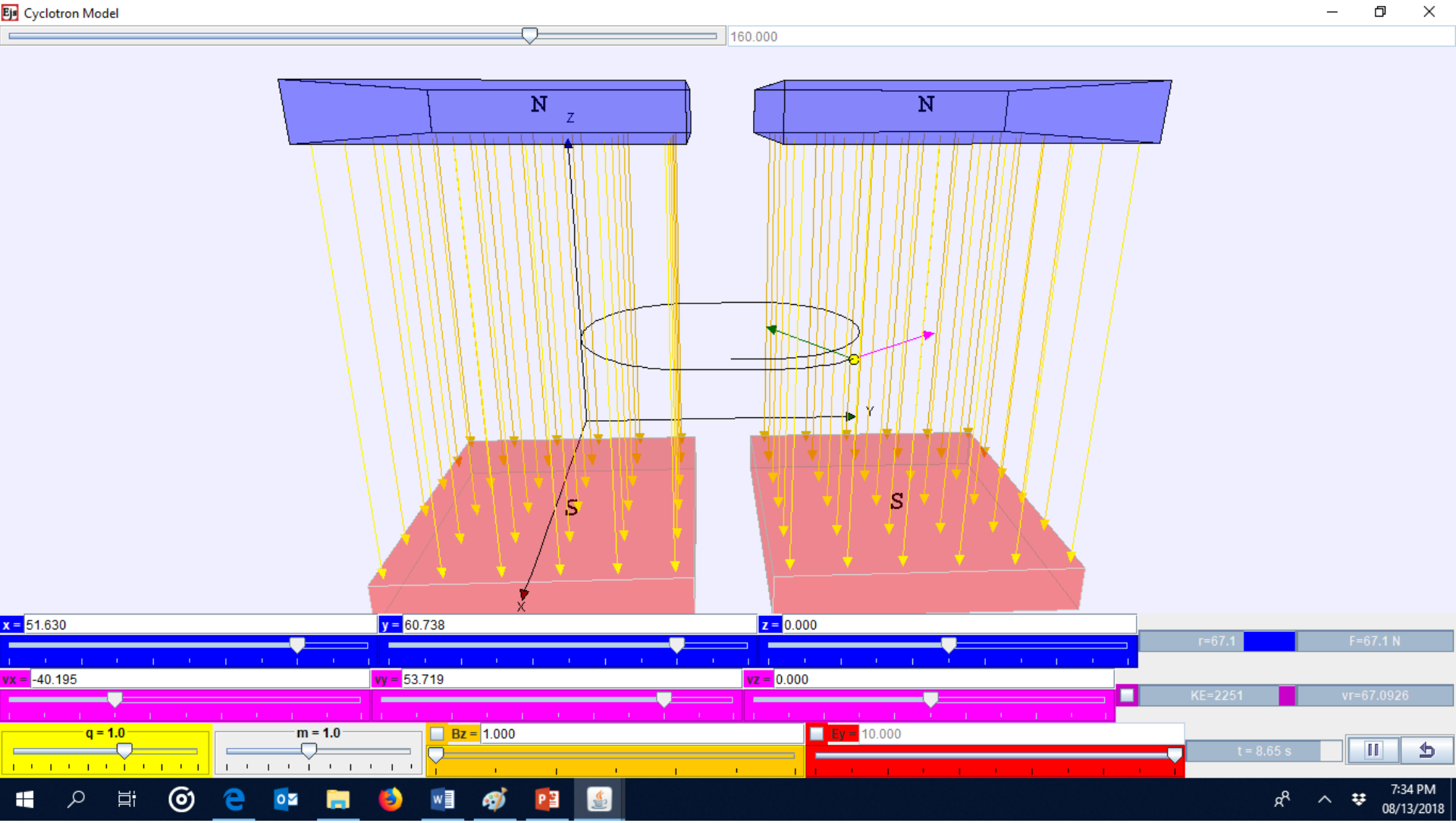
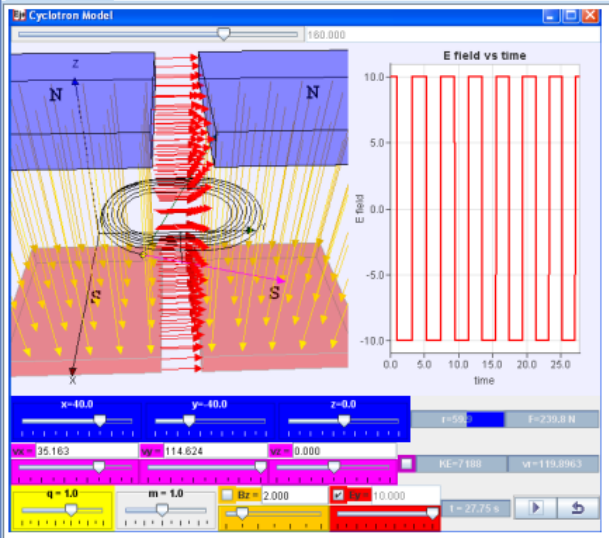


Explanation

Description for ChargeInNScyclotron

Intro Page | Excercises



Cyclotron Model

Cyclotron Model Simulation

How the cyclotron works? http://en.wikipedia.org/wiki/Cyclotron and http://webphysics.davidson.edu/physlet_resources/bu_semester2/c13_cyclotron.html

The charged particles, injected near the center of the magnetic field Bz, accelerate only when passing through the gap between the electric field Ey electrodes with increase in kinetic energy. The perpendicular magnetic field Bz bends moving charges into a semicircular path between the magnets with no increase in kinetic energy. The magnetic field causes the charge to follow a half-circle that carries it back to the gap. While the charge is in the gap the electric field Ey is reversed, so the charge is once again accelerated across the gap. The cycle continues with the magnetic field in the dees continually bringing the charge back to the gap. Every time the charge crosses the gap it picks up speed. This causes the half-circles in the dees to increase in radius, and eventually the charge emerges from the cyclotron at high speed.

The combined motion is a result of increasing energy of the particles in electric field Ey and the magnetic field Bz forces the particles to travel in an increasing radius of the circle after each entry into the other magnetic field. This results in a spiral path of which the particles than emerged at a higher speed than when it was injected into the center of the magnetic field Bz.

Uses of the cyclotron http://en.wikipedia.org/wiki/Cyclotron

For several decades, cyclotrons were the best source of high-energy beams for nuclear physics experiments; several cyclotrons are still in use for this type of research.

Cyclotrons can be used to treat cancer. Ion beams from cyclotrons can be used, as in proton therapy, to penetrate the body and kill tumors by radiation damage, while minimizing damage to healthy tissue along their path.

Problems solved by the cyclotron http://en.wikipedia.org/wiki/Cyclotron

The cyclotron was an improvement over the linear accelerators

Language: default

7:35 PM
08/13/2018

Exercises

Description for ChargeInNScyclotron

Intro Page | Excercises

Explore
1. Explore the simulation, this simulation is designed with a charge particle in a system of magnetic fields in z direction.
2 The play button runs the simulation, click it again to pause and the reset button brings the simulation back to its original state.
3 select Bz = 0 (key in the value 0 follow by "enter" on keyboard), Ey = 0, vy = 60, and play the simulation. Notice that the path of the particle in a straight line in the y direction. What is the physics principle simulatted here.
hint: newton's 1st law
4 reset the simulation.
5 using the default values(Bz = 1, Ey=0, Vy=60), play the simulation. what did you observe? explain the motion in terms of the influences of magnetic field (assume gravitational effect can be neglected)
6 explore the slider x, y, and z. what do these sliders control?
7 explore the slider vx, vy, and vz. what do these sliders control?
8 by leaving the cursor on the slider, tips will appear to give a description of the slider. you can try it the following sliders such as the charge q, mass m, radius of dee(magnets) R.
9 there are some values radius of circular path r, kinetic energy of particle KE, resultant velocity vr and resultant force F on the m.
10 vary the simulation and get a sense of what it does.

