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I.C.P.E. Medal Presented to Dieter Nachtigall in Duisburg, Germany - 26th August 1998

Professor Paul J. Black, Chairman, International Commission on Physics Education,

Medal Citation

Professor Dr. Dieter Nachtigall, born on February 4th 1927, is awarded the ICPE medal because his remarkable contributions to physics education have been outstanding and international in their scope and influence, and have extended over a considerable period of time.

He first started a career in nuclear physics in Dresden, Juelich and Geneva at CERN, resulting in more than 40 publications in radiation physics. But in spite of these successful activities he became more and more interested in problems of physics education, and finally switched to this scientific field.. More than 60 publications show that he was a highly successful researcher in this field, the UNESCO document No.48 "Internalising Physics", the Proceedings of the International Conference on Physics Teacher Education 1992, and several textbooks translated into Chinese being among them.

After about ten years of intensive research on the local level within Germany, Dieter Nachtigall started another and international career as a visiting professor, mostly in developing countries. The list of sites where he went to help develop and improve physics curricula for physics

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Fire and Ice: The 1998 International Physics Olympiad in Reykjavík, Iceland

Dwight E. Neuenschwander, Academic Director, US Physics Team

The Land of Fire and Ice

As descendants of the Vikings, Icelanders have always been explorers. In 986 Eric the Red discovered Greenland; and in the year 1000 Leifur Eriksson discovered a new land which he called *Vinland*, which later generations would know as *America*. Last July 2-10, five *Vinlanders* and 261 students from 55 other nations crossed the seas to Reykjavík, for the XXIX International Physics Olympiad.

Scholarship has always been a priority in Iceland. Icelandic remains the most originally intact of the Nordic languages, thanks to the full literacy of Icelanders since the Middle Ages, and their determination to preserve their identity. Modern Icelanders can still read their 13th century *Sagas* and *Eddas* in the original. Iceland also boasts the world's oldest continuous representative government as its parliament, the Althing, was founded in 930.

The geologic creation of Iceland continues with the work of the Mid-Atlantic Rift and some 200 volcanoes, with an eruption every five years on the average. Over the fires sit several glaciers, including Vatnajökull, the largest in Europe.

The 1998 IPO opening ceremonies were held July 3 at the University of Iceland. Folk music was provided by The Hamrahlíð Choir, three dozen secondary school students dressed in traditional costume. In Icelandic, they sang

Come and be joyful,
I will dance merrily
with my sweetheart.
May God let us drink
from the goblet of joy...

"Who can worry about the future with such wonderful people around?" asked the master of ceremonies, Guðrún Pétursdóttir.

With 267,000 citizens, Iceland was the smallest nation to host an IPO, and the 1998 event was one of the largest ever. Nevertheless, the 1998 IPO was first-rate. The participants experienced Icelandic friendliness personally, as all

Inside:

ICPE Medal to Nachtigall *(Continued from page 1)*

education both at school and university level is remarkable: more than 40 universities in Asia, others in Africa and south America. Several universities in China, a special focus of his activities, have nominated him an Honorary Professor. In many cases he founded a completely new system of pre- and in-service teacher training based on direct experience with low-cost hands-on experiments. He always put a special emphasis on bringing out the preconceptions of students and the possible misconceptions of teachers and a new teacher self-concept was the special focus of his activities.

Summarising Dieter Nachtigall's activities, he may be characterised as an enthusiastic ambassador for physics education who has been accepted in many foreign countries because of his sensitivity to local cultures.

Papers in Physics Education Research: 1998

This list includes papers published in a variety of journals that may be of interest to researchers in physics education and to physics teachers interested in making their classrooms more effective. Papers have been selected that focus on high school or college level physics teaching, though we may occasionally include papers describing work with younger students if they seem relevant.

The American Journal of Physics, Vol. 66

- Richard R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses", No. 1, Jan. 1998, pp. 64-74.
- Lawrence A. Coleman, Donald F. Holcomb, and John S. Rigden, "The Introductory University Physics Project 1987-1995: What has it accomplished?", No. 2, Feb. 1998, pp. 124-137.
- Tara O'Brien Pride, Stamatis Vokos, and Lillian C. McDermott, "The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems", No. 2, Feb. 1998, pp. 147-157.
- Edward F. Redish, Jeffery M. Saul, and Richard N. Steinberg, "Student expectations in introductory physics", No. 3, March 1998, pp. 212-224.
- Ronald K. Thornton and David R. Sokoloff, "Assessing student learning of Newton's laws" The Force and Motion Conceptual Evaluation and the evaluation of active learning laboratory and lecture curricula", No. 4, April 1998, pp. 338-352.
- J. Poulis, C. Massen, E. Robens, and M. Gilbert, "Physics lecturing with audience paced feedback", No. 5, May 1998, pp. 439-441.
- David Hestenes, "Who needs physics education research!?", No. 6, June 1998, pp. 465-467.
- Saalih Allie and Andy Buffler, "A course in tools and procedures for Physics I", No. 7, July 1998, pp. 613-624.

