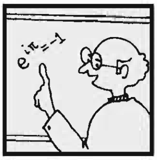

In this section of* Resonance, *we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

International Physics Olympiad'98
1. Experiments

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Experiments are an important component of science. Almost all the laws of nature and the empirical truths known to date were formulated on the basis of actual experimentation in the past.

The International Physics Olympiad (IPhO) was started by an enthusiastic group of physicists in the year 1967 at Warsaw, Poland. Since then, the IPhO has been organised almost every year in different countries. Each participating country is represented by upto five pre-university students at this event. The IPhO has two components: 1) theoretical and 2) experimental. The experimental component of the IPhO carries 40 percent of the total weightage.

India participated for the first time in 1998. The 29th International Physics Olympiad was held from 2nd to 10th July 98 at Reykjavik, the beautiful capital city of Iceland. Initially, thirty five students were selected out of about 13,000 students from all over India, through a two stage examination process. These students were imparted extensive training in a month long training camp held at the Homi Bhabha Centre for Science Education (HBCSE). Five students were selected at the end of

Education (HBCSE). Five students were selected at the end of the camp to represent India at the IPhO'98. The team of five students was accompanied by two professors, one of whom served as the 'delegation leader' and the other as the 'pedagogical leader'. The team consisted of:-

1. *Abhishek Kumar* (Presently doing BTech in Computer Science (CS) at IIT, Delhi)
Awards at the IPhO

- Silver medal
- Award of the President of IPhO [given to the best participant of the first time participating countries]

2. *Vijay Bhat* (Presently doing BS at Princeton University, NJ, USA)
Awards at the IPhO :

- Bronze medal
- Best solution to the theoretical problem number 2.

3. *Shivi Shekhar Bansal* (Presently doing BTech in CS at IIT, Kanpur)
Awards at the IPhO: Honourable Mention.

4. *Dilys Thomas* (Presently doing BTech in CS at IIT, Powai, Mumbai)
Awards at the IPhO: Honourable Mention.

5. *Saikat Guha* (Presently doing BTech in EE at IIT, Kanpur)
Awards at the IPhO:

- Honourable Mention,
- European Physical Society (EPS) Award [for the best balance between theory and experiment]

6. *Hemachandra Pradhan*, delegation leader (Senior research scientist, TIFR, Mumbai)

7. *T S Natarajan*, pedagogical leader (Professor, Department of Physics, IIT, Chennai)

I found the experimental program of the IPhO training camp held at the HBCSE extremely enlightening. The training camp was organised and supervised by Arvind Kumar, Director HBCSE and Hemachandra Pradhan, without whose dedicated efforts the realization of the debut participation of an Indian team at the International Physics Olympiad would have been impossible. I hereby also wish to take the opportunity to thank Rajesh B Khaparde and his colleagues at HBCSE who set up the fifteen experiments and under whose expert guidance the experiments were carried out by us at the training camp.

All the fifteen experiments were thought-provoking and required quite a bit of understanding of physical principles involved and sometimes extensive theoretical deductions and planning before one could start the experiments. Some of the interesting experiments were as follows:

1. Calculating the efficiency of a light emitting diode using a photo detector arrangement, given the inverse square law of light intensity and the quantum efficiency of the photo diode (quantum efficiency = number of electrons emitted/number of incident photons)

2. Calculating the magnetic moment of a small magnet, by measuring the change in the time period of oscillations of a physical pendulum with the small magnet attached at its bottom due to the field of a larger permanent magnet.

3. Studying the reflectivity behaviour of pi and sigma components of a He-Ne laser on a glass prism to find the Brewster's angle and thereby calculating the refractive index of the glass prism.

4. Finding the electrical circuit (given the type and the number of components used) inside three or four terminal 'black boxes' by performing appropriate experiments.

5. Solving linear algebraic simultaneous equations and second order linear differential equations with constant coefficients using operational amplifiers.