11 reset the simulation
12 using the values(Bz = 1, Ey=0, Vy=60, Ey = 10. observe the difference in the introduction of Ey in the gaps.
13 notice that the Ey field is alternating, explain the purpose of this Ey in this simulation.
14 propose the logic deployed by this simulation to time the switching of Ey. Can you think of other swtiching logic?
15 note the first time the charge crosses the whole gap its kinetic energy increases by an amount ΔK. determine this value from looking at the value bar of KE, you may select the checkbox to view the scientific graph of KE vs t.
answer: 2421.4-2021.5 = 399.9 ≈ 400 J
16What is the change in kinetic energy associated with just moving in each half-circle in a dee (the magnetic field).
hint: look at the value bar of KE, you may select the checkbox to view the scientific graph of KE vs t.
Explain:
16 explain why this it is so?
hint: In the dee(magnetic field) the force on the charge comes from the magnetic field, so the force is perpendicular to the velocity. The speed, and hence the kinetic energy, stays constant, so the change is zero.
17 The first time the charge crosses the gap its kinetic energy increases by an amount ΔK say 400 J. Assuming the electric field in the gap is the same magnitude at all times but in opposite direction to earlier time, what is the change in kinetic energy the second time the charge crosses the gap?
hint: 2819.5-2421.4 = 398.1 ≈ 400 J
Elaborate
18 suggest with reason why the values for 15 and 17 are not exactly the same
hint: look at the value of vx
answer: the exiting from magnetic field causes the vx to be slightly bigger than 0, thus the resultant velocity is increased very slightly.
Evaluate:
19 A scientist ask a question "To increase the speed of the particles when they emerge from the cyclotron. Which is more effective, increasing the electric field Ey=-Vy/dy across the gap or increasing the magnetic field Bz in the dees? " play the simulation for different initial condition and design an experiment with tables of values to record systematically, determine what is the more "effective" method. State your assumptions made.
hint: assumption is outside physical radius of dee = R is fixed.
the start velocity vy = 0
the start x = 0
Note that whatever the magnitudes of the fields the final half-circle the charge passes through in the dee has a radius approximately equal to R, the radius of the dee itelf. The radius of the circular path of a charged particle in a magnetic field is:
N2L: F = ma
circular: v.B.q = m.v^2/r
r = mv/Bq.
In this case the speed of the particle is RBq/m = v
Therefore the final kinetic energy is:

Language: default

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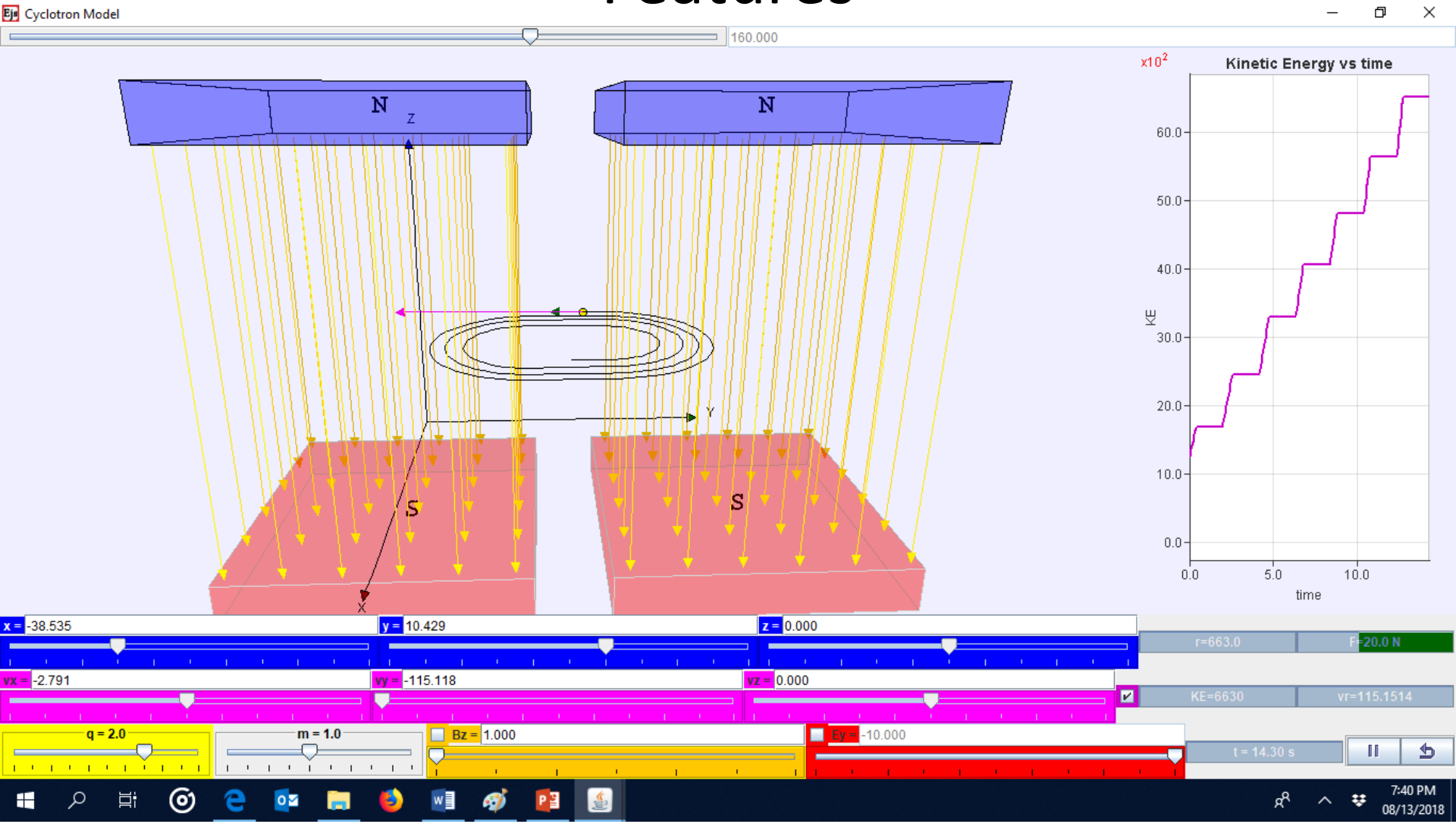
08/13/2018

Features

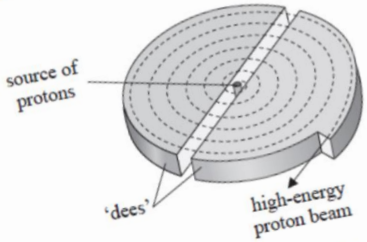

Cyclotron Model
160.000
N
N
S
S
Z
Y
X
Kinetic Energy vs time
x10^2
KE
time
0.0
10.0
20.0
30.0
40.0
50.0
60.0
0.0
5.0
10.0
x = -38.535
y = 10.429
z = 0.000
r=663.0
F=20.0 N
vx = -2.791
vy = -115.118
vz = 0.000
KE=6630
vr=115.1514
q = 2.0
m = 1.0
Bz = 1.000
Ey = -10.000
t = 14.30 s
7:40 PM
08/13/2018

The Cyclotron…continued

Q1.

Proton beam therapy is being introduced in the UK as a new cancer treatment.

A beam of protons is accelerated by a cyclotron to an energy of 23 MeV and is then focused onto a tumour.



(6)

* Explain how the cyclotron produces the high-energy proton beam.

Indicative content

- There is an alternating p.d./E-field
- P.d./E-field accelerates protons between dees
- Magnetic field perpendicular to plane of dees
- Proton path curved by magnetic field
- As velocity of protons increases radius of path in dees increases
- The time for which a proton is in a dee remains constant

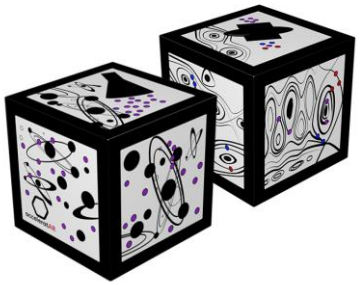
Or the frequency of p.d./E-field is constant

Picture taken by Ben Simmons

acceleratAR

the augmented reality particle accelerator

Build up your own accelerator by placing the cubes on a tabletop, and then bring it to life using the **acceleratAR** app!