International Journal of Science Education, Vol. 20

- Manuela Welzel and Wolff-Michael Roth, "Do interviews really assess students' knowledge?", No. 1, Jan. 1998, pp. 25-44.
- K. F. Collis, B. L. Jones, T. Sprod, J. M. Watson, and S. P. Fraser, "Mapping development in students' understanding of vision using a cognitive structural model", No. 1, Jan. 1998, pp. 45-66.
- Eduardo Fleury Mortimer, "Multivoicedness and univocality in classroom discourse: an example from theory of matter", No. 1, Jan. 1998, pp. 67-82.
- Karine Bécu-Robinault and Andrée Thiberghien, "Integrating experiments into the teaching of energy", No. 1, Jan. 1998, pp. 99-114.
- A. T. Borges and J. K. Gilbert, "Models of magnetism", No. 3, March 1998, pp. 361-378.
- Philip Johnson, "Progression in children's understanding of a 'basic' particle theory" a longitudinal study", No. 4, Apr-May 1998, pp. 393-412.
- Chin-Chung Tsai, "An analysis of Taiwanese eighth graders' science achievement, scientific epistemological beliefs and cognitive structure outcomes after learning basic atomic theory", No. 4, Apr-May 1998, pp. 413-425.
- I. D. Johnston, K. Crawford, and P. Fletcher, "Stedent difficulties in learning quantum mechanics", No. 4, Apr-May 1998, pp. 427-446.
- Saalih Allie, Andy Buffler, Loveness Kaunda, Bob Campbell, and Fred Lubben, "First-year physics students' perceptions of the quality of experimental measurements", No. 4, Apr-May 1998, pp. 447-459.
- Christoph von Rhöneck, Karl Grob, Gerhard W. Schnaitmann, and Bruno Völker, "Learning in basic electricity: how do motivation, cognitive and classroom climate factors influence achievement in physics?", No. 5, June 1998, pp. 551-565.
- Philip Johnson, "Children's understanding of changes of state involving the gas state, Part 1: Boiling water and the particle theory", No. 5, June 1998, pp. 567-583.
- Fernando Cajas, "Using out-of-school experience in science lessons: an impossible task?", No. 5, June 1998, pp. 623-625; K. Mayoh and S. Knutton, "Response to Dr. Cajas, Michigan State University", pp. 627-628.

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Physics Olympics *(Continued from page 1)*

students, and later in the week all coaches, were invited one evening into the homes of local families. A nation's greatest resource is its people, and Iceland is abundantly blessed despite its small population. Indeed, one finds a refreshing openness where it seems that everybody knows everyone! Everyone goes by their *first* name, even in the telephone book. Instead of surnames, Icelanders retain the ancient patronymic custom of using for the last name the father's first name with *son* or *dóttir* suffix.

The Exam

On July 4 the students took the five-hour Theoretical Exam.

* Problem 1 developed the mechanics of a hexagonal prism rolling down an inclined plane.

* In Problem 2, the pressure beneath an ice cap was modeled, including a prediction of the slumping of the surface that results after a conical intrusion of lava melts a cavity beneath the ice. A presentation later in the week by Dr. Magnús Tumi Guðmundsson of the University of Iceland Geophysics Department, describing the spectacular eruption beneath the Vatnajökull Glacier in 1996, showed how realistic was this simple model!

* Problem 3 used 1994 data reporting an apparent superluminal motion of a jet of matter in a galactic radio source. After leading the students through some implications of the paradox, it was resolved by re-calibrating of the distance to the source using the relativistic Doppler shift.

On July 5, in between the Theoretical and Practical Exams, the students went on holiday and toured some of Iceland's striking scenery.

On July 6 the student gathered up their own courage for the Practical Exam.

* In Problem 1, the attenuation of a magnetic field by various thicknesses of aluminum was measured, including the frequency dependence of the attenuation coefficient.

* In the second problem, the students explored the self-inductance of two coils, then linked them together like a transformer to measure mutual inductance and the magnetic susceptibility of the core material.

A Sense of Community

In the competition there were 11 gold and 15 silver medals presented, down from recent years. Five gold medals went to China, and to Russia three golds and two silvers. Iran won one gold, three silvers and a bronze; one silver and four bronzes to Vietnam; Hungary earned five bronze medals and Germany four, the USA earned a silver and a bronze. India delivered an impressive performance in this their first IPO, also with one silver and one bronze.

