

**Massachusetts Institute of Technology  
Physics Department**

**8.01X**

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**EXPERIMENT FM: Force between Magnets**

**About Forces and Fields**

There are forces that don't change appreciably from one instant to another, said to be constant in time, and forces that don't change appreciably from one point to another, said to be constant in space. The weight of a mass on the earth is an example,  $\vec{F}_{grav} = m\vec{g}$ .

There are forces that increase as you move away. When a mass is attached to one end of a spring and the spring is stretched a distance  $|x|$ , the spring force increases in strength proportional to the stretch,  $|\vec{F}| = k|x|$

There are forces that stay constant in magnitude but always point towards the center of a circle, for example when a ball is attached to a rope and spun in a circle, the tension force acting on the ball is directed towards the center of the circle. This type of attractive central force is called a centripetal force

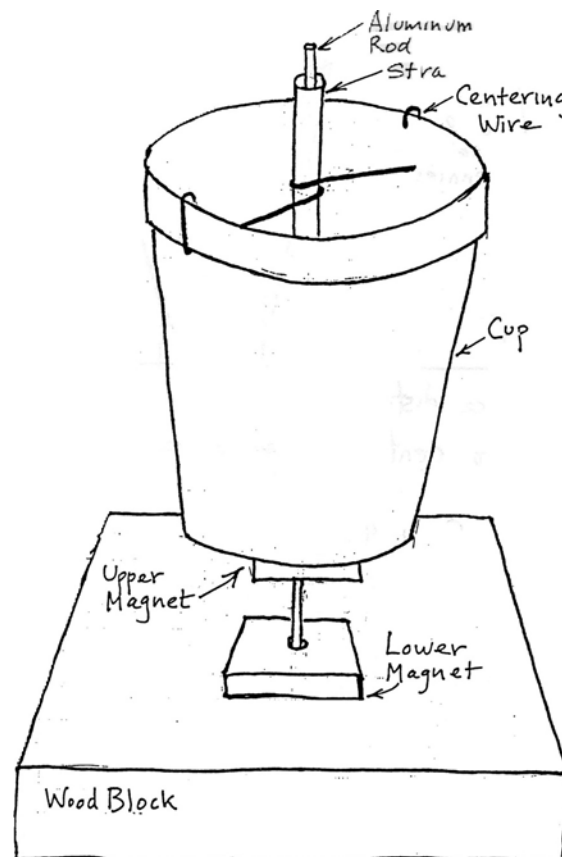
There are forces that spread out in space such that their influence becomes less with distance. Common examples are the gravitation and electric forces. The gravitational force between two masses falls off as the inverse square of the distance separating the masses provided the masses are of a small dimension compared to the distance between them. More complicated arrangements of attracting and repelling things give rise to forces that fall off with other powers of  $r$ : constant,  $1/r$ ,  $1/r^2$ ,  $1/r^3$ , etc., Thus you might expect the force between 2 rectangular magnets to vary with distance in some not very obvious way—but calculable with time and patience.

In this experiment you'll measure the force  $F$  newtons (N) required to press two rectangular magnets together as a function of the distance between the centers of the magnets. One magnet will be fixed to a block and the other magnet will be suspended above. A cup is balanced on top of the upper magnet. Pennies will be added to the cup pressing the magnets together.

**Assembling the Apparatus**

- Press the aluminum wire into the hole in the wooden block. Don't bend the wire.
- Cut off a 100 mm length of the 7 mm OD plastic soda straw
- Make a hole (from below) in the center of the bottom of the Styrofoam cup with the Phillips screwdriver in your kit.