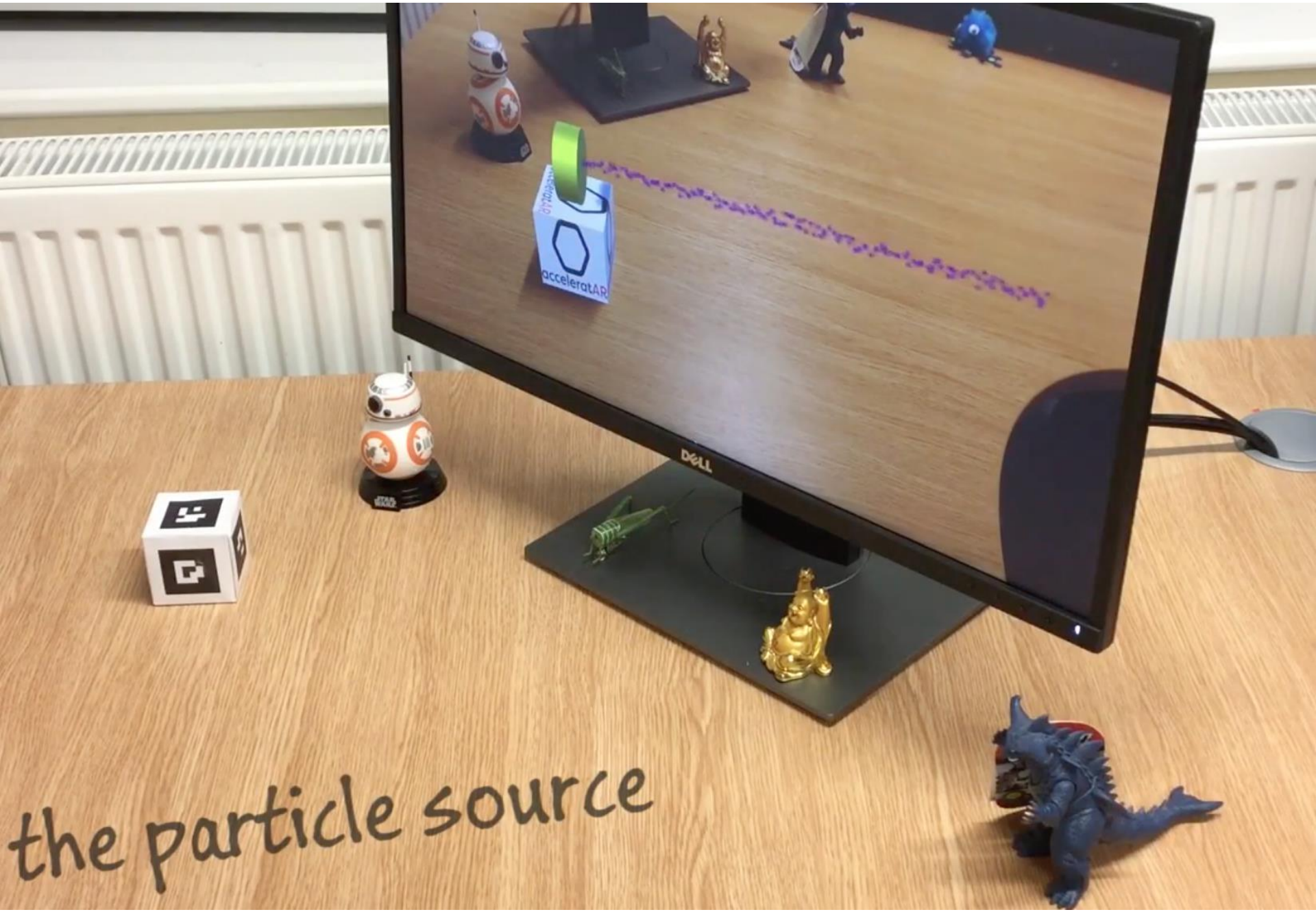


UNIVERSITY OF LIVERPOOL

The Cockcroft Institute of Accelerator Science and Technology

MANCHESTER 1824 The University of Manchester

Science & Technology Facilities Council



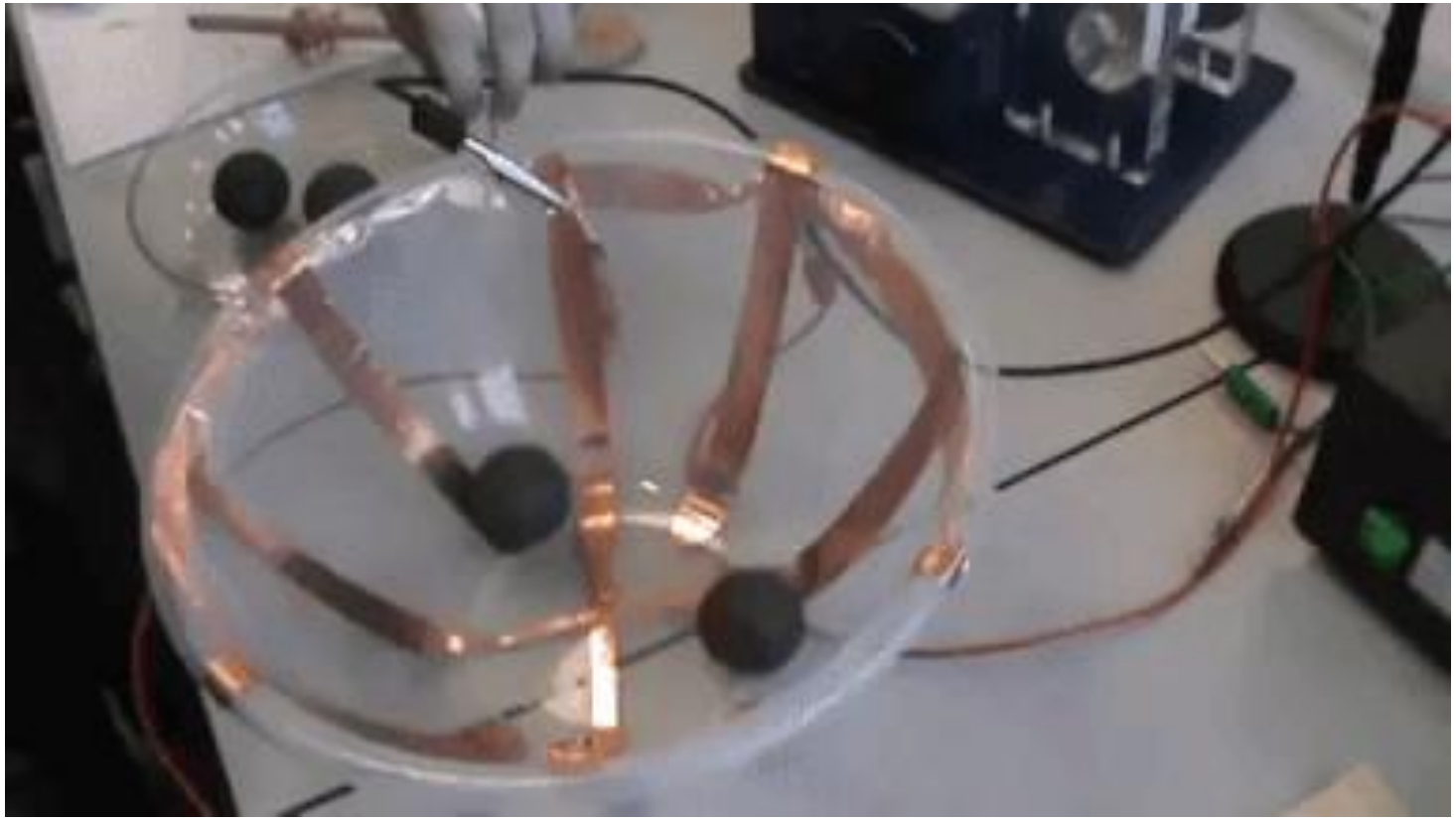
Screenshot from acceleratAR website

Screenshot from acceleratAR website

Screenshot from acceleratAR website

Screenshot from acceleratAR website

The Salad Bowl Accelerator

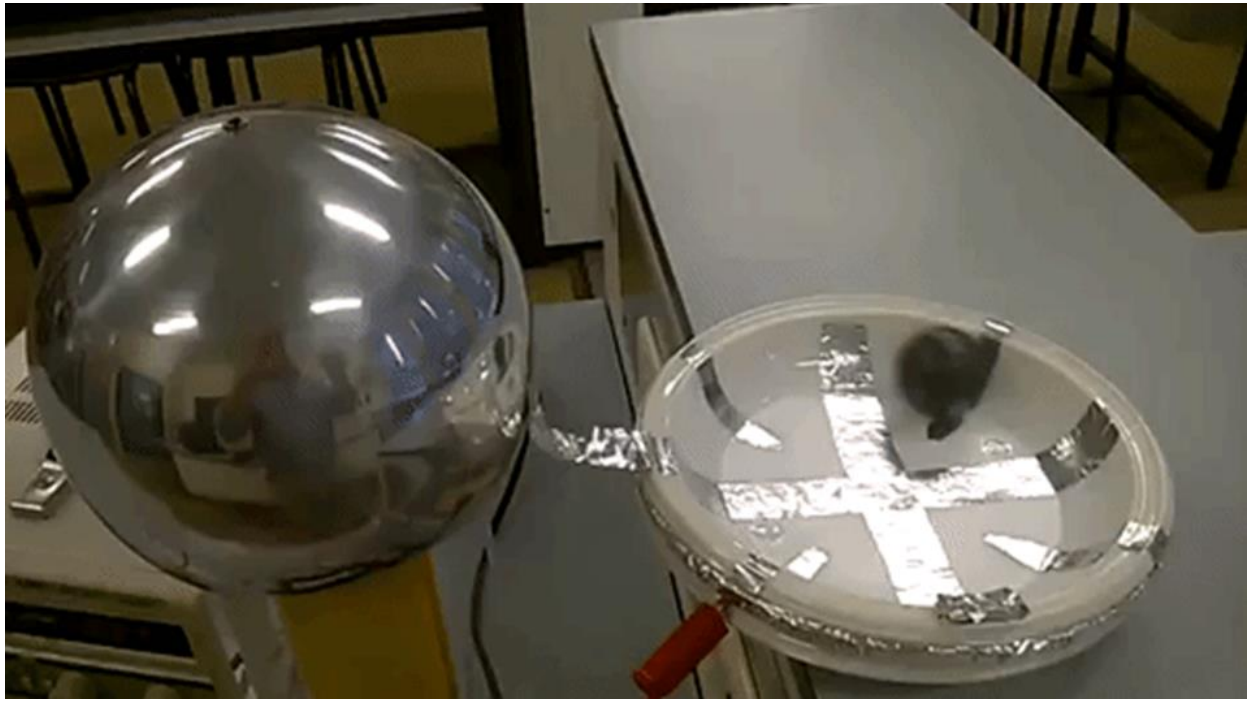


https://www.cockcroft.ac.uk/archives/4941

The Salad Bowl Accelerator

https://www.youtube.com/watch?v=uN2kxNKDdxM&feature=youtu.be

The Salad Bowl Accelerator



Problem Based Learning

How to build it,
isolate different variables:

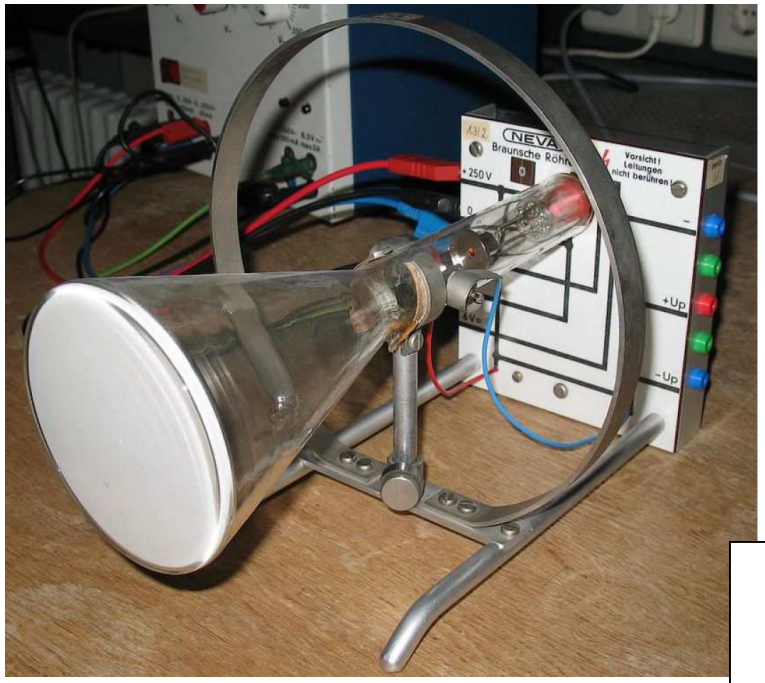
dish or bowl ?
slope of the border
aluminium strips: which kind? Kitchen? Sticky?

Ball: which kind ?
Which conductive painting to be used?

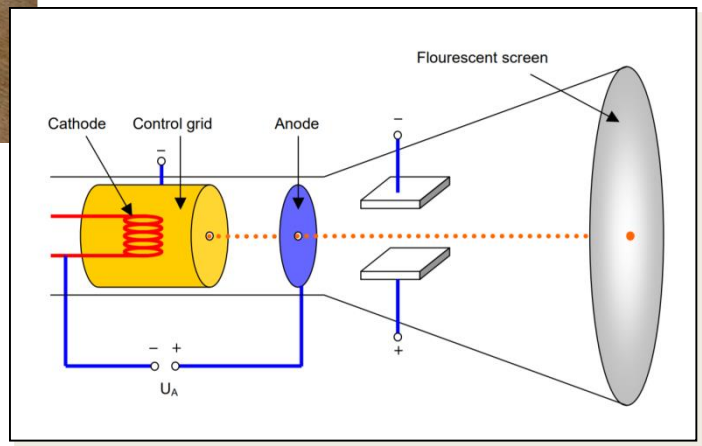
