27th INTERNATIONAL PHYSICS OLYMPIAD OSLO, NORWAY

EXPERIMENTAL COMPETITION JULY 4 1996

Time available: 5 hours

READ THIS FIRST :

1. Use only the pen provided.
2. Use only the marked side of the paper.
3. No points will be given for error estimates except in 2c. However, it is expected that the correct number of significant figures are given.
4. When answering problems, use as little text as possible. You get full credit for an answer in the form of a numerical value, a drawing, or a graph with the proper definition of axes, etc.
5. Write on top of *every* sheet in your report:
   - Your candidate number (IPhO ID number)
   - The section number
   - The number of the sheet
6. Write on the front page the total number of sheets in your report, including graphs, drawings etc.
7. Ensure to include in your report page 10 used for answering section 2a and 3b, as well as all graphs requested.

SAFETY HAZARD: Be careful with the two vertical blades on the large stand. The blades are sharp!

This set of problems consists of 10 pages.

SUMMARY

The set of problems will cover a number of topics in physics. First, some mechanical properties of a physical pendulum will be explored, and you should be able to determine the acceleration of gravity. Then, magnetic forces are added to the pendulum. In this part the magnetic field from a permanent magnet is measured using an electronic sensor. The magnetic moment of a small permanent magnet will be determined. In addition, a question in optics in relation to the experimental setup will be asked.

INSTRUMENTATION

The following equipment is available (see Figure 1):

A	Large aluminium stand
B	Threaded brass rod with a tiny magnet in one end (painted white) (iron in the other).
C	2 Nuts with a reflecting surface on one side
D	Oscillation period timer (clock) with digital display
E	Magnetic field (Hall) probe, attached to the large stand
F	9 V battery
G	Multimeter, Fluke model 75
H	2 Leads
I	Battery connector
J	Cylindrical stand made of PVC (grey plastic material)
K	Threaded rod with a piece of PVC and a magnet on the top
L	Small PVC cylinder of length 25.0 mm (to be used as a spacer)
M	Ruler

If you find that the large stand wiggles, try to move it to a different position on your table, or use a piece of paper to compensate for the non-flat surface.

The **pendulum** should be mounted as illustrated in Figure 1. The long threaded rod serves as a physical pendulum, hanging in the large stand by one of the nuts. The groove in the nut should rest on the two vertical blades on the large stand, thus forming a horizontal axis of rotation. The reflecting side of the nut is used in the oscillation period measurement, and should always face toward the timer.

The **timer** displays the period of the pendulum in seconds with an uncertainty of ±1 ms. The timer has a small infrared light source on the right-hand side of the display (when viewed from the front), and an infrared detector mounted close to the emitter. Infrared light from the emitter is reflected by the mirror side of the nut. The decimal point lights up when the reflected light hits the detector. For proper detection the timer can be adjusted vertically by a screw (see N in Figure 1). Depending on the adjustment, the decimal point will blink either once or twice each oscillation period. When it blinks twice, the display shows the period of oscillation, T. When it blinks once, the displayed number is $2T$. Another red dot appearing after the *last* digit indicates low battery. If battery needs to be replaced, ask for assistance.
The **multimeter** should be used as follows:
Use the "VΩ" and the "COM" inlets. Turn the switch to the DC voltage setting. The display then shows the DC voltage in volts. The uncertainty in the instrument for this setting is

±(0.4%+1 digit).