The comaradarie is the glory of this event. Everybody connected with the Olympiad knows that some countries could field several competitive teams if the rules allowed, while other countries' programs are heroically run from the briefcases of a couple of dedicated individuals facing enormous obstacles. Some coaches look forward to the day when they will have their first student win a medal. Yet they keep coming back, a persistence which I greatly admire. It's the character-building qualities of the event, not the physics for its own sake, that ultimately matters. We're all doing this *because we love students.*

Closing Ceremonies

In the closing ceremony on July 9, Þórunn Ragnarsdóttir of Íslandbanki, a sponsor of IPO '98, reflected on reasons to support the Physics Olympiad: it forms "the best way to open our dreams to tomorrow... Young people carry the future..." The 1998 IPO General Manager, Viðar Ágústsson, noted that "Life is not only a competition- it's living and enjoying... Your knowledge can never be taken away. The memories you gathered here will form a lasting treasure..."

The immeasurable worth of this lasting treasure was revealed at the final banquet, held in the village of Hveragerði, one hour east of Reykjavík. After dinner the stage was opened to the students. The range of their abilities beyond physics was inspiring. For example, Saikal Guha from India performed with incredible skill on the violin a difficult classical work of the Indian musical literature, the raga "Mishra Bhairarn," which describes the morning in India.

This was also a moment for miracles. As she was joined by her teammates and by the team from Taiwan for a joint performance, Yuan Liu from the People's Republic of China announced, "This is a song of China, called 'Good Wish.'" Students from Yugoslavia performed arm-in-arm with students from Croatia. Twenty students from countries of the former Soviet Union sang together in Russian. The Romanians led an enthusiastic sing-along rendition of "We Are the World" that swept the entire audience.

Near the end of the evening, the students of Team USA organized an ensemble to sing three verses of "Amazing Grace."

In this land of fire and ice, we boarded the bus at 1:00am, under a sky still bright with the midnight sun. But the brightest light of all shines in the eyes- and the futures- of these 266 International Physics Olympiad competitors and the millions of peers they represent. They are the world. May they always be blessed by an amazing grace!

Takk fyrir, og vertu sæll!

[1] Excerpt from an open letter to the coaches of all 1998 competing nations, from Waldemar Gorzkowski, President of the IPO, & Andrzej Kotlicki, Secretary, on the occasion of the death of Prof. Rudolf Kunfalvi of Hungary: *"This year we lost the last of three Fathers of the International Physics Olympiad."*

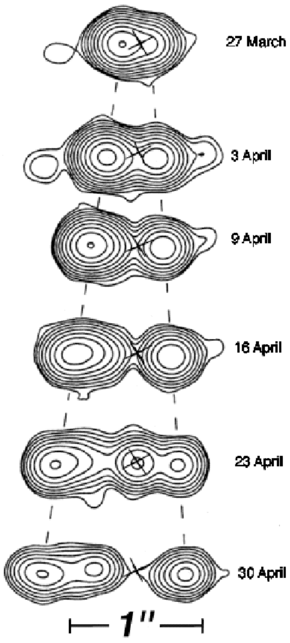
The problems start on page 4.

Problem 1: Faster than light?

In this problem we analyze and interpret measurements made in 1994 on radio wave emission from a compound source within our galaxy.

The receiver was tuned to a broad band of radio waves of wavelengths of several centimeters. Figure 1.1 shows a series of images recorded at different times. The contours indicate constant radiation strength in much the same way as altitude contours on a geographical map. In the figure the two maxima are interpreted as showing two objects moving away from a common center shown by crosses in the images. (The center, which is assumed to be fixed in space, is also a strong radiation emitter but mainly at other wavelengths). The measurements conducted on the various dates were made at the same time of day.

Figure 1.1: Radio emission from a source in our galaxy.



The scale of the figure is given by a line segment showing one arc second (as). (as=1/3600 of a degree). The distance to the celestial body at the center of the figure, indicated by crosses, is estimated to be R = 12.5 kpc. A kiloparsec (kpc) equals 3.09×10^{19} m. The speed of light is $c = 3.00 \times 10^{8}$ m/s.

a) We denote the angular positions of the two ejected radio emitters, relative to the common center, by $\theta_1(t)$ and $\theta_2(t)$, where the subscripts 1 and 2 refer to the left and right hand ones, respectively, and t is the time of observation. The angular speeds, as seen from the Earth, are ω_1 and ω_2. The corresponding apparent transverse linear speeds of the two sources are denoted by $v'_{1\perp}$ and $v'_{2\perp}$.