Which forces make the ball run? Electric field… Bending force…

Similarities and differences with particle accelerator. Ball vs particles….charges….

Cathode Ray Tube



- ✓ Vacuum
- ✓ Energy
- ✓ Lenses
- ✓ Focus and defocus



http://project-physicsteaching.web.cern.ch/project-physicsteaching/english/experiments/cathode-ray-tube.pdf

Cathode Ray Tube

- ✓ Vacuum
- ✓ **Energy**
- ✓ Lenses
- ✓ Focus and defocus

What is the speed of electrons that have been accelerated with 250 V at the cathode ray tube?
What is the speed of electrons that have been accelerated with 90 kV at the first electrostatic accelerator of the LHC (located inside the proton source)?

2. Kinetic energy of the electrons: $E = 250\ eV = 4 \cdot 10^{-17}\ J$

   Speed of the electrons: $v = \sqrt{\frac{2 \cdot E}{m_e}} = 9{,}38 \cdot 10^6\ \frac{m}{s}$

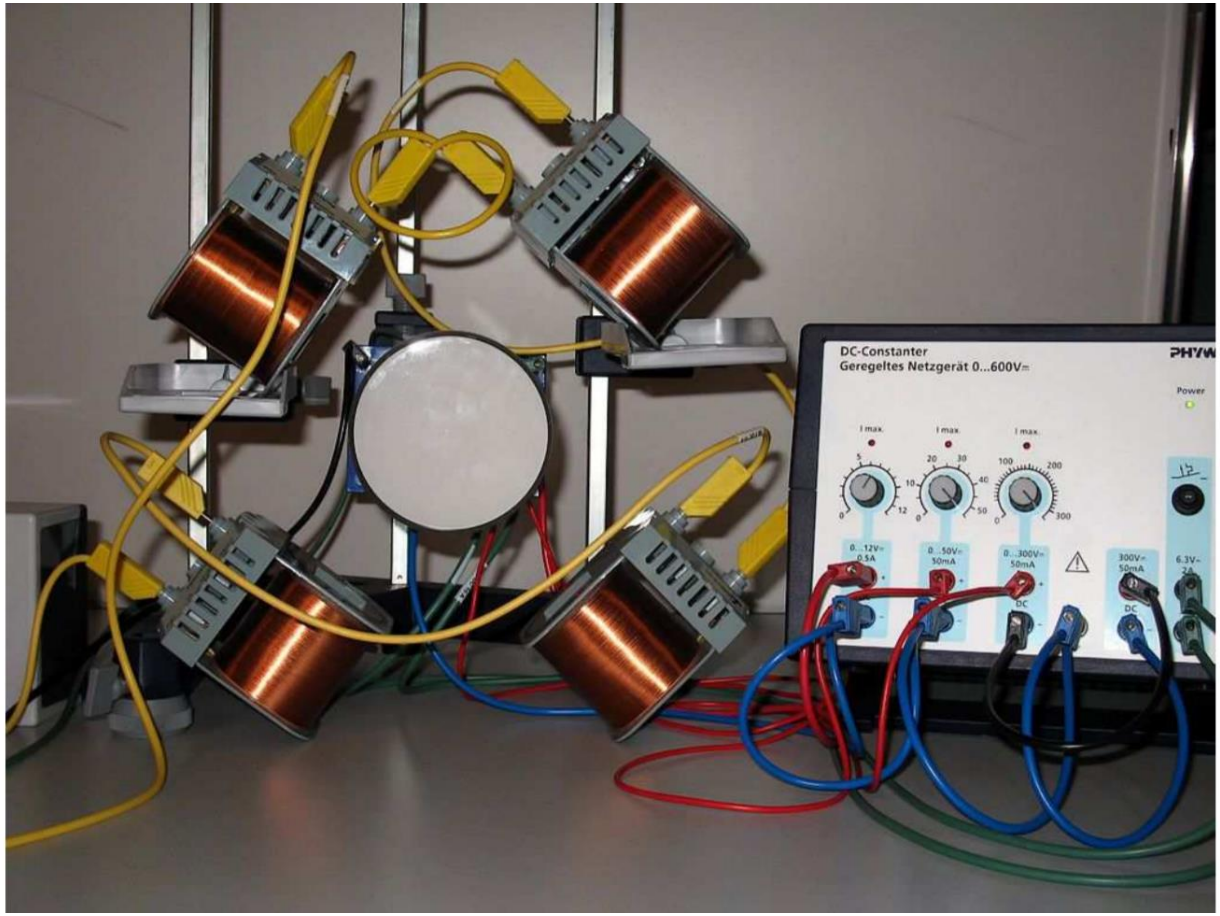
3. Energy of the protons: $E = 90\ keV = 1{,}44 \cdot 10^{-14}\ J$

