Synchrotrons from a Physics Perspective

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Summary: This lesson explains how a synchrotron works while using some very basic physics. The demonstrations help clarify some of the different physics concepts. Students will be challenged to think about what is happening and gain a better understanding of how a synchrotron works.

Pan-Canadian Objectives

Science Grade	Knowledge	Science, technology, society and the environment	Skills	ATTITUDES
10-12	*325-4, 325-5, 325-8, 325-12, 325-13, 326-1, 328-2*	*116-3, 116-4, 116-7,*	212-4, 213-8	439, 442, 443, 445
7-9	309-2	110-2, 111-1, 111-3	208-3, 208-5, 210-11, 210-16	422, 426, 428, 430

Materials

- Lazy Susan, Container (glass, has to be taller then the candle), Candle
- String attached to a ball

Activity

1. Hand out the Synchrotron question sheets before doing the demonstrations.
2. After the question sheets are completed hand out the sheets with the explanations and get them to correct the questions.

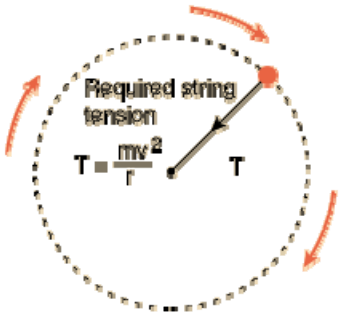
Demo 1:

Set a lazy Susan somewhere where everyone can see. Attach a glass towards the edge of the lazy Susan (still vertical), with silly putty or by melting the wax onto the surface and sticking it on. Anchor the candle inside the glass in the same way. Ask the students what they think will happen to the flame when the Lazy Susan is spun. Slowly spin the lazy Susan and observe what happens to the flame. What you are observing is the centripetal acceleration, because the flame is experiencing a greater acceleration then the candle. For further explanation refer to: http://www.physicsclassroom.com/Class/circles/u6l1b.html

A candle flame accelerometer indicates an inward acceleration

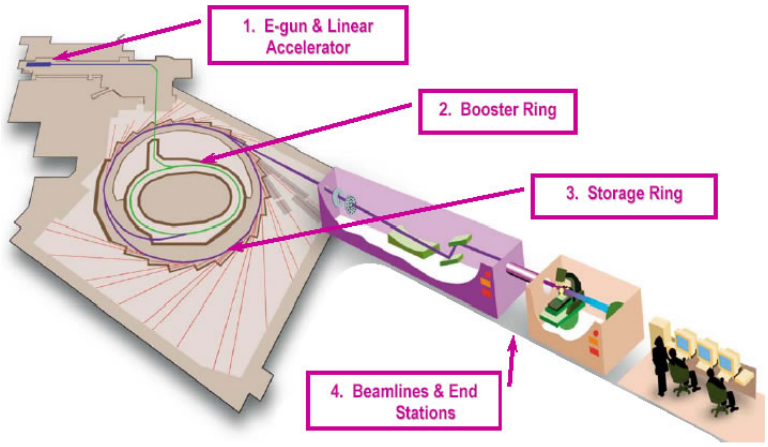
Demo 2 http://hyperphysics.phy-astr.gsu.edu/hbase/cf.html#cf

Spin a ball around on a string in a horizontal circle so that the there is no slack in the string. Observe the movement of



the ball. Think about centripetal force. What force is the string? What would happen if the string broke?

What is a Synchrotron?
A Synchrotron is a machine that produces a very intense light using useful physics concepts. Firstly, a linear accelerator accelerates the electrons produced by the electron gun to almost the speed of light. The electrons are injected into the booster ring where they are given more energy by a radiofrequency cavity. Once the electrons have enough energy they are transferred to the outside ring called the storage ring. In the storage ring the path of the electrons are bent into a circular path by very powerful magnets. When the path of the electrons is bent some of the energy that the electrons are carrying continues in a straight line in the form of light, and is used to do an assortment of experiments.



Acceleration is any change of speed or direction. The electrons experience acceleration in the linear accelerator as they are sped up to 99.9998% the speed of light and again when they are forced to go around in a circle by very powerful magnets.

Centripetal Force is the inward force that is needed to keep an object on a circular path. When something travels along a curve there needs to be a force directed towards the center of curvature of the path. In a synchrotron the bending magnets provide the centripetal force needed to keep the electrons on track. Demo 1 helps you understand the direction of the acceleration when something is traveling in a circular pattern.

Centrifugal Force is a false force. There is no force actually acting outwards on an object, it is just the objects' resistance to change. The electrons want to continue travelling in a straight line, and when the centripetal force acts on them the synchrotron light is the result of the centrifugal force.

Newton's First Law of motion states that an object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force. Some of the energy that travels with the electrons when they go through the bending magnet continues moving in a straight line. In demo 2 if the string was cut the ball would continue in a straight line, and this is following Newton's First Law of motion.

Newton's Third Law of motion states that for every action there is an equal and opposite reaction. The forces on the electrons have to be balanced to keep them on track. To travel

in a circular path in demo 2 the inward force provided by the string has to equal the ball's desire to follow Newton's First Law of motion and travel in a straight line, just like the electrons.

Conservation of Momentum explains the creation of synchrotron light. Momentum is neither created nor destroyed. Momentum is only changed through the action of unbalanced forces. There always has to be a balance between the centripetal force and the centrifugal force applied to an object so that the object continues traveling around a curve and satisfies the law of the conservation of momentum. The amount of energy that the electrons have and the amount of energy that is given off in the form of synchrotron light add up to the amount of momentum the electron had before its' path was bent.

Synchrotron Light is electromagnetic radiation emitted in a path tangent to the particles orbit when charged particles travelling close to the speed of light are forced to change direction. This light is extremely bright and highly focused, which makes it very useful for performing detailed experiments. The Canadian Light Source Synchrotron produces light across the electromagnetic spectrum from infrared light all the way to hard x-rays. **http://www.physicsclassroom.com/**

Synchrotron Questions

Acceleration occurs when an object increases or decreases its speed or changes direction. How does this explain the direction of the candle flame?

What controls in a car allow the car to be accelerated?

In a synchrotron, when do electrons experience acceleration?

In the demonstration with the ball, what would happen if the string broke? What is the string?

How is the path of electrons bent? What is the force exerted on the electrons?

What keeps the electrons on track?

Why do the photons keep going in a straight line?

How does centripetal force relate to Newton's first law: Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it?

What questions do you have? Try to answer them.

Advanced: http://www.physicsclassroom.com/Class/circles/U6L1b.html
Calculate the centripetal force required to keep electrons on track?
Mass of electron = $9.10938188 \times 10^{-31}$ kg
Speed of light = 299792458 m/s
Diameter of Storage Ring = 54 m
Centripetal force = mv^2/r