Using Figure 1.1, make a graph to find the numerical values of ω_1 and ω_2 in milli-arc-seconds per day (mas/d). Also determine the numerical values of by $v'_{1\perp}$ and $v'_{2\perp}$. (You may be puzzled by some of the results).

b) In order to resolve the puzzle arising in part (a), consider a light-source *A* moving with velocity *v* at an angle ϕ ($0 \le \phi \le \pi$) to the direction towards a distant observer *O* (Figure 1.2). The speed may be written as $v=\beta c$, where c is the speed of light. The distance to the source, as measured by the observer, is *R*. The angular speed of the source, as seen from the observer, is ω, and the apparent linear speed perpendicular to the line of sight is $v'_\perp$.

Find w and $v'_\perp$ in terms of β, R and ϕ.

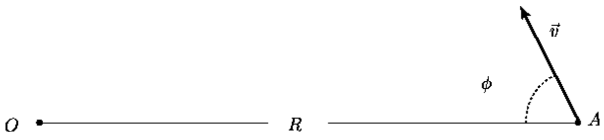


Figure 1.2: The observer is at O and the original position of the light source is at A. The velocity vector is v .

c) We assume that the two ejected objects, described in the introduction and in part (a), are moving in opposite directions with equal speeds v=βc. Then the results of part (b) make it possible to calculate β and ϕ from the angular speeds ω_1 and ω_2 and the distance *R*. Here ϕ is defined as in part (b), refereing to the left hand object, corresponding to subscript 1 in part (a).

Derive formulas for β and ϕ in terms of known quantities and determine their numerical values from the data in part (a).

d) In the one-body situation of part (b), find the condition for the apparent perpendicular speed $v'_\perp$ to be larger than the speed of light *c*.

Write the condition in the form $\beta > f(\phi)$ and provide an analytic expression for the function *f*.

Draw on the graph answer sheet the physically relevant region of the (β, ϕ)-plane. Show by shading in which part of this region the condition $v'_\perp > c$ holds.

e) Still in the one-body situation of part (b), find an expression for the maximum value $(v'_\perp)_{\max}$ of the apparent perpendicular speed $v'_\perp$ for a given β and write it in the designated field on the answer sheet. Note that this speed increases without limit when $\beta \to 1$.

f) The estimate for *R* given in the introduction is not very reliable. Scientists have therefore started speculating on a better and more direct method for determining *R.* One idea for this goes as follows. Assume that we can identify and measure the Doppler shifted wavelengths λ_1 and λ_2 of radiation from the two ejected objects, corresponding to the same known original wavelength λ_0 in the rest frames of the objects.

Starting from the equations for the relativistic Doppler shift, $\lambda = \lambda_0 (1-\beta \cos\phi)(1-\beta^2)^{-1/2}$, and assuming, as before, that both objects have the same speed *v*, show that the unknown $\beta = v\ c$ can be expressed in terms of λ_0, λ_1 and λ_2 as

$$\beta = \sqrt{1 - \frac{\alpha \lambda_0^2}{(\lambda_1 + \lambda_2)^2}} \qquad (1.1)$$

Find the numerical value of the coefficient α.

Note that this means that the suggested wavelength measurements will in practice provide a new estimate of the distance.

Problem 2: Rolling of a hexagonal prism

Consider now a long, solid, regular hexagonal prism like

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a common type of pencil (Figure 2.3). The mass of the prism is M and it is uniformly distributed. The length of each side of the cross-sectional hexagon is a. The moment of inertia I of the hexagonal prism about its central axis can be written as

$$I = \frac{5}{12} M a^2 \qquad (2.1)$$

The moment of inertia I' about an edge of the prism, can similarly be written as

$$I' = \frac{17}{12} M a^2 \qquad (2.2)$$

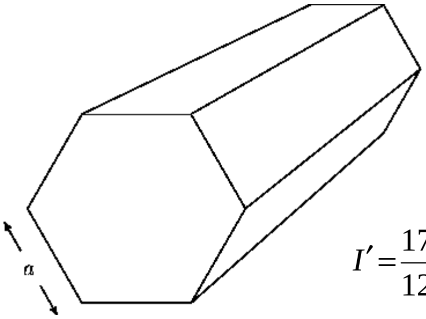
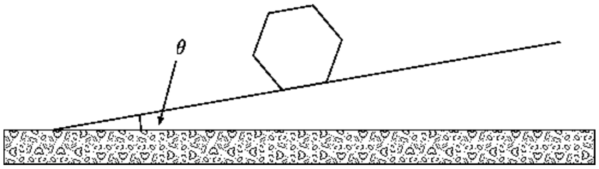


Figure 2.1: A solid prism with the cross section of a regular hexagon.

a) The prism is initially at rest with its axis horizontal on an inclined plane which makes a small angle θ with the horizontal (Figure 2.2). Assume that the surfaces of the prism are slightly concave so that the prism only touches the plane at its edges. The effect of this concavity on the moment of inertia can be ignored. The prism is now displaced from rest and starts an uneven rolling down the plane. Assume that friction prevents any sliding and that the prism does not lose contact with the plane. The angular velocity just before a given edge hits the plane is ω_i while ω_f is the angular velocity immediately after the impact.