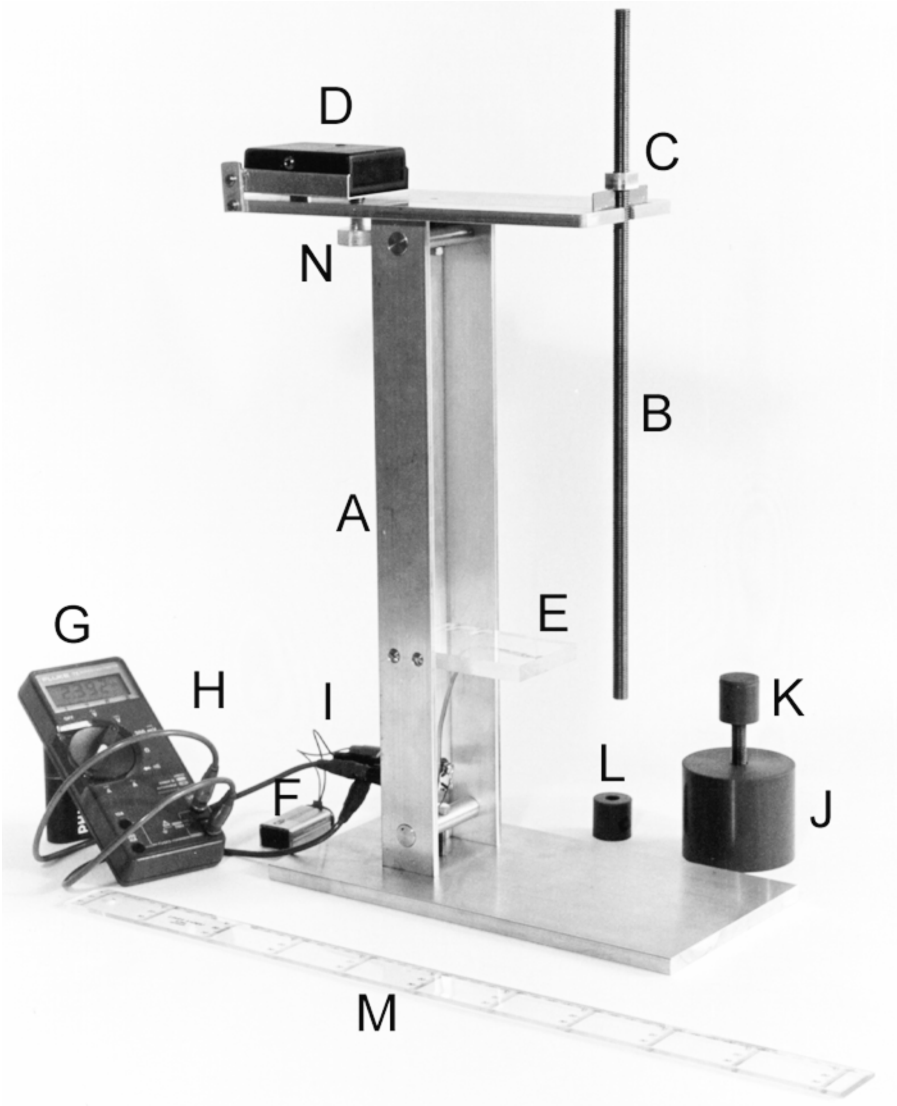

Figure 1. The instrumentation used.

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THE PHYSICAL PENDULUM

A *physical pendulum* is an extended physical object of arbitrary shape that can rotate about a fixed axis. For a physical pendulum of mass M oscillating about a horizontal axis a distance, l, from the centre of mass, the period, T, for small angle oscillations is

$$T = \frac{2\pi}{\sqrt{g}}\sqrt{\frac{I}{Ml} + l} \qquad (1)$$

Here g is the acceleration of gravity, and I is the moment of inertia of the pendulum about an axis parallel to the rotation axis but through the centre of mass.

Figure 2 shows a schematic drawing of the physical pendulum you will be using. The pendulum consists of a cylindrical metal rod, actually a long screw, having length L, average radius R, and at least one nut. The values of various dimensions and masses are summarised in Table 1. By turning the nut you can place it at any position along the rod. Figure 2 defines two distances, x and l, that describe the position of the rotation axis relative to the end of the rod and the centre of mass, respectively.