6. Studying the dispersion and various orders of rainbow

formation by white light falling on a liquid droplet by a spectrometer arrangement and thereby, using the deviation angles of the different orders of the rainbow, (along with appropriate ray-optics theory – to be worked out by the student) to estimate the refractive index of the given liquid.

In the following pages, I shall present the statement of the experimental problem posed at the IPhO. In a subsequent issue of this journal, I shall present the entire solution to the problem accompanied by the required theoretical deductions and actual experimental observations.

The maximum time allowed for this experiment was 5 hours. The IPhO also had a theoretical examination consisting of three problems, of 5 hours duration. Zhifeng Deng (China) obtained the best score in the experimental competition. The experimental problem consists of two parts. In the first part, we were to study the magnetic shielding effect of aluminum foils for time varying magnetic fields. In the second part, which is the longer one, we were asked to do several experiments to study the magnetic flux linkage in a transformer – like magnetic circuit made of two U-shaped ferrite cores.

29th International Physics Olympiad,
Reykjavik, Iceland.
[Experimental Competition]
(An extract)
Monday, July 6th , 1998 (Time available : 5 hours)

Instrumentation provided :

1) Platform with 6 banana jacks
2) Pickup coil embedded into the platform
3) Ferrite U-core with two coils marked 'A' and 'B'
4) Ferrite U-core without coil
5) Aluminum foils of thicknesses : 25μm, 50μm and 100μm
6) Function generator with output leads
7) Two multimeters
8) Six leads with banana plugs

9) Two rubber bands and two small pieces of grease proof paper

Part I: Magnetic Shielding with Eddy Currents

Time dependent magnetic fields induce eddy currents in conductors. The eddy currents in turn produce counteracting magnetic fields. In superconductors, the induced eddy currents will expel the magnetic field completely from the interior of the conductor. Due to their finite nonzero conductivity normal metals are not as effective in shielding magnetic fields. To describe the shielding of aluminium foils, we will assume the following phenomenological model suggested in the question paper:

$$B = B_0 \exp(-\alpha d) \tag{1}$$

where B is the magnetic flux density beneath the foils, B_0 is the magnetic flux density at the same point in the absence of foils, α is an attenuation coefficient and d is the foil thickness.

Experiment

Put the ferrite core with the coils, with legs down, on the raised block such that coil A is directly above the pickup coil embedded in the platform. Secure the core to the block by stretching rubber bands over the core and under the block recess (see *Figure* 1).

1. Connect the leads for coils A and B to the jacks. Measure the resistance of all coils to make sure you have good connections.

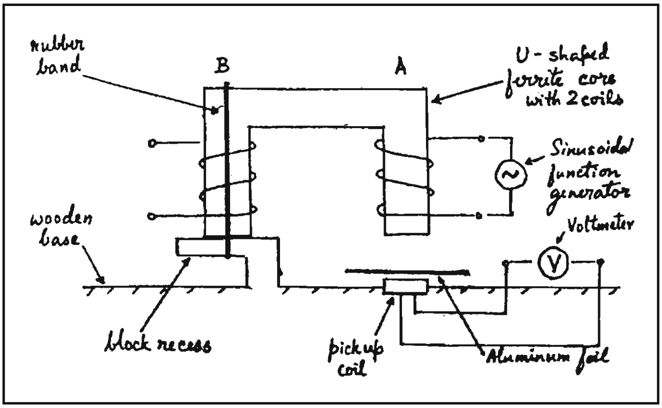


Figure 1. Experimental arrangement and circuit.

You should expect values of less than 10 ohms.

2. Collect data to validate the model given above and evaluate the attenuation coefficient α for the aluminium foils (25–175μm), for frequencies in the range of 6 – 18 kHz. Place the foils inside the square, above the pickup coil and apply a sinusoidal voltage to coil A.

3. Plot α versus frequency, and write an expression describing the function $\alpha(f)$.

Part – II: Magnetic Flux Linkage

The response of two coils on a closed ferrite core to an external alternating voltage (V_g) from a sinusoidal signal generator is studied.