Figure 2.2: A hexagonal prism lying on an inclined plane.



Show that we may write

$$\omega_f = s\omega_i \qquad (2.3)$$

and write the numerical value of the the coefficient s.

b) The kinetic energy of the prism just before and after impact is similarly K_i and K_f .

Show that we may write

$$K_f = rK_i \qquad (2.4)$$

and write the numerical value of the coefficient r.

c) For the next impact to occur, K_i must exceed a minimum value $K_{i,min}$ which may be written in the form

$$K_{i,min} = \delta Mga \qquad (2.5)$$

where $g = 9.81$ m/s^2 is the acceleration of gravity.

Find the coefficient δ in terms of the slope angle θ and the coefficient r.

d) If the condition of part c) is satisfied, the kinetic energy K will approach a limiting value $K_{i,0}$ as the prism rolls down the incline.

Given that the limit exists, show that $K_{i,0}$ may be written

$$K_{i,0} = \kappa Mga \qquad (2.6)$$

and write the coefficient κ in terms of θ and r.

e) Calculate, to within 0.1°, the minimum slope angle θ_0 for which the uneven rolling, once started, will continue indefinitely.

Problem 3: Water under an icecap

An icecap is a thick sheet of ice (up to a few km in thickness) resting on the ground below and extending horizontally over tens or hundreds of km. In this problem, we consider the melting of ice and the behavior of water under a temperate icecap, i.e., and icecap at its melting point. We may assume that under such conditions the ice causes pressure variations in the same manner as a viscous fluid, but deforms in a brittle fashion, principally by vertical movement. Data for this problem is below.

a) Consider a thick icecap at a location of average heat flow J_Q from the interior of the earth. Using the data from the table, calculate the thickness d of the ice layer melted every year.

Density of water	$\rho_w = 1.000\,10^{3}\ kg/m^3$
Density of ice	$\rho_i = 0.917\,10^{3}\ kg/m^3$
Specific heat of ice	$c_i = 2.1\,10^{3}\ J/(kg°C)$
Specific latent heat of ice	$L_i = 3.4\,10^{5}\ J/kg$
Density of rock & magma	$\rho_r = 2.9\,10^{3}\ kg/m^3$
Specific heat of rock & magma	$c_r = 700\ J/(kg°C)$
Specific latent heat of rock & magma	$L_r = 4.2\,10^{5}\ J/kg$
Average outward heat flow through the surface of the earth	$J_Q = 0.06\ W/m^2$
Melting point of ice	$T_o = 0°C$

b) Consider now the upper surface of an ice cap. The ground below the ice cap has a slope angle α. The upper surface of the cap slopes by an angle β as shown in Figure 3.1. The vertical thickness of the ice at x=0 is h_0. Hence the lower and upper surfaces of the ice cap can be described by the equations

$$y_1 = x \tan\alpha,\ y_2 = h_0 + \tan\beta \qquad (3.1)$$

Derive an expression for the pressure p at the bottom of the icecap as a function of the horizontal coordinate x.

Figure 3.1: Cross section of an ice cap with a plane surface resting on an inclined plane ground. S: surface,G: ground, I: ice cap.

In order that the water layer between the icecap and the ground remains static, show that α and β must satisfy an

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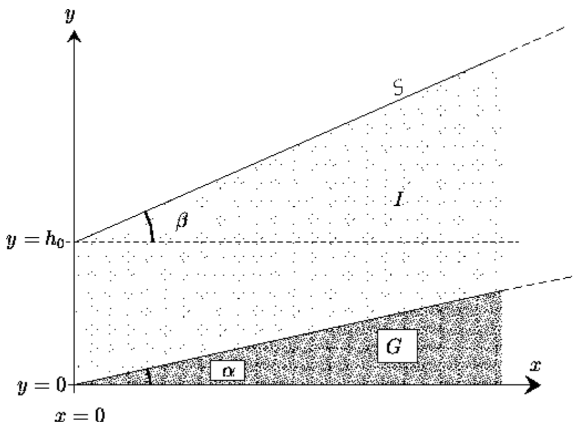
equation of the form

$$\tan\beta = s \tan\alpha \qquad (3.2)$$

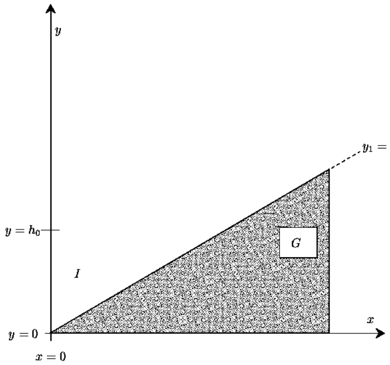


and calculate s.

