COUNTRY:_______________

XXIV INTERNATIONAL PHYSICS OLYMPIAD
WILLIAMSBURG, VIRGINIA, U.S.A.

PRACTICAL COMPETITION

Experiment No. 2

July 14, 1993

Time available: 2.5 hours

READ THIS FIRST!

INSTRUCTIONS:

1. Use only the pen provided, and only the equipment supplied.
2. Use only the marked side of the paper.
3. Write at the top of each page:
   - The number of the problem
   - The number of the page of your report
   - The total number of pages in your report.

   Example (for problem 1): 1 1/4; 1 2/4; 1 3/4; 1 4/4

Experimental Problem 2

MAGNETIC MOMENTS AND FIELDS

This experiment has two parts:

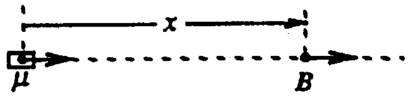
Part 1: To determine the absolute magnitude μ_X of the magnetic moment of a small cylindrical permanent magnet, contained in the envelope marked "X". (A similar magnet, also needed for the experiment, is contained in the envelope marked "A".)

Part 2: To investigate the magnetic field of a given axially symmetric distribution of magnets, contained in the envelope marked "B".

In your experiments, you should make use of the following facts:

(1) The magnetic field **B** produced by a dipole magnet at a point along its axis at distance x from its center is parallel to that axis and of strength given by:

$$B(x) = \frac{2\mu K}{x^3},$$



where **B** is in Tesla [= N/(A m)], $K = 10^{-7}$ Tesla m/A, x is in m, and μ is in A m^2.

(2) The period of small torsional (angular) oscillations of a horizontal freely suspended magnet, such as a compass needle in the Earth's magnetic field, is given by:

$$T = 2\pi\sqrt{\frac{I}{\mu B_h}},$$

where B_h is the horizontal component of the net field at the magnet, and I is the moment of inertia of the magnet about a vertical axis through its center.

Apparatus

The apparatus is illustrated in the diagrams at the end. A thin thread is suspended from the upper of two shelves on a wooden stand. A magnet ("X" or "A") can be attached to the bottom end of the thread. A copper plate can be placed on the lower shelf, just below the suspended magnet, to damp out its motion if desired. Two auxiliary wooden stands are provided. One of these serves as a holder for either "A" or "X" in Part 1; the other holds the magnet system B (used in Part 2). Distances between a suspended magnet and a magnet mounted in one of the auxiliary stands can be measured with a ruler mounted on that stand.

Warning: **These magnets are extremely strong. Hold onto them tightly and be careful not to let them be pulled out of your fingers.**

PART 1

The magnetic moment to be determined (μ_X) is that of the pair of magnets in envelope X, labelled at the ends with a letter-number combination. Always keep this pair together. The moment of inertia of this pair has been calculated and written on envelope X. Envelope A contains another pair of magnets with north and south poles marked respectively with black and red spots. This pair is similar to the pair from envelope X, though its magnetic moment (μ_A) cannot be assumed equal to μ_X. A given pair of magnets can be "split" and placed around the bronze disk attached to the thread, forming a "compass" whose torsional oscillation period may be measured. (The value I_X given on envelope X includes the effects of the bronze disk.)

One magnet-pair, centered in the hole in the wooden holder, can be used to influence the "compass" pair, possibly affecting its period and its angular equilibrium position. The angular position is best studied by placing the copper plate a few millimeters below the "compass" so as to provide electromagnetic damping. **Please do not mark or write on the copper plate.**

You will need to use more than one arrangement of the magnets. **Draw clearly labelled diagrams showing each experimental arrangement used. Also, write equations to show how you will combine your different observations to obtain the value of μ_X.**

Keep all magnets in the same horizontal plane. Note for the main stand that the top knob can be rotated, and the thread length adjusted. The position of each shelf can also be adjusted.

Practical Details (IMPORTANT!)