   Speed of the protons: $v = \sqrt{\frac{2 \cdot E}{m_p}} = 4{,}15 \cdot 10^6\ \frac{m}{s}$

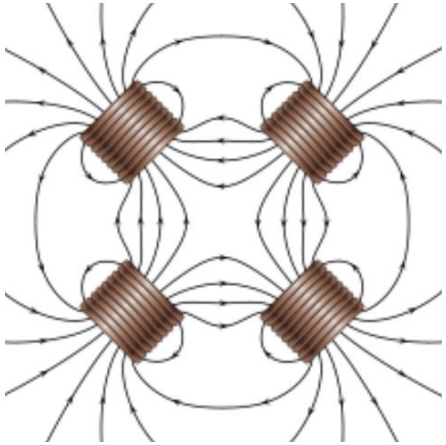
Consequences for particle physics:
Though protons are accelerated with 90 kV at the CERN proton source, they do not even reach the speed of the electrons accelerated with only 250 V at the Braun's tube. The reason is the high mass of the protons. In fact, proton accelerators like the LHC need much more energy to accelerate particles to high speed.

http://project-physicsteaching.web.cern.ch/project-physicsteaching/english/experiments/cathode-ray-tube.pdf

Cathode Ray Tube



- ✓ Vacuum
- ✓ Energy
- ✓ **Lenses**
- ✓ **Focus and defocus**



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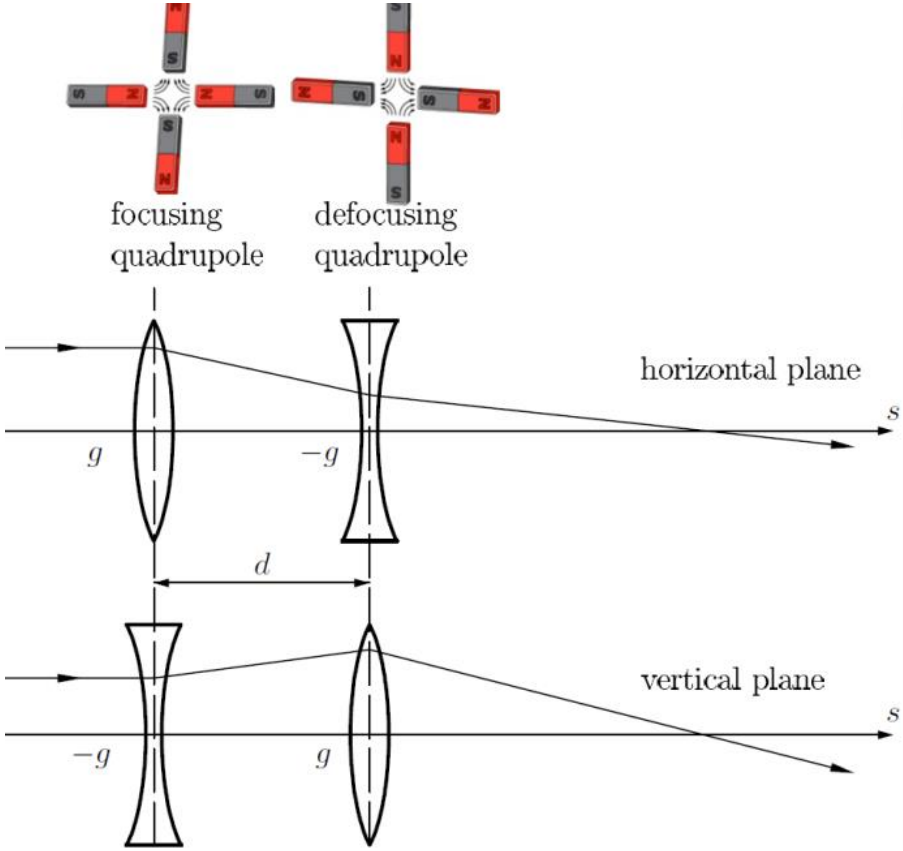
Cathode Ray Tube



- ✓ Vacuum
- ✓ Energy
- ✓ **Lenses**
- ✓ **Focus and defocus**

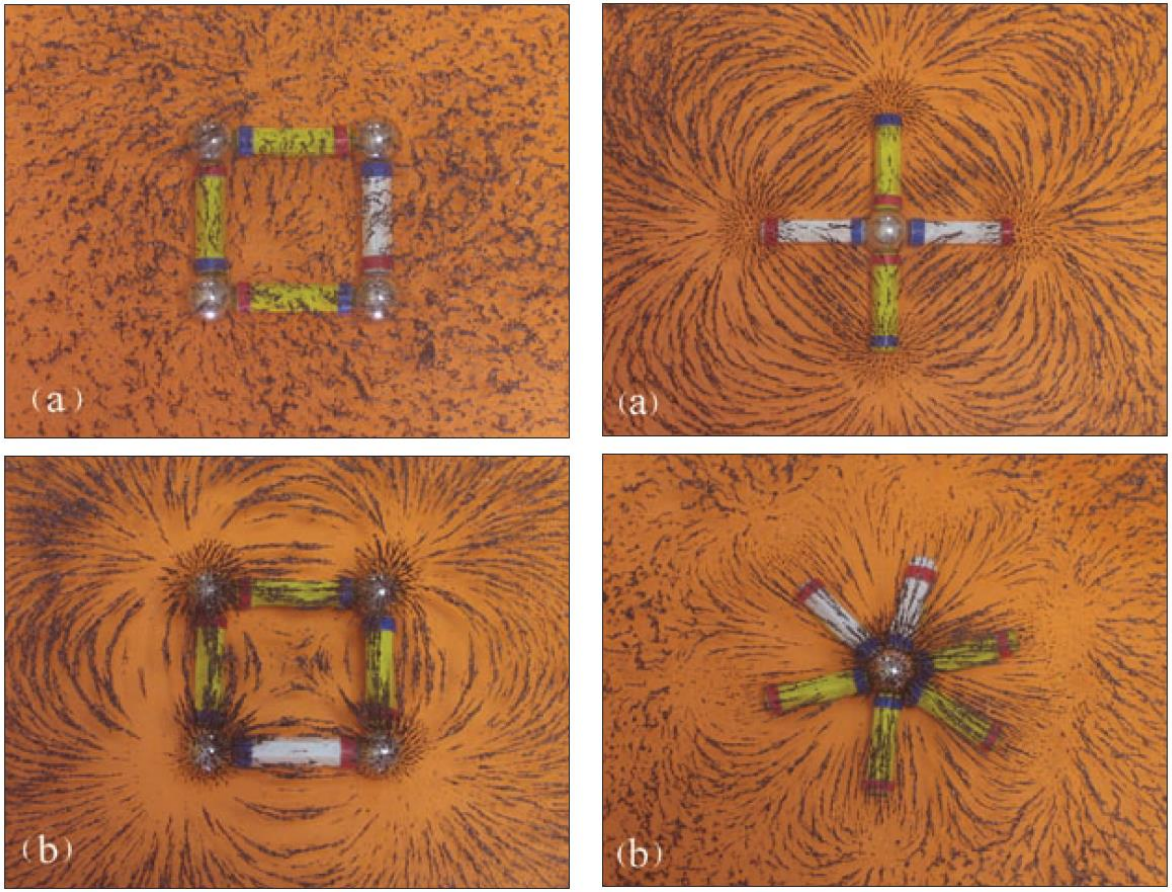
$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}.$$

$$\frac{1}{F} = \frac{d}{f_1^2}$$

http://project-physicsteaching.web.cern.ch/project-physicsteaching/english/experiments/cathode-ray-tube.pdf
S.Gilardoni, Introduction to accelerators, lecture slides during HST2014 CERN

Quadrupoles with GEOMAG

Quadrupoles with GEOMAG



GEOMAG™ Paradoxes

Silvia Defrancesco, Fabrizio Logiurato, and Grzegorz Karwasz

Citation: The Physics Teacher **45**, 542 (2007); doi: 10.1119/1.2809146
View online: https://doi.org/10.1119/1.2809146
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Quadrupoles with GEOMAG