The line $y_1 = 0.8x$ in Figure 3.2 shows the surface of the earth below an ice cap. The vertical thickness h_0 at $x = 0$ is 2 km. Assume that water at the bottom is in equilibrium. Draw the line y_1 and add a line y_2 showing the upper surface of the ice. Indicate on the figure which line is which.

Figure 3.2: Cross section of a temperate ice cap resting on an inclined ground with water at the bottom in equilibrium. G: ground, I: ice cap.

c) Within a large ice sheet on horizontal ground and originally of constant thickness $D = 2.0$ km, a conical body of water of height $H = 1.0$ km and radius $r = 1.0$ km is formed rather suddenly by melting of the ice (Figure 3.3). We assume that the remaining ice adapts to this by vertical motion only. Show analytically and pictorially on a graph, the shape of the surface of the icecap after the water cone has formed and hydrostatic equilibrium has been reached.



d) In its annual expedition, a group of scientists explores a temperate ice cap in Antarctica. The area is normally a wide plateau, but this time they find a deep crater-like depression formed like a top-down cone with a depth h of 100 m and a radius r of 500 m (Figure 3.4). The thickness of the ice in the area is 2000 m.

Figure 3.3: A vertical section through the mid-plane of a water cone inside an ice cap.
S: surface,
W: water,
G: ground,
I: ice cap.

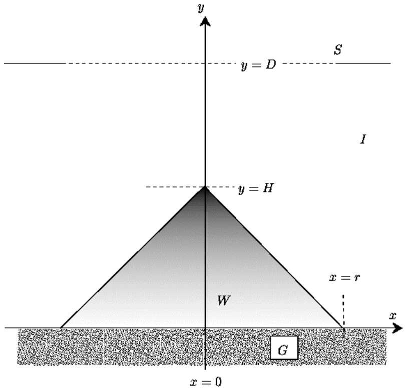
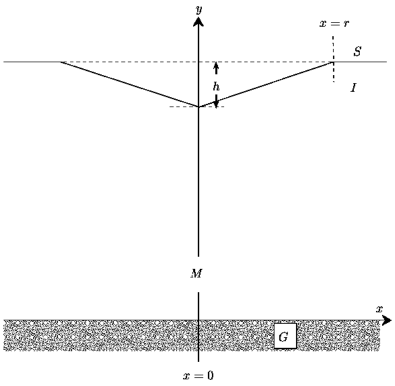


Figure 3.4: A vertical and central cross section of a conical depression in a temperate ice cap.
S: surface,
G: ground,
I: ice cap,
M: magma and water intrusion for the student to draw.



After a discussion, the scientists conclude that most probably there was a minor volcanic eruption below the icecap. A small amount of magma (molten rock) intruded at the bottom of the icecap, solidified and cooled, melting a certain volume of ice. The scientists try as follows to estimate the volume of the intrusion and get an idea of what became of the melt water.

Assume that the ice only moved vertically. Also assume that the magma was completely molten and at 1200°C at the start. For simplicity, assume further that the intrusion had the form of a cone with a circular base vertically below the conical depression in the surface. The time for the rising of the magma was short relative to the time for the exchange of heat in the process. The heat flow is assumed to have been primarily vertical such that the volume melted from the ice at any time is bounded by a conical surface centered above the center of the magma intrusion.

Given these assumptions the melting of the ice takes place in two steps. At first the water is not in pressure equilibrium at the surface of the magma and hence flows away. The water flowing away can be assumed to have a temperature of 0°C. Subsequently, hydrostatic equilibrium is reached and the water accumulates above the intrusion instead of flowing away.

When thermal equilibrium has been reached, you are asked to determine the following quantities:

1.The height H of the top of the water cone formed under the ice cap, relative to the original bottom of the ice cap.

2.The height h_1 of the intrusion, its volume V_1 and its mass m_1.

3.The total mass m_{tot} of the water produced and the mass m' of water that flows away.