1) COMPASS ASSEMBLY AND USE: Hold one magnet from a given pair between the thumb and forefinger of one hand. Center the bronze disk over one end. Then, carefully, and without pulling on the thread, slowly bring in the second magnet. This forms the compass pair ("X" or "A"). Also, avoid pulling on the thread in taking the compass apart.
   Warning: Rapid snapping of magnets or magnet pairs together can break the thread or chip the magnets. The tiny loop can be threaded again if thread breakage occurs. (Consult the organizers if necessary.)

2) Study the torsional mode of oscillation. To prevent excitation of the "pendulum" mode, a small assembly made of copper wire is mounted on the lower shelf of the main stand. Rotate this assembly so that the horizontal piece is up against the thread at a point about 2 mm above where the thread is tied. With a slight additional rotation in the same direction, move the wire a few mm further .
   Warning: If this is not done, the two modes can "couple," causing a periodic variation in the amplitude of the torsional oscillations, and affecting their period.
   Use the nail (see diagrams at end) to start the torsional oscillations in a controlled way.

3) Keep magnetic or magnetizable objects stationary, and as far as possible from the experimental area. Consider such items as the nail, wrist watches, pens, etc. The table has some steel support parts; if you want to change the position of the apparatus, consider this fact.

Suggestions

(i) The torsion constant of the thread is quite small. It turns out that you can neglect its effect in the analysis provided the thread is reasonably long, e.g. around 15 cm.

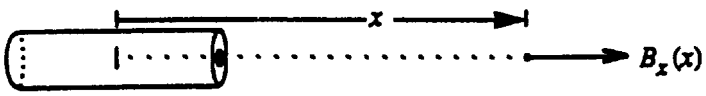
(ii) You may notice that a given magnet pair does not hang horizontally. This is because of the vertical component of the Earth's field. The effect of this on the analysis is small and should be neglected. In other words, simply pretend that the magnet is horizontal.

(iii) We suggest that you postpone the error analysis for Part 1 until after you have made the measurements needed for Part 2.

(iv) **You should not make any assumptions about the magnitude of the Earth's field.**