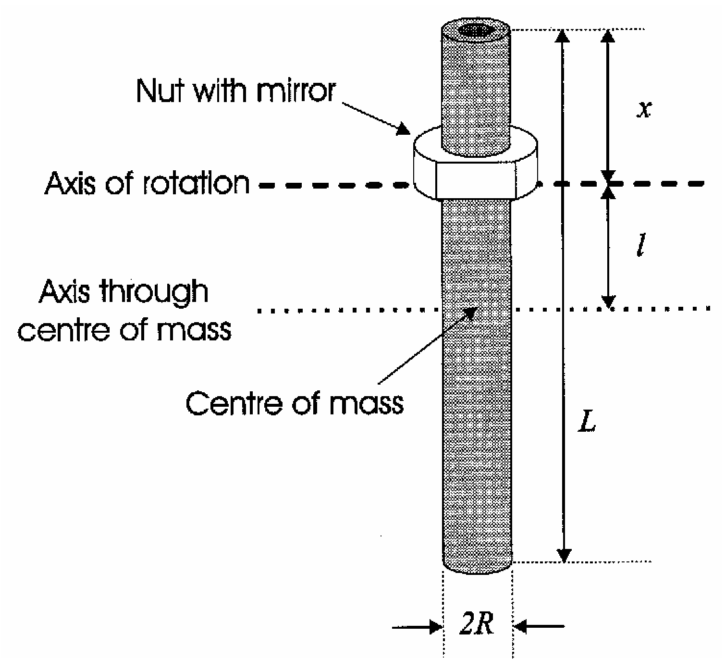

Figure 2: Schematic drawing of the pendulum with definition of important quantities.

Table 1: Dimensions and weights of the pendulum

Rod	Length	L	(400.0 ± 0.4) mm
	Average radius	R	(4.4 ± 0.1) mm
	Mass	M_{ROD}	(210.2 ± 0.2) $\cdot 10^{-3}$ kg
	Distance between screw threads		(1.5000 ± 0.0008) mm
Nut	Height	h	(9.50 ± 0.05) mm
	Depth of groove	d	(0.55 ± 0.05) mm
	Mass	M_{NUT}	(4.89 ± 0.03) $\cdot 10^{-3}$ kg

A reminder from the front page: No points will be given for error estimates except in 2c. However, it is expected that the correct number of significant figures are given.

Section 1 : Period of oscillation versus rotation axis position (4 marks)

a) Measure the oscillation period, T, as a function of the position x, and present the results in a table.

b) Plot T as a function of x in a graph. Let 1 mm in the graph correspond to 1 mm in x and 1 ms in T. How many positions give an oscillation period equal to T = 950 ms, T = 1000 ms and T = 1100 ms, respectively?

c) Determine the x and l value that correspond to the minimum value in T.

Section 2 : Determination of *g* (5 marks)

For a physical pendulum with a *fixed* moment of inertia, I, a given period, T, may in some cases be obtained for two different positions of the rotation axis. Let the corresponding distances between the rotation axis and the centre of mass be l_1 and l_2. The the following equation is valid:

$$l_1 l_2 = \frac{I}{M} \qquad (2)$$

a) Figure 6 on page 10 illustrates a physical pendulum with an axis of rotation displaced a distance l_1 from the centre of mass. Use the information given in the figure caption to indicate *all* positions where a rotation axis parallel to the drawn axis can be placed without changing the oscillation period.

b) Obtain the local Oslo value for the acceleration of gravity *g* as accurately as possible. *Hint: There are more than one way of doing this. New measurements might be necessary.* Indicate *clearly* by equations, drawings, calculations etc. the method you used.

c) Estimate the uncertainty in your measurements and give the value of *g* with error margins.

Section 3 : Geometry of the optical timer (3 marks)

a) Use direct observation and reasoning to characterise, qualitatively as well as quantitatively, the shape of the reflecting surface of the nut (the mirror). (You may use the light from the light bulb in front of you).

Options (several may apply):

1. Plane mirror
2. Spherical mirror
3. Cylindrical mirror
4. Concave mirror
5. Convex mirror

In case of 2-5: Determine the radius of curvature.

b) Consider the light source to be a point source, and the detector a simple photoelectric device. Make an illustration of how the light from the emitter is reflected by the mirror on the nut in the experimental setup (side view and top view). Figure 7 on page 10 shows a vertical plane through the timer display (front view). Indicate in this figure the whole region where the reflected light hits this plane when the pendulum is vertical.

