Magnetic Particle Accelerator

PHYS 1301

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. Through quantum mechanics and relativity, which you will study in detail in this course, the collisions reveal the behaviour of matter at small distances and allow the creation of new kinds of particle. In this way, scientists can also 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 they have. You may have heard about the Large Hadron Collider (LHC), which accelerates and collides protons with energies hitherto unobtainable. The LHC produces forms of matter never before observed in the laboratory, such as Higgs Bosons (believed to be the cause of mass) and may be able to make Dark Matter (invisible particles that seem to make up most of the mass in the universe). 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. The LHC will also search for signals of extra dimensions of space, dimensions that we may never have noticed before because of their small size.

Such experiments need to both accelerate particles to high energy and detect the debris from the collisions. We will study in some detail, in a later lab, how particle detectors are used to methodically analyze the collisions. In this lab, we will build a very simple model of a particle accelerator, trying to make it as efficient as possible, i.e. accelerate the particles to as high energy as possible. Real particle accelerators use the electric force; that is why the electrically charged particles, such as protons or electrons, are used. They are usually accelerated in stages, each stage pushing the particles to higher speeds. In our simple models, you will be using the magnetic force to accelerate steel ball bearings (BBs) in stages. (Note: the magnetic force is also used in a real particle accelerator to *guide* the beams of protons or electrons). Because our accelerator is just a table-top model, it will be sufficient to use classical physics to understand the results.

The objective is to achieve, starting from rest at one end of the model accelerator, a BB moving with maximum speed possible at the other end. You will be shown a prototype accelerator at the beginning of the lab but are encouraged to modify and experiment with your apparatus set-up in order to obtain the maximum speed you can.

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

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

$g = 9.80\ m/s^2$ 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:

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

Use your measurements of *x* and *y* to calculate several values of *v* and then average the results. What are the units on your value of *v* ?

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