Theory

In the following basic discussion, and in the treatment of the data, it is assumed that the ohmic resistance in the two coils, hysteresis losses in the core and eddy current losses have insignificant influence on the measured currents and voltages. (These assumptions are reasonable because of the small resistance of the coils and because of properties of ferrites.) Because of these simplifications in the treatment below, some deviations will occur between measured and calculated values.

Single Coil

Let us first look at a core with a single coil, carrying a current I. The magnetic flux φ is proportional to current I and to the number of turns N of the winding. The flux depends furthermore on a geometrical factor g, which is determined by the size and shape of the core, and the magnetic permeability $\mu = \mu_r \mu_0$ of the core material. μ_r and μ_0 denote the relative permeability and the permeability of free space, respectively. We will assume that μ_r is a constant. This is a reasonable assumption if the ferrite core is not driven into saturation.

The magnetic flux φ is thus given by

$$\varphi = \mu g N I = c N I \qquad (2)$$

where $c = \mu g$. The induced voltage is given by Faraday's law of induction,

$$\varepsilon(t) = -N\frac{d\varphi(t)}{dt} = -c N^2 \frac{dI(t)}{dt} \qquad (3)$$

The conventional way to describe the relationship between current and voltage for a coil is through the self inductance of the coil L, defined by,

$$\varepsilon(t) = -L\frac{dI(t)}{dt} \qquad (4)$$

A sinusoidal signal generator connected to the coil will drive a current through it given by

$$I(t) = I_0 \sin \omega t \qquad (5)$$

where ω is the angular frequency and I_0 is the amplitude of the current. It can be seen from (3) that this alternating current will induce a voltage across the coil given by

$$\varepsilon(t) = -\omega c N^2 I_0 \cos \omega t \qquad (6)$$

The current will be such that the induced voltage is equal to the signal generator voltage V_g. There is a 90 degree phase difference between the current and the voltage. If we only look at the magnitudes of the alternating voltage and current, we have

$$\varepsilon = \omega c N^2 I \qquad (7)$$

where ε and I denote the rms values (from now on we shall drop the subscript 0).

Two Coils

Let us now assume that we have two coils on one core. Ferrite cores can be used to link magnetic flux between coils. In an ideal core the flux will be the same for all cross-sections of the core. However, because of local air paths, not all the flux associated with coil A links coil B. Thus the second coil on the core will in general experience a reduced flux compared to the flux-generating coil. The flux φ_B in the second coil B is therefore related to the flux φ_A in the primary coil A through

$$\varphi_B = k\,\varphi_A \tag{8}$$

where k is a constant. Similarly, a flux component φ_B created by a current in coil B will have a component flux $\varphi_A = k\varphi_B$ linking coil A. The factor k, which is called the coupling factor, has a value less than unity.

The ferrite core under study has two coils A and B in a transformer arrangement. Let us assume that coil A is the primary coil. A sinusoidal voltage of angular frequency ω is applied to coil A. If no current flows in coil B ($I_B = 0$), the induced voltage ε_A due to I_A is equal and opposite to V_g. The flux created by I_A inside the secondary coil is determined by (8). The induced voltage in coil B is

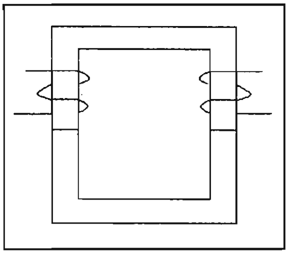
$$\varepsilon_B = \omega kc\, N_A N_B I_A \tag{9}$$

If a current I_B flows in coil B, it will induce a voltage in coil A, which is described by a similar expression. The total voltage across the coil A will then be given by

$$V_g = \varepsilon_A = \omega c N_A^{\,2} I_A - \omega kc N_A N_B I_B \tag{10}$$

The current in the secondary coil thus induces an opposing voltage in the primary coil, leading to an increase in I_A. A similar equation can be written for ε_B. As can be verified by measurements, k is independent of which coil is taken as the primary coil. In the above equations the voltages and currents are represented in terms of their rms values.