Section 4 : Measurement of magnetic field (4 marks)

You will now use an electronic sensor (Hall-effect sensor) to measure magnetic field. The device gives a voltage which depends linearly on the vertical field through the sensor. The field-voltage coefficient is $\Delta V / \Delta B$ = 22.6 V/T (Volt/Tesla). As a consequence of its design the sensor gives a non-zero voltage (zero-offset voltage) in zero magnetic field. Neglect the earth's magnetic field.

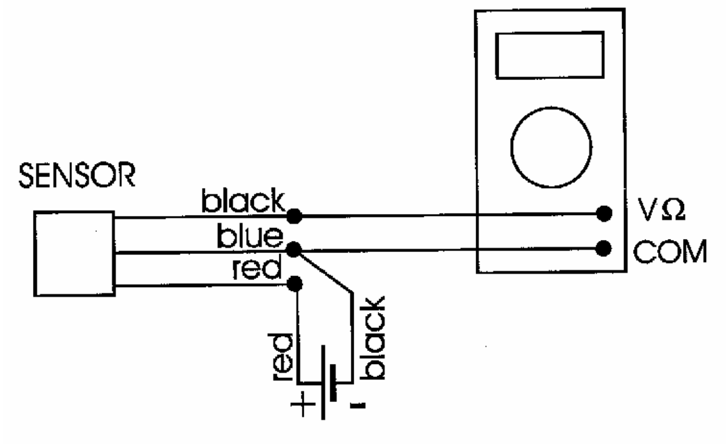

Figure 3: Schematics of the magnetic field detector system

a) Connect the sensor to the battery and voltmeter as shown above. Measure the zero-offset voltage, V_0.

A permanent magnet shaped as a circular disk is mounted on a separate stand. The permanent magnet can be displaced vertically by rotating the mount screw, which is threaded identically to the pendulum rod. The dimensions of the permanent magnet are; thickness $t = 2.7$ mm, radius $r = 12.5$ mm.

b) Use the Hall sensor to measure the vertical magnetic field, B, from the permanent magnet along the cylinder axis, see Figure 4. Let the measurements cover the distance from $y = 26$ mm (use the spacer) to $y = 3.5$ mm, *where* $y = 1$ mm *corresponds to the sensor and permanent magnet being in direct contact*. Make a graph of your data for B versus y.

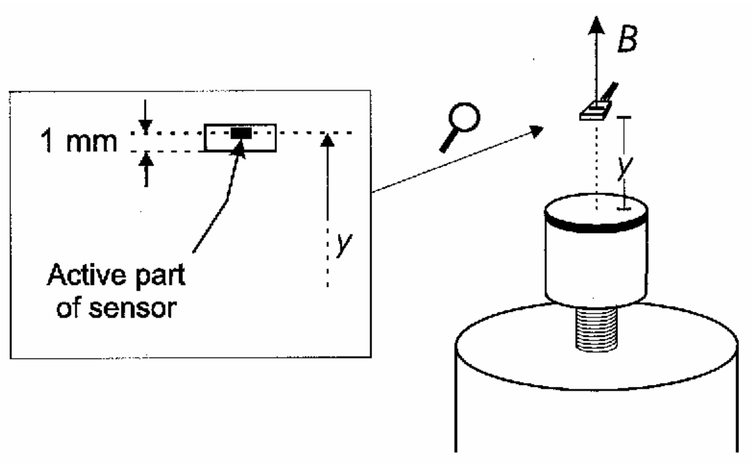

Figure 4: Definition of the distance y between top of magnet and the active part of the sensor.

c) It can be shown that the field along the axis of a cylindrical magnet is given by the formula

$$B(y) = B_0 \left[\frac{y+t}{\sqrt{(y+t)^2 + r^2}} - \frac{y}{\sqrt{y^2 + r^2}} \right] \qquad (3)$$

where t is the cylinder thickness and r is the radius. The parameter B_0 characterizes the strength of the magnet. Find the value of B_0 for your permanent magnet.§ Base your determination on two measured B-values obtained at different y.