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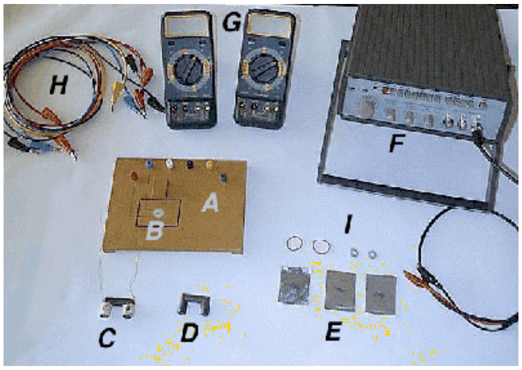
Plot on a graph the shapes of the rock intrusion and of the body of water remaining. Use the coordinate system suggested in Figure 3.4.

Experimental Problem

Equipment Provided



A

Platform with six banana jacks

B Pickup coil embedded into the platform

C Ferrite U-core with two coils marked "A" and "B"

D Ferrite U-core without coils

E Aluminium foils of thicknesses: 25 µm, 50 µm and 100 µm

F Function generator with output leads

G Two multimeters

H Six leads with banana plugs

I Two rubber bands and two small pieces of grease proof paper

Multimeters

The multimeters are two-terminal devices that in this experiment are used for measuring AC voltages, AC currents, frequency and resistance. In all cases one of the terminals is the one marked **COM**. For the voltage, frequency and resistance measurements the other terminal is the red one marked **V-Ω**. For current measurements the other terminal is the yellow one marked **mA**. With the central dial you select the meter function (V~ for AC voltage, A~ for AC current, Hz for frequency and Ω for resistance) and the measurement range. For the AC modes the measurement uncertainty is ± (4% of reading + 10 units of the last digit).

Function generator

To turn on the generator you press in the red button marked **PWR**. Select the 10 kHz range by pressing the button marked 10k, and select the sine waveform by pressing the second button from the right marked with a wave symbol. No other buttons should be selected. You can safely turn the amplitude knob fully clockwise. The frequency is selected with the large dial on the left. The dial reading multiplied by the range selection gives the output frequency. The frequency can be verified at any time with one of the multimeters. Use the output marked **MAIN**, which has 50 Ω internal resistance.

Ferrite cores

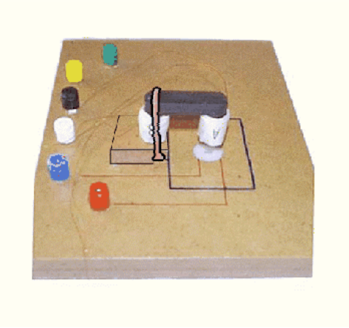
Handle the ferrite cores gently, they are brittle! Ferrite is a ceramic magnetic material, with low electrical conductivity. Eddy current losses in the cores are therefore low.

Banana jacks

To connect a coil lead to a banana jack, you loosen the colored plastic nut, place the tinned end between the metal nut and plastic nut, and tighten it again.

Part I: Magnetic Sheilding with Eddy Currents

Figure 1: Experimental arrangement for part I.



Time-dependent magnetic fields induce eddy currents in conductors. The eddy currents in turn produce a counteracting magnetic field. In real conductors, this field will not completely counteract the applied field inside the material. To describe the shielding effect of aluminium foils we will apply the following model

$$B = B_0 e^{-ad} \qquad (1)$$

where B is the magnetic field beneath the foils, B_0 is the magnetic field at the same point in the absence of foils, a an attenuation constant, and d 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, as shown in Figure 1. Secure the core on the block by stretching the rubber bands over the core and under the block recess. The uncertainty in the thickness of the foils can be neglected, as can the error in the frequency when measured by the multimeter.

1. Connect the leads for coils A and B to the jacks. Measure the resistance of all three coils to make sure you have good connections. You should expect values of less than 10 Ω.
2. Collect data to validate the model above and evaluate the attenuation constant a for the aluminum foils (25 - 175 µm), 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.

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. With the equipment provided, we may assume that saturation effects can be ignored, and the

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permeability μ of the material is constant.

Theory

In the following basic theoretical discussion, and in the treatment of the data, it is assumed that the ohmic resistance in the two coils and all hysteresis effects in the core have insignificant influence on the measured currents and voltages. 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, that the current creates in the ferrite core inside the coil, is proportional to the current I and to the number of turns N. The flux depends furthermore on a geometrical factor g, which is determined by the size and shape of the core, and the magnetic permeability $\mu = \mu_r \mu_0$, which describes the magnetic properties of the core material. The relative permeability is denoted μ_r and μ_0 is the permeability of free space.

The magnetic flux Φ is thus given by

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

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

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

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. As follows from equation (3), 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° phase difference between the current and the voltage. If we only look at the amplitudes ε_0 and I_0 of the alternating voltage and current, allowing for this phase difference, we have

$$\varepsilon_0 = \omega c N^2 I_0 \qquad (7)$$

From now on we drop the subscript 0.