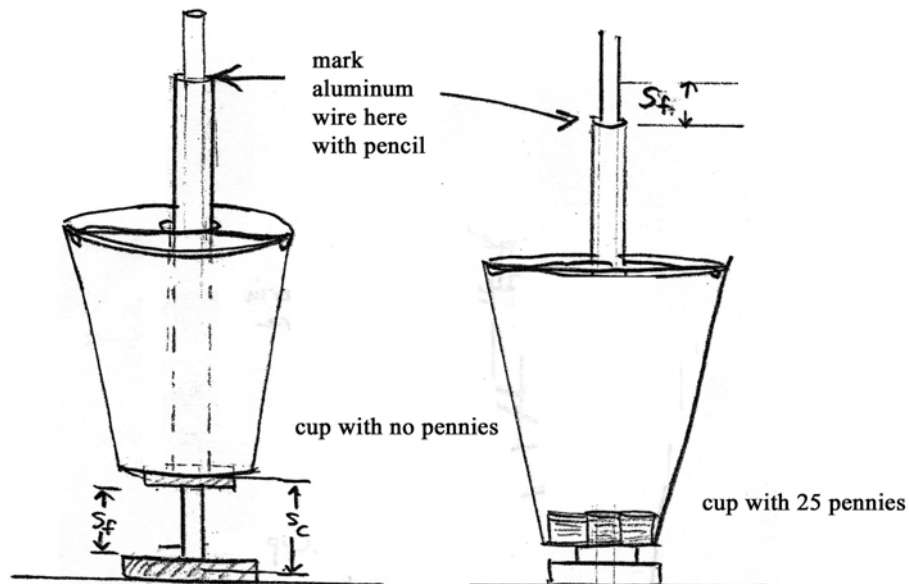
- Carefully enlarge the hole with the long-nose pliers so that the plastic soda straw fits tightly in the hole with one end flush with the bottom of the cup. NOTE: You can practice this first in the side of the cup if you like.
- Take the 140 mm length of number 22 wire and form a loop in the middle that will fit around the straw—just wrap it around. This is the centering wire.
- Make two holes diametrically opposite in the side of the cup about 13 mm below the top edge, just below the reinforcing thicker part of the rim of the cup.
- Put the wire loop over the straw. Bend the straw first to one side and then to the other in order to put the ends of the wire through the two holes.
- Squeeze the cup a few millimeters out of round, until the straw is centered in the opening and bend up the wire on one side.
- Again squeeze the cup out of round, until the straw is centered in the opening and bend up the wire on the other side.
- Clamp the wooden block to your desk, put the two magnets over the aluminum wire in such a way that one repels the other and slide the cup with its central straw over the wire.



To make sure the apparatus is OK, press down on the cup with two fingers on a diameter until the magnets touch and release it—the cup should bounce up and down about 3 or 4 times. Give the cup a twist of say  $20^\circ$  —it should oscillate a few times, 3 or 4. Now remove the cup.

## Experiment

- The first measurement you will make are the width of the magnets. You should find this width to be about 4 mm.
- The second measurement you will make is the distance between the magnets without the weight of the cup and pennies acting on the suspended magnet. To do this, place your ruler on the block and measure the distance to the center of the upper magnet. You may notice that the upper magnet is tilted at an angle so try to estimate the location of the center of the upper magnet. Subtract half the width of a magnet (about 2 mm) in order to obtain the center distance  $S_c$ , between the faces. This distance corresponds to a force equal to the weight of 1 magnet,  $0.074 \pm 0.002$  N. Make this the first entry in your table of separation between magnet faces,  $S_c$  (in mm) and  $F$  (in N).



$S_f$  = face to face distance

$S_c$  = center to center distance

$S_c = S_f + \text{width of magnet} = S_f + 4 \text{ mm}$

- Place the upper magnet and cup on the wire. The magnets are now closer because of the weight of the cup, straw and centering wire,  $0.025 \pm 0.003$  N. Make a pencil mark on the aluminum wire next to the top of the straw.
- Put 5 pennies in the cup placed symmetrically around the straw at the bottom. Make another pencil mark on the aluminum wire next to the top of the straw.
- Continue adding pennies in groups of 5, always placing them symmetrically around the straw, and making pencil marks on the aluminum wire.
- As the magnets get close you may need to bend the aluminum wire slightly so that the magnet faces are parallel. With about 25 pennies the magnets are essentially touching and the center to center distance,  $S_c$ , corresponds to the width of a magnet (about 4 mm).