Section 5 : Determination of magnetic dipole moment (4 marks)

A tiny magnet is attached to the white end of the pendulum rod. Mount the pendulum on the stand with its magnetic end down and with $\boldsymbol{x}$ **= 100 mm**. Place the permanent magnet mount under the pendulum so that both the permanent magnet and the pendulum have common cylinder axis. The alignment should be done with the permanent magnet in its lowest position in the mount. (Always avoid close contact between the permanent magnet and the magnetic end of the pendulum.)

a) Let z denote the air gap spacing between the permanent magnet and the lower end of the pendulum. Measure the oscillation period, T, as function of the distance, z. The measurement series should cover the interval from z = 25 mm to z = 5.5 mm while you use as small oscillation amplitude as possible. Be aware of the possibility that the period timer might display 2T (see remark regarding the timer under *Instrumentation* above). Plot the observed T versus z.

b) With the additional magnetic interaction the pendulum has a period of oscillation, T, which varies with z according to the relation

$$\frac{1}{T^2} \propto 1 + \frac{\mu B_0}{Mgl} f(z) \qquad (4)$$

Here $\propto$ stand for "proportional to", and μ is the magnetic dipole moment of the tiny magnet attached to the pendulum and B_0 is the parameter determined in section 4c. The function *f(z)* includes the variation in magnetic field with distance. In Figure 5 on page 9 you find the particular *f(z)* for our experiment, presented as a graph.
Select an appropriate point on the graph to determine the unknown magnetic moment μ.

§ $2B_0$ is a material property called remanent magnetic induction, B_r.