Two coils

Let us now assume that we have two coils on one core (see Figure 2). 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. Due to flux leakage in real cores, a second coil on the core will in general experience a reduced flux compared to the flux-generating coil. The flux Φ_B in the secondary coil B is therefore related to the flux Φ_A in the primary coil A through

$$\Phi_B = k\Phi_A \qquad (8)$$

Similarly a flux component Φ_B created by a current in coil B will create a flux $\Phi_A = k\Phi_B$ in coil A. The factor k, which is called the coupling factor, has a value less than one.

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 (connected to the signal generator). If no current flows in coil B (I_B=0), the induced voltage ε_A due to I_A is equal and opposite to the generator voltage V_g. The flux created by I_A inside the secondary coil is determined by equation (8) and the induced voltage in coil B is

$$\varepsilon_B = \omega k c N_A N_B I_A \qquad (9)$$

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

$$V_g = \varepsilon_A = \omega c N^2_A I_A - \omega k c N_A N_B I_B \qquad (10)$$

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.

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 the two coils, A and B, are: N_A = 150 turns and N_B = 100 turns (± 1 turn on each coil).

Figure 2: A transformer with a closed magnetic circuit.

1. Show that the algebraic expressions for the self-inductances L_A and L_B are,

$L_A = \varepsilon_A/(\omega I_A)$ when $I_B = 0$

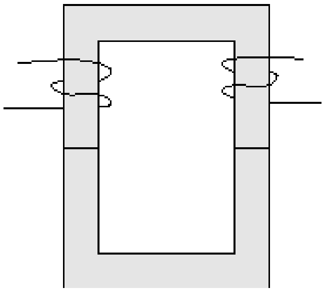
$L_B = \varepsilon_B/(\omega I_B)$ when $I_A = 0$

and that expressions for the coupling factor k are,

$k = (N_B I_B)/(N_A I_A)$

when $\varepsilon_B = 0$

Draw circuit diagrams showing how these quantities are determined. Calculate the numerical values of L_A, L_B & k.



2. 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. Measure I_P.

3. 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.

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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.

3.2. Measure the voltages V_A and V_B when the flux contributions of the two coils oppose each other. Find their values and the ratio of the voltages. Derive an expression for the ratio of the voltages across the two coils.

4. Use the results obtained to verify that the self inductance of a coil is proportional to the square of the number of its windings.

5. Verify that it was justified to neglect the resistance of the primary coil and write your arguments as mathematical expressions.

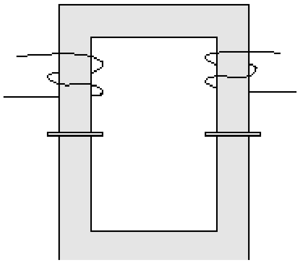
6. Thin pieces of paper inserted between the two half cores (as shown in Figure 3) reduce the coil inductances drastically. Use this reduction to determine the relative permeability m_r of the ferrite material, given Ampere's law and continuity of the magnetic field B across the ferrite - paper interface. Assume $m = m_0 = 4p´\ 10^{-7}\ Ns^2/C^2$ for the pieces of paper and a paper thickness of 43 mm. The geometrical factor can be determined from Ampere's law

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

where I_{total} is the total current flowing through a surface bounded by the integration path.

Write the algebraic expression for m_r in field 6.a on the answer sheet and the numerical value.

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



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The 6th Nordic Research Symposium in Science

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- Philip Johnson, "Children's understanding of changes of state involving the gas state, Part 2: Evaporation and condensation below boiling point", No. 6, July 1998, pp. 695-709.
- L. G. Enderstein and P. E. Spargo, "The effect of context, culture and learning on the selection of alternative options in similar situations by South African pupils", No. 6, July 1998, pp. 711-736.
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Themes of the symposium include

- Science education as a part of culture
- Science education and social issues
- Technology as a tool and a part of the contents in the teaching of the natural sciences

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> It might have been expected that the Sun, our parent, would contain the familiar earthly elements, as we were certainly, in a distant age, bone of his bone and flesh of his flesh. But what about the Stars, so far away, apparently so faint? ...with a Spectroscope attached to the telescope, we may behold a radiant and beautiful sight, for the twinkling starlight becomes a band showing all the rainbow colors, also crossed by the telltale dark lines. The stars then, are suns.
>
> *— Annie Jump Cannon, 1926*

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> [The general maxim "That like causes produce like effects"] is only true when small variations in the initial circumstances produce only small variations in the final state of the system. In a great many physical phenomena this condition is satisfied; but there are other cases in which a small initial variation may produce a very great change in the final state of the system, as when the displacement of the "points" causes a railway train to run into another instead of keeping its proper course.
>
> *—James Clerk Maxwell, Matter and Motion (1877)*

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