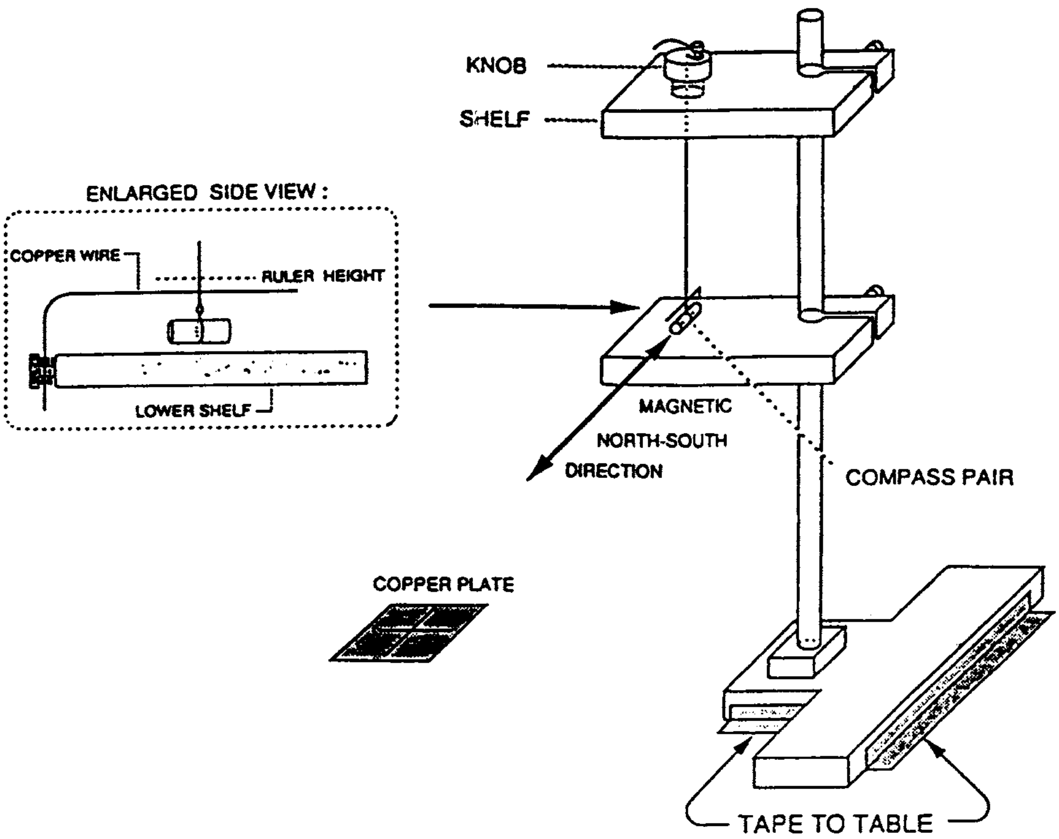
PART 2

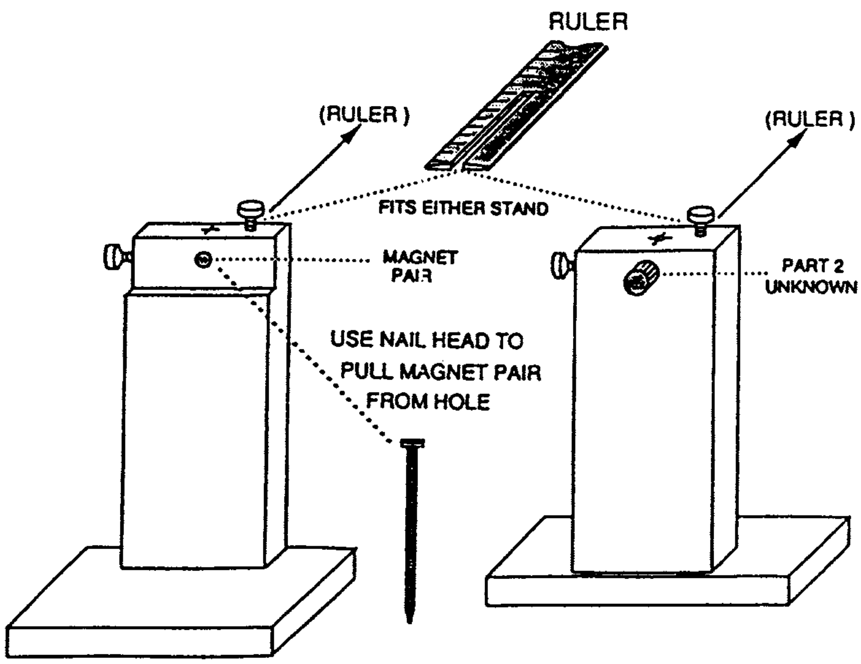
The aluminum tube (in envelope B) contains an axially symmetrical distribution of magnets. The magnetic field along the x axis, B_x, of this assembly varies as a function of distance x measured from the center of the tube according to the relation $B_x(x) = Cx^p$. Determine the exponent p, with its approximate error. As sketched below, you should study the field on the side in the direction of the end marked with a black spot.



WRITE YOUR SET-UP NUMBER ON YOUR REPORT. THIS IS THE LETTER-NUMBER COMBINATION PRINTED ON THE EQUIPMENT BOX AND ALSO ON THE MAGNET ENVELOPES LIKE THIS:

[ ]


KNOB
SHELF
ENLARGED SIDE VIEW :
COPPER WIRE
RULER HEIGHT
LOWER SHELF
MAGNETIC
NORTH-SOUTH
DIRECTION
COMPASS PAIR
COPPER PLATE
TAPE TO TABLE


RULER
(RULER)
(RULER)
FITS EITHER STAND
MAGNET
PAIR
PART 2
UNKNOWN
USE NAIL HEAD TO
PULL MAGNET PAIR
FROM HOLE