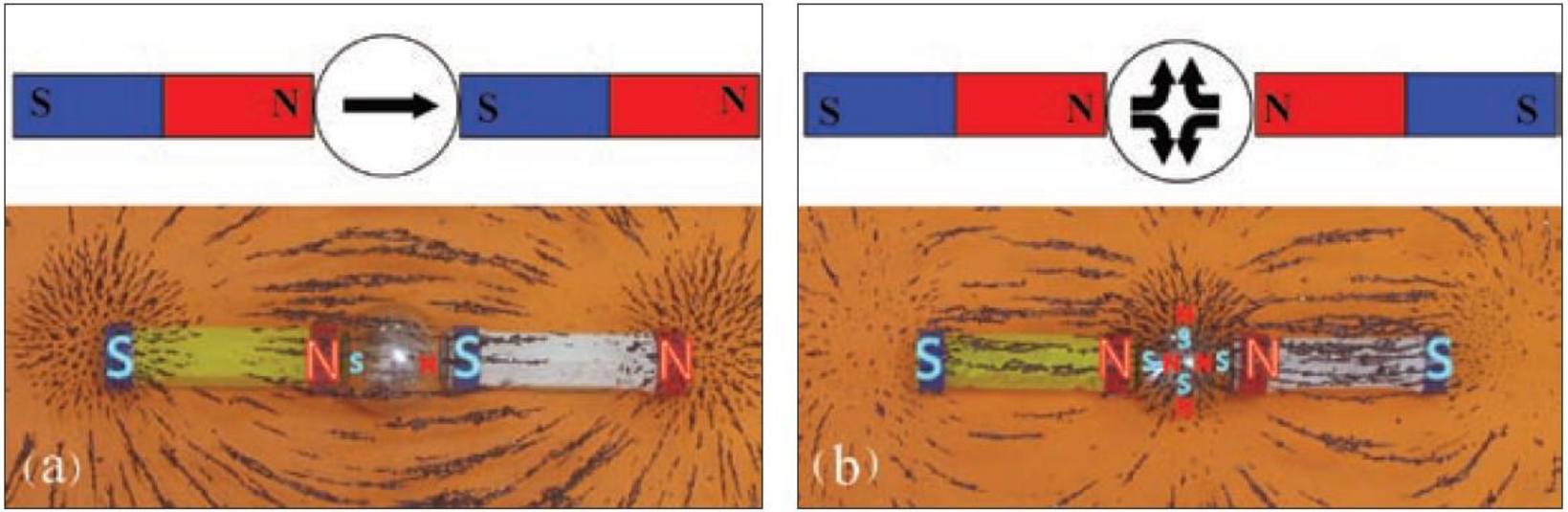

Fig. 2. (a) When the opposite poles of the two magnets face each other, they induce a magnetization in the same direction in the sphere; the resultant field of the sphere is similar to a dipole. (b) On the contrary, when the facing poles are similar, the induced magnetization in the sphere is similar to a quadrupole. The orientation of some elementary dipoles within the sphere is shown. In the upper figures the direction of the field lines inside the sphere is illustrated.

GEOMAG™ Paradoxes

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Citation: The Physics Teacher **45**, 542 (2007); doi: 10.1119/1.2809146
View online: https://doi.org/10.1119/1.2809146
View Table of Contents: http://aapt.scitation.org/toc/pte/45/9
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Your smartphone can do Physics!

Collider is a mobile application that lets you view high energy particle collisions directly from the Large Hadron Collider, making it simple to understand what's going on at a glance.

Your smartphone can do Physics!

LHSee grabs live collision events from the underground detectors in Geneva, and beam them direct to your own device.

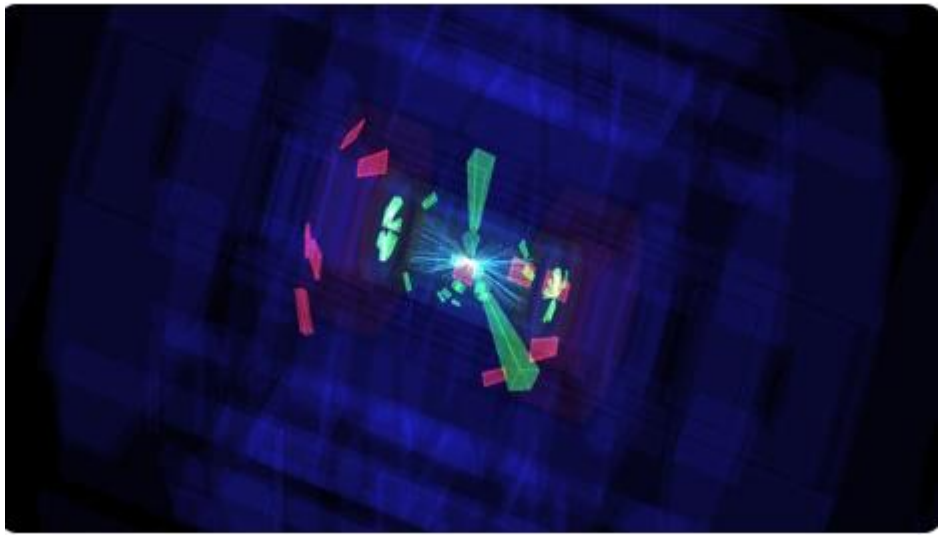
Variety of educational resources.

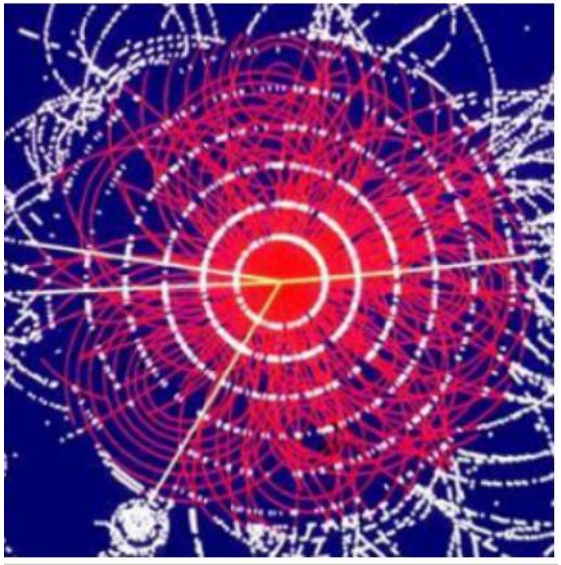
Collision events in full 3D graphics.

Learn how to identify different types of collision.

"Hunt the Higgs" game.

Your smartphone can do Physics!





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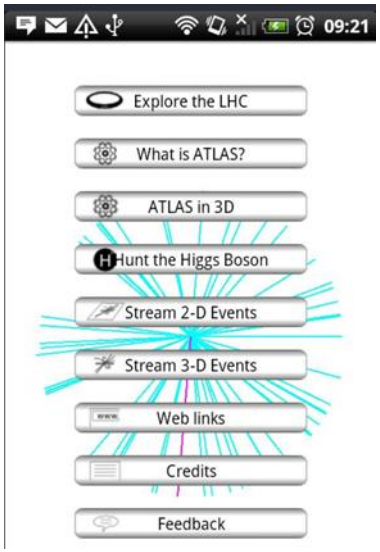
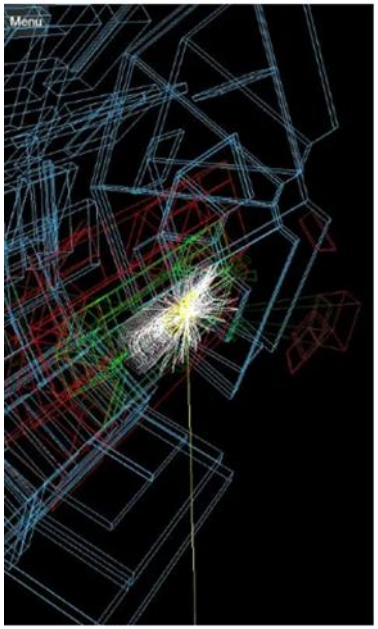
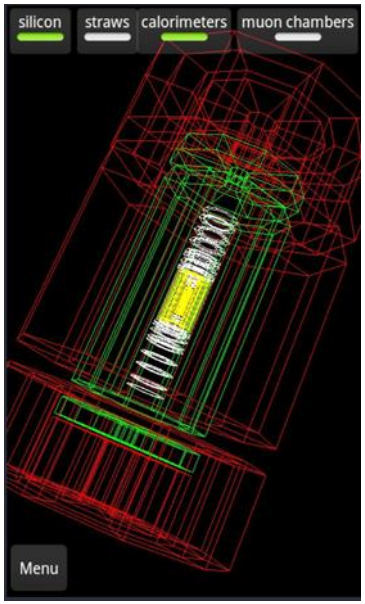
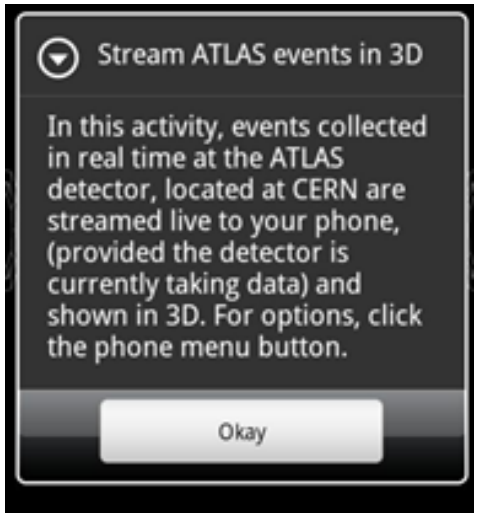