### Data

Remove the cup and upper magnet. Measure the distance between your highest pencil mark and the lowest pencil mark. This corresponds to the face-to-face distance between the magnets when there are no pennies in the cup. Add the width of one magnet to get the center-to-center distance,  $S_c$ . Continue this procedure after putting 5 pennies in the cup, measuring the distance between your highest pencil mark and your lowest pencil mark. This corresponds to the face-to-face distance between the magnets when there are 5 pennies in the cup. Add the width of one magnet to get the center-to-center distance,  $S_c$ . Estimate your measurements to the nearest 0.5 mm. Continue for 10, 15, 20, and 25 pennies.

Post 1982 pennies have a mass of 2.50 grams and therefore a weight of 0.0245 N. Compute the cup and penny weights in newtons from their masses. Thus your cup, straw and centering wire mass, 2.5 grams, should be added to the magnet mass,  $7.6 \pm 0.2$  grams. For example, 5 pennies, with a mass 12.5 grams yield a total mass of 22.6 grams, corresponds to a force of 0.22 N.

Tabulate the data, with two columns labeled Force (N), and Center-to-Center Distance,  $S_c$ , (mm). Make two plots of the data; one on linear paper and the other on log-log paper with center-to-center distance  $S_c$  (in mm), along the horizontal axis and Force (in N) along the vertical axis.

### Analysis

On the log-log paper try to fit a straight line between the data points to match your best-fit curve. If you cannot match one straight line, you may be able to find two different regions where there are straight line fits. This means that the force between these magnets can be described by different inverse powers at different distances. In particular when they are very close and the separation is small compared to their width and length we

often say they are infinite planes. Since any finite gap is in effect zero compared to infinity, you would not expect the force to vary—another way of thinking about this is that with  $\infty$  featureless planes there is no scale of length and no way of telling how far away you are. This is why there is a slower variation of  $F$  with  $S_c$  when  $S_c$  is small. On the other hand, for very large distances one can expect  $F$  to go with some inverse power law.

Calculate the slope of the  $\log F$  vs.  $\log S_c$  best-fit straight lines. This gives the approximate power law for the force between the magnets for different ranges of center-to-center separation distance.

You may use a program to find the best fit straight line. If you want to calculate the slope note that if the force is a power law

$$F = a(S_c)^b,$$

where  $a$  is a constant and  $b$  is the power. Then

$$\log F = \log(a(S_c)^b) = \log(a) + \log((S_c)^b) = \log(a) + b \log(S_c).$$

The slope of the  $\log F$  vs.  $\log S_c$  graph is the power exponent  $b$ , and the intercept is the constant  $a$ . On the log-log graph paper choose two points that lie on your best-fit straight line. For example, suppose you choose the points

$$(x_1, y_1) = (9.0 \text{ mm}, 0.9 \text{ N})$$

$$(x_2, y_2) = (4.0 \text{ mm}, 3.0 \text{ N}).$$

Then the slope is

$$\text{slope} = \frac{\log y_2 - \log y_1}{\log x_2 - \log x_1} = \frac{\log(3.0 \text{ N}) - \log(0.9 \text{ N})}{\log(4.0 \text{ mm}) - \log(9.0 \text{ mm})} = \frac{\log(3.0 \text{ N} / 0.9 \text{ N})}{\log(4.0 \text{ mm} / 9.0 \text{ mm})} = -1.5$$

## Parts

- 1 wooden block
- 1 length #8 (1/8 in) aluminum wire, 140 mm
- 1 styrofoam cup
- 1 plastic soda straw
- 1 length #22 copper wire, 140 mm
- 1 paper clip #1
- 2 rectangular magnets with ~4 mm hole
- 50 US pennies