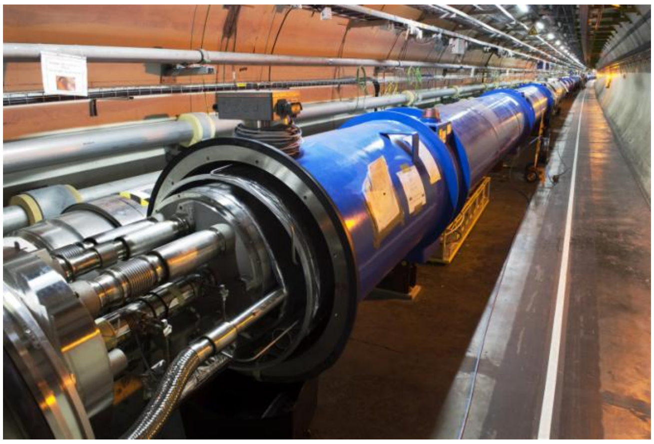
PHYS 1301

Magnetic Particle Accelerator

Introduction

The method modern physics uses to study the fundamental building blocks of matter in the laboratory is basically to smash it together in the hope of seeing something interesting happen. Partly we are interested in how matter interacts when collisions occur and partly we wish to create new forms of matter. In the latter scenario, Einstein's famous equation $E = mc^2$ is being used in reverse; rather than extracting energy from mass, as occurs in the Sun, we are making new forms of mass from the energy of the collision. Even if new matter is not created, the details of the collisions themselves can be very informative. Recalling de Broglie's relationship between particle momentum, the wavelength of its corresponding quantum wave, and the related resolving power of microscopes, high momentum particles in collision reveal the behavior of matter at small distance scales. In this way, scientists can investigate fundamental questions such as whether space is continuous or discrete, or whether there are extra dimensions of space.



Typically, the matter particles that are collided consist of beams of electrons or protons that have been accelerated to speeds close to the speed of light by a particle accelerator. The closer they get to the speed of light, the more energy and momentum they have. You may have heard about a new particle accelerator, the Large Hadron Collider (LHC), which accelerates and collides protons with energies hitherto unobtainable. A section of the 27 km-long accelerator is shown here, with part of the insides revealed. The LHC makes new kinds of matter never before observed in the laboratory. Note that this is not like creating new forms of matter in chemistry or many other branches of physics, where known forms are grouped together in novel ways.

Such experiments need to both accelerate particles to high energy and detect the debris from the collisions. We will study in some detail in another lab how particle detectors are used to methodically analyze the collisions. In the current lab, you will build a particle accelerator. Accelerators like the LHC need billions of dollars and thousands of scientists, but you will make a very simple model that uses the same principles of acceleration as the LHC. The objective will be to make it as efficient as possible, i.e. accelerate the particles to as high energy as possible. Particle accelerators like the LHC use the electric force to cause acceleration; that is why electrically charged particles are used. They are usually accelerated in stages, each stage pushing the particles to higher speeds – each of the blue sections in the previous picture is a stage in the LHC. In your simple model for this lab, you will be using the magnetic force to accelerate steel ball bearings (BBs) in stages. (Note: the magnetic force is also used in the LHC, but only to *guide* the beam of protons).

You will be shown a prototype at the beginning of the lab. One stage of the prototype is shown above – the BB to the left is attracted to the magnet in the middle and the BB to the far right then gets "kicked" to the right at high speed. The objective is to achieve, starting from rest at one end of the model accelerator, a BB moving with the maximum speed possible at the other end by experimenting with the stage design and number of stages. As part of this exercise, you will need to take measurements in order to calculate the final BB speed.

Equipment

- a length of grooved molding, about 1 foot long,
- some steel ball bearings (BBs)
- some Neodymium magnets to accelerate the BBs along the grooves
- a white sheet of paper and carbon paper
- a metre ruler
- tape

Procedure

1. After setting the magnets and BBs in the molding, align the end of the molding with the edge of the table.

2. Test fire your accelerator and observe approximately where the BB strikes the floor. Repeat for various different apparatus set-ups until you think you have the optimum one.

3. Now use masking tape to attach a piece of white paper to the floor near the location where the BB struck with the optimum set-up.

4. Place (do not tape) a sheet of carbon on top of the white paper.

5. Reload and fire several times.

6. **Before you remove the white paper from the floor,** measure the horizontal distances x from the end of the accelerator to the BB marks.

7. Measure the height y of the accelerator from the floor.

In order to calculate the final ball-bearing speed as it exits the accelerator one can use the definition

$$v = x / t \qquad \text{(Speed = Distance divided by Time)}$$

Here, x is the *horizontal* distance travelled by the BB while in flight and t is the time of flight. While it is straightforward to measure x with a ruler, it is difficult to measure t precisely with something like a stopwatch because it is so short. We can use a trick, however, to calculate t very precisely by measuring y, the height through which the BB falls, and using Galileo's equation of free fall

$$y = \tfrac{1}{2}\, g\, t^2$$

$g = 9.80\ \text{m/s}^2$ is the acceleration (downward) due to gravity. Combining the last two equations allows us to eliminate t and we get an equation for the BB speed v as it leaves the accelerator in terms of quantities that are known or easily measured:

$$v = x \sqrt{(g / 2y)}$$

Use your measurements of x and y to calculate several values of v and then average the results with an uncertainty. Take care with units during your calculations.

Results

	x	y	v
Measurement 1	___________	________	___________
Measurement 2	___________		___________
Measurement 3	___________		___________
Measurement 4	___________		___________
Measurement 5	___________		___________
Average Value			___________

Calculations:

Questions

1. Draw a labeled diagram of your optimum apparatus set-up.
2. Summarize the variations you made in the set-up.
3. What are the main sources of error in deducing v ?

Conclusions