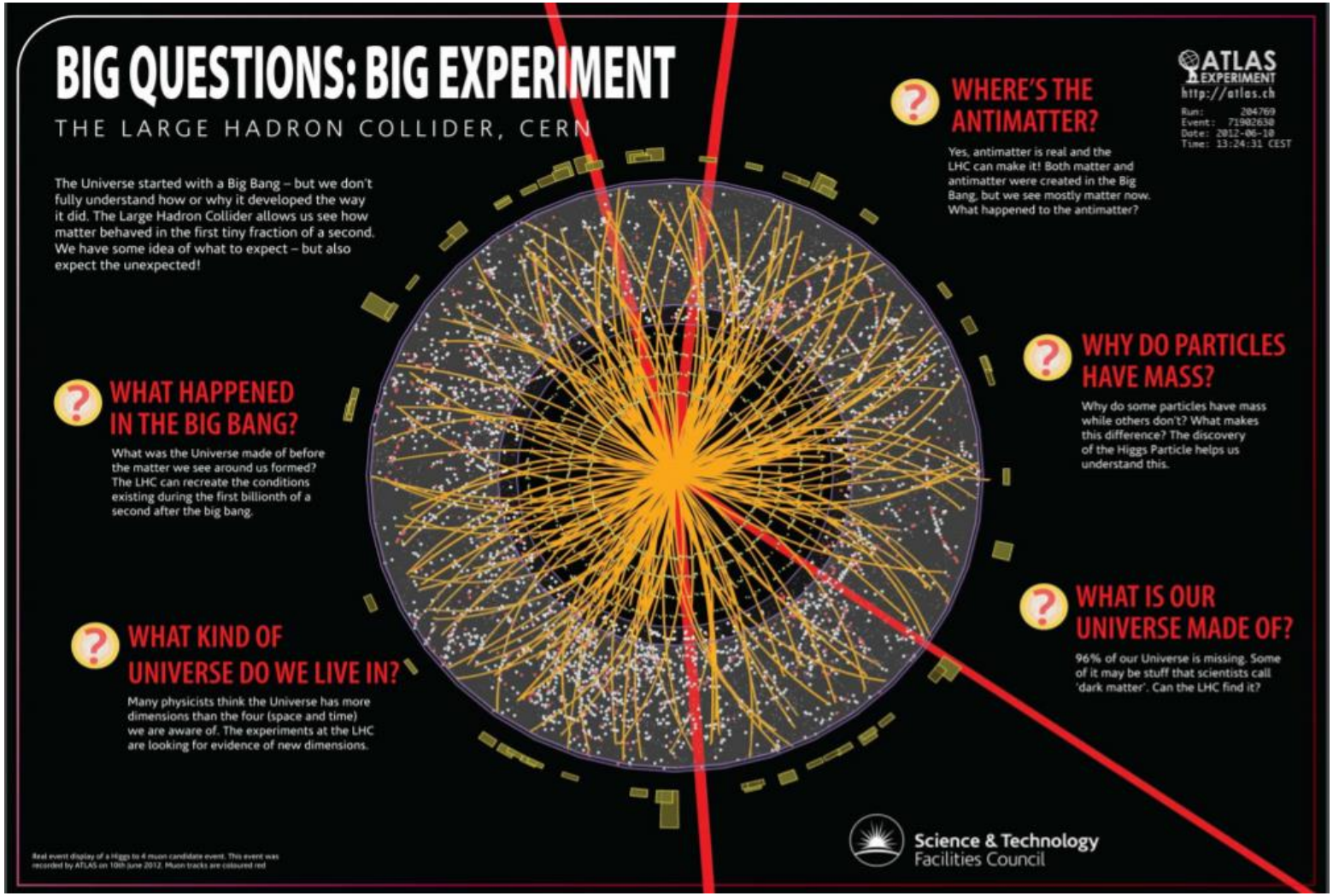
Content and Language Integrated Learning

'CLIL refers to situations where subjects, or parts of subjects, are taught through a foreign language with dual-focused aims, namely the learning of content, and the simultaneous learning of a foreign language'.

Marsh, David. 1994. Bilingual Education & Content and Language Integrated Learning. International Association for Cross-cultural Communication, Language Teaching in the Member States of the European Union. University of Sorbonne. Paris

What?

Examples



https://stfc.ukri.org/files/educational-publications/big-questions-big-experiments-the-large-hadron-collider/

Examples

Exercise 1. With your partner, consider the gaps in the text below. Try to put the right word in each gap.

The words are the following:

switches – in time - undergo – gap - charged - pulled forward - generator - magnetic – timing cavities – bend - accelerate – negative

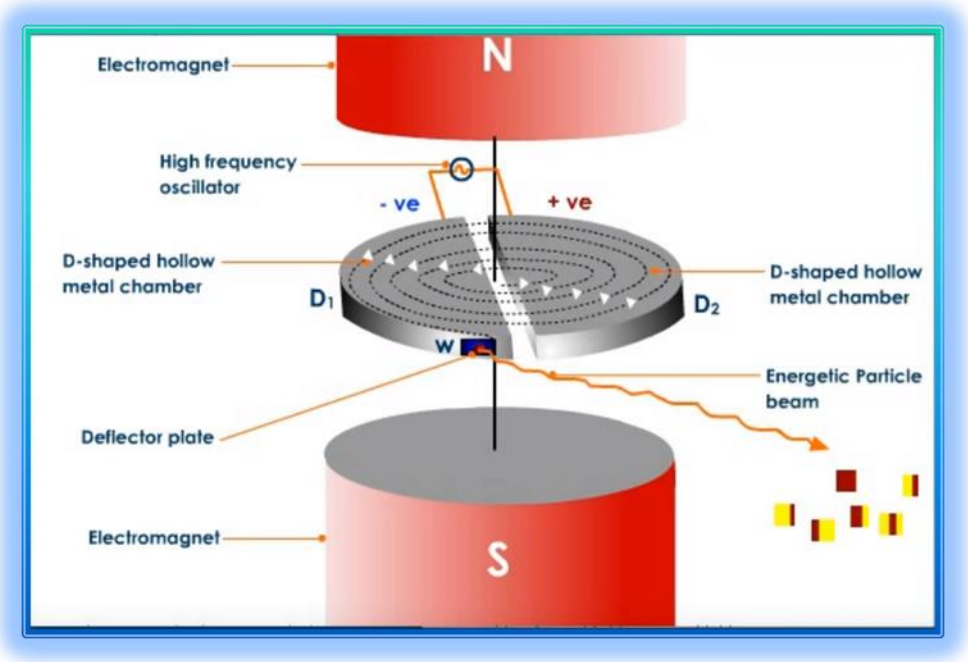
Cyclotron

A cyclotron is a machine used to _____charged particles to high energies. The first cyclotron was built by E. O. Lawrence and his graduate student, M. S. Livingston, at the University of California, Berkley, in the early 1930's.

A cyclotron consists of two D-shaped _____ sandwiched between two electromagnets. A radioactive source is placed in the center of the cyclotron and the electromagnets are turned on. The radioactive source emits _____ particles. It just so happens that a magnetic field can _____the path of a charged particle so, if everything is just right, the charged particle will circle around inside the D-shaped cavities. However, this doesn't accelerate the particle. In order to do that, the two D-shaped cavities have to be hooked up to a radio wave_____. This generator gives one cavity a positive charge and the other cavity a _____ charge. After a moment, the radio wave generator _____ the charges on the cavities. The charges keep switching back and forth as long as the radio wave generator is on. It is this switching of charges that accelerates the particle.