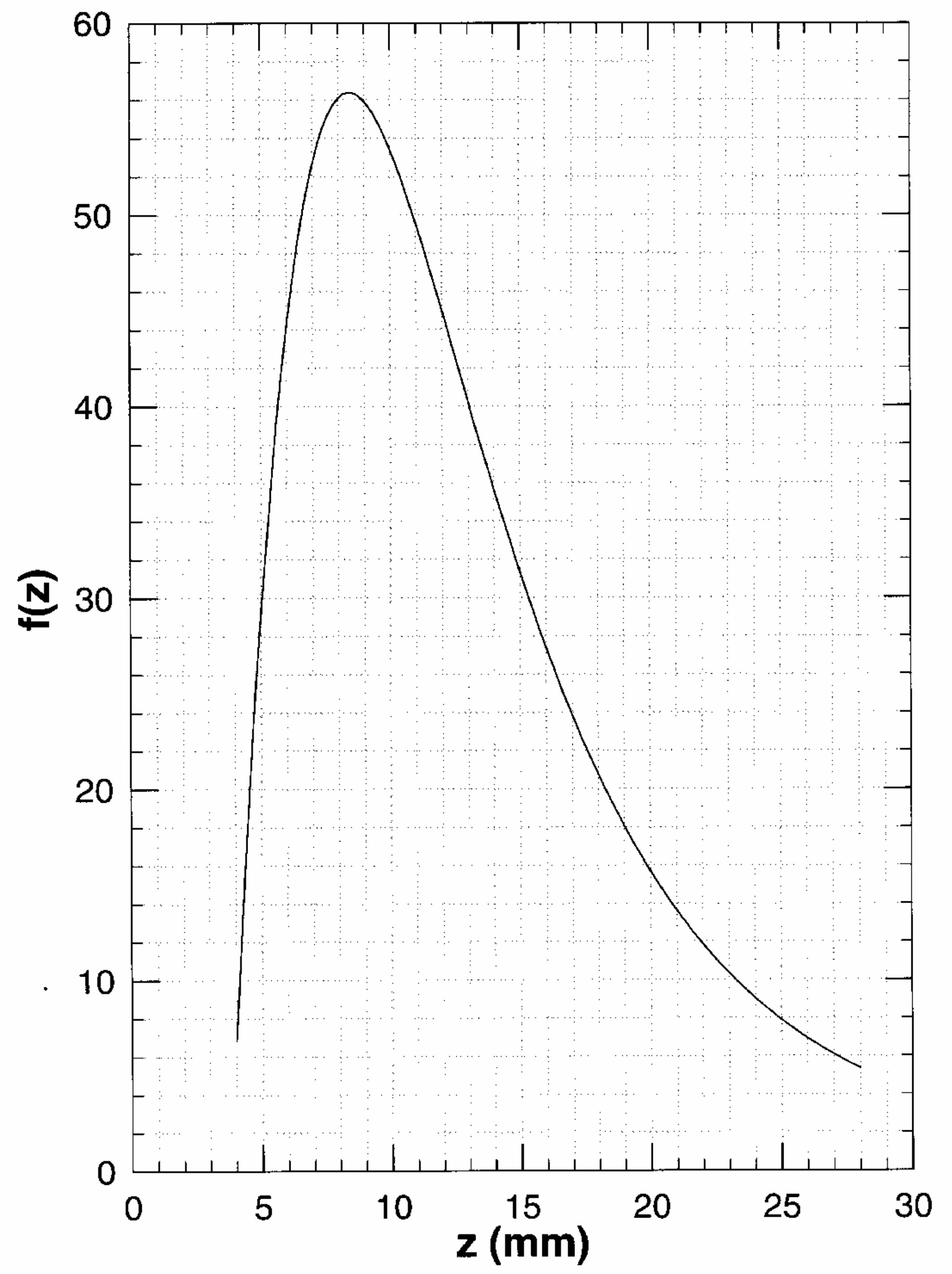

Figure 5. Graphs of the dimension-less functions f(z) used in section 5b.

Candidate:	Question:	Page ..... of .....

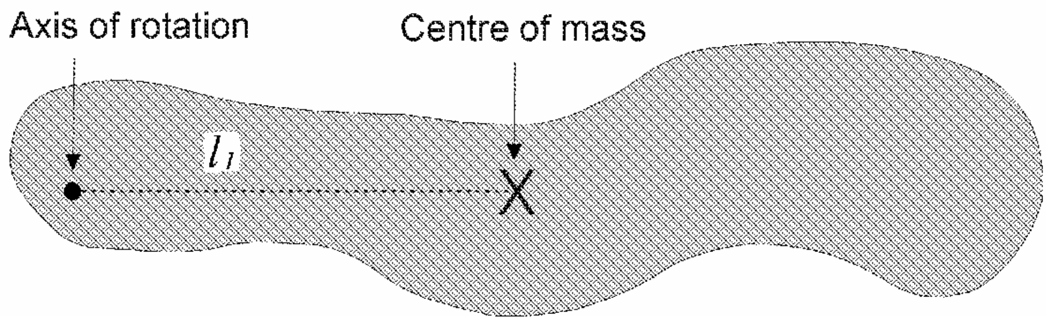

Figure 6. **For use in section 2a**. *Mark* all *positions where a rotation axis (orthogonal to the plane of the paper) can be placed without changing the oscillation period. Assume for this pendulum (drawn on scale, 1:1) that I/M = 2100 mm*^{2}.

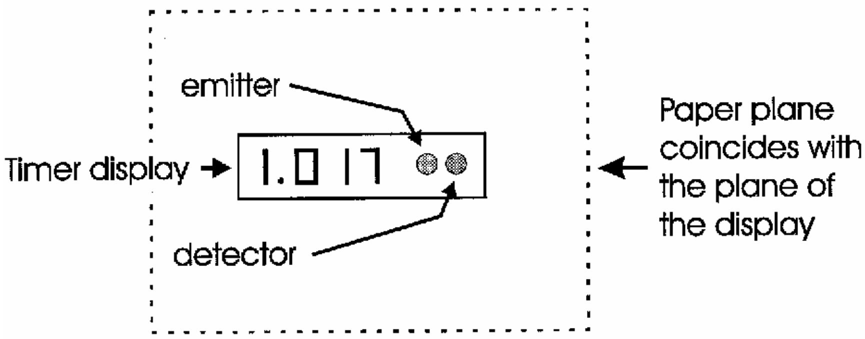

Figure 7. **For use in section 3b.** *Indicate the whole area where the reflected light hits when the pendulum is vertical.*

Include this page in your report!