Figure 2. A transformer with a closed magnetic circuit.



Experiment

Place the two U – cores together as shown in *Figure* 2, and fasten them with the rubber bands. Set the function generator to produce a 10 kHz sine wave. Remember to set the multimeters to the most sensitive range suitable for each measurement. The number of turns of coils A and B are: $N_A = 150$ turns and $N_B = 100$ turns (1 turn on each coil).

1. (3.5 pts) Find out the algebraic expressions for the self inductances L_A, L_B and the coupling factor k and write your numerical results. Draw appropriate circuit diagrams showing how these quantities are determined.

2. (2 pts) When the secondary coil is short-circuited, the current I_P in the primary coil will increase. Use the equations above to derive an expression giving I_P explicitly in terms of the primary voltage, the self inductance of the primary coil and the coupling constant, and write your numerical answer based on your expression on the answer sheet. Measure I_P and compare with the numerical value earlier obtained.

3. (2.5 pts) Coils A and B can be connected in series in two different ways such that the two flux contributions are either added to or subtracted from each other.

3.1 Find the self inductance of the serially connected coils, L_{A+B}, from measured quantities in the case where the flux contributions produced by the current I in the two coils add to (strengthen) each other and write your answer in the answer sheet.

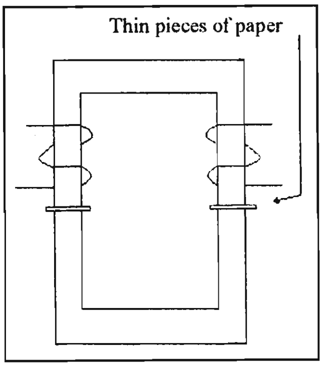
3.2 Measure the voltages V_A and V_B when the flux contributions of the two coils oppose each other. Write your values of V_A, V_B and the ratio of the voltages in the answer sheet. Derive an expression for the ratio of the voltages across the two coils in terms of the winding numbers and the coupling constant.

4. (1 pt) Use the results obtained to verify that the self inductance of a coil is proportional to the square of the number of its windings and write your result in the answer sheet.

5. (1 pt) Verify that it was justified to neglect the resistance of the primary coil and write your argument as a mathematical expression in the answer sheet.

6. (2 pts) Thin pieces of paper inserted between the two half cores (as shown in *Figure* 3) reduce the coil inductances drastically. Use this reduction to determine the relative permeability μ_r of the ferrite material, given Ampere's law and

Figure 3. The ferrite cores with the two spacers in place.



continuity of the magnetic flux density B across the ferrite–paper interface. Assume $\mu = \mu_0 = 4\pi \times 10^{-7} Ns^2/C^2$ for the paper and a paper thickness of 43 μm. The geometrical factor can be determined from Ampere's law

$$\oint \frac{1}{\mu} B dl = I_{\text{total}} \qquad (11)$$

where I_{total} is the total current flowing through a surface bounded by the integration path. Write your algebraic expression for μ_r and the numerical value obtained in your answer sheet.

The complete solution to the above experiment shall be presented in the Part 2 of this article in a subsequent issue of *Resonance*. In the meantime this experiment can be performed in various schools and colleges as it does not require any sophisticated instruments.

Acknowledgements

1) I thank Vijay Singh (Professor, Department of Physics, IIT, Kanpur) for helping me in editing the piece and arranging for experimental data for the actual experiment. He is actively involved in the IPhO programme and was the delegation leader for this year's (1999) Indian team.

2) I am grateful to S S Prabhu (Retd Professor, Department of Electrical Engineering, IIT, Kanpur) for helping me with some of the theoretical portions of this experimental problem.

In art nothing worth doing can be done without genius; in science even a very moderate capacity can contribute to a supreme achievement.

Bertrand Russell