Let's say that we have an alpha particle inside our cyclotron. Alpha particles have a charge of +2, so their paths can bent by _____ fields. As an alpha particle goes around the cyclotron, it crosses the _____ between the two D-shaped cavities. If the charge on the cavity in front of the alpha particle is negative and the charge on the cavity in back of it is positive, the alpha particle is _____(remember that opposite charges attract while like charges repel). This just accelerated the alpha particle! The particle travels through one cavity and again comes to the gap. With luck, the radio wave generator has changed the charges on the cavities_____, so the alpha particle once again sees a negative charge in front of it and a positive charge in back of it and is again pulled forward. As long as the _____is right, the alpha particle will always see a negative charge in front of it and a positive charge in back of it when it crosses the gap between cavities. This is how a cyclotron accelerates particles!

Unfortunately, there's one more thing to worry about. The faster a charged particle moves, the less it is affected by a magnetic field. So, as particles speed up in a cyclotron, they spiral outwards. This makes it easy to get the particles out of the cyclotron, but also puts a limit on the amount of acceleration they can_____.



https://image.slidesharecdn.com/cyclotron-140912090543-phpapp01/95/cyclotron-10-638.jpg?cb=1410512821

Examples

The Large Hadron Collider

Exercise 2. Match the words with the definitions.

a Big Bang **b** beam **c** collide **d** intersect **e** magnet
f mass **g** matter **h** quark **i** subatomic particle

1 line of light or other form of energy *beams*

2 tiny part of matter that forms part of an atom or is smaller than an atom _____

3 very small unit of matter that the particles of an atom consist of _____

4 the amount of matter that something contains _____

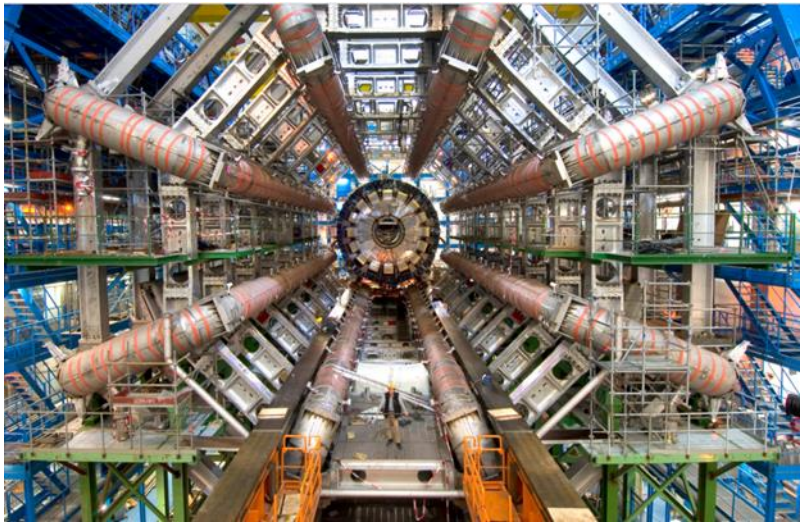
5 an explosion that some scientists believe happened 15 billion years ago and started the universe _____

6 crash into each other _____

7 piece of metal that can make iron or steel objects come to it so that they seem to stick to it _____

8 to join or cross each other _____

9 the physical substance that everything in the world is made of _____



Exercise 3. Complete the text with words and expressions from Exercise 1.

How it works

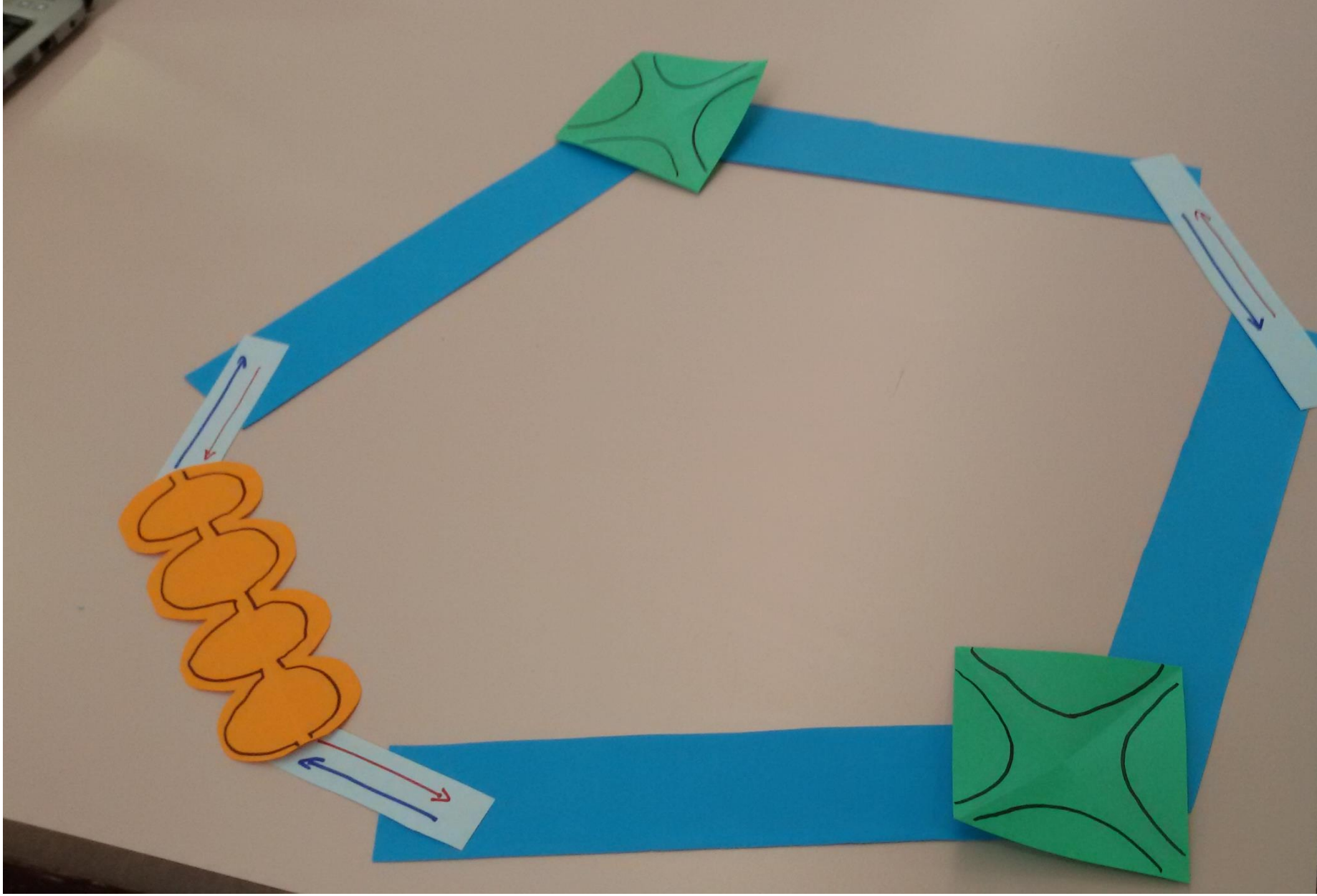
The Large Hadron Collider (LHC) is a very big machine that makes hadrons. It works like this: **(1)** *Subatomic particles*, made up of tiny **(2)** _____, accelerate in two **(3)** _____ of light, which rotate in opposite directions. When the particles reach their maximum speed (almost the speed of light), they are made to **(4)** _____ with each other with the help of **(5)** _____. This occurs at four points where the two rings of the LHC **(6)** _____. Scientists record and measure the results of these collisions and try to identify and track the behaviour of the new particles which they produce.

What it can be used for

The purpose of the LHC is to develop our understanding of physics. The LHC will be able to simulate the conditions just after the **(7)** _____, when our universe was created, improving our understanding of the origins of the universe and the basic structure of **(8)** _____ and its **(9)** _____.

http://www.macmillaninspiration.com/new/files/2010/12/CLIL_NI_4_Unit_3_Science.pdf

https://apod.nasa.gov/apod/image/1112/atlas_cern_3008.jpg



$\vec{F} = q \cdot \vec{v} \otimes \vec{B}$
$E = mc^2$
$\vec{p} = m\vec{v}$
$F = ma$
$F = q\vec{v} \times \vec{B}$
$a = v^2/R$
N
S
N
S
$\vec{F}$
sin φ
a
cos φ
mg

Thank you for listening.