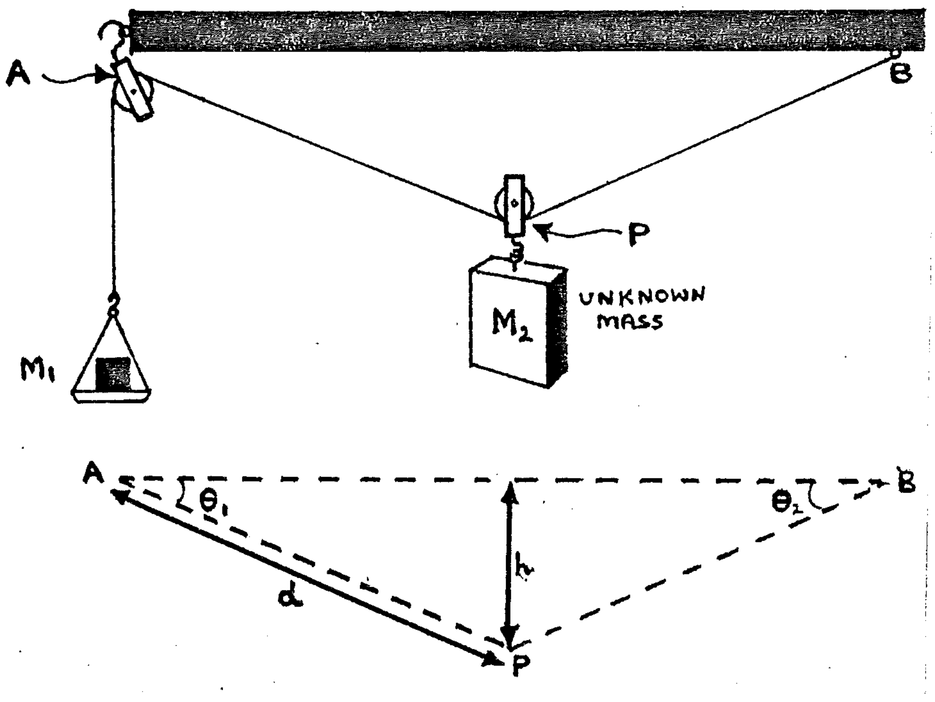
Advanced Level Experimental Physics



Advanced Level Experimental Physics

by

Bob Drach & Norman Price

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NOTE: Practical exercise reference numbers refer to the relevant topic reference number in the Tanzanian National Syllabus. For example, H5 is topic Natural Radioactivity. Past exam reference numbers indicate the year and question.

Introduction

This exciting collection of practical exercises and past National Exam papers from the United Republic of Tanzania is for Advanced Level students. In these experiments students are encouraged to apply physics theory to a wide range of practical topics. The experiments collected in this book have each been performed successfully by Tanzanian students. They have been revised and retested until students made no errors in following procedures. Teachers are therefore largely freed from explaining procedures and are able to use the practical period to assist students in understanding theory and in analyzing experimental results. Students CAN perform these experiments and teachers and technicians CAN assemble or create all the needed equipment.

The biggest problem facing teachers and students doing practical exercises is the shortage of equipment. Because of this problem these experiments are best suited for use in a circus of practical exercises. Students will be grouped in pairs. In the first week each pair of students performs one of a set of experiments. In the second week, each pair performs a different experiment from the same set. In the third week, each pair performs another experiment and so on until all the students have done all the experiments in that set. The only exceptions to this rotation are two introductory practicals (A1-1 and A1-2) and the past National Exam papers which can be done by half of the class at a time in sessions seperate from the regular circus sessions.

Based on the Tanzanian two term academic year, at the minimum, each term practical sessions should be done as follows:

Form 5 first term -- Practical exercises A1-1 and A1-2 in the first two weeks, then a circus of eight other experiments.

Form 5 second term -- Circus of eight experiments, then two exam practicals.

Form 6 first term -- Exam practical in the first week, then a circus of eight experiments, then one exam practical.

Form 6 second term -- Two exam practicals one per week, then two exam practicals in one 3 hour session.

A sample Form 5 first term schedule is shown below.

WEEK	GROUP 1	2	3	4	5	6	7	8	9	10	11	12
1	A1-1	A1-1	A1-1	A1-1	A1-1	A1-1	A1-2	A1-2	A1-2	A1-2	A1-2	A1-2
2	A1-2	A1-2	A1-2	A1-2	A1-2	A1-2	A1-1	A1-1	A1-1	A1-1	A1-1	A1-1
3	B1-1	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1				
4		B1-1	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1			
5			B1-1	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1		
6				B1-1	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1	
7					B1-1	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1
8	C3-1					B1-1	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1
9	C2-1	C3-1					B1-1	B1-2	B3-1	B5-1	B5-2	C1-1
10	C1-1	C2-1	C3-1					B1-1	B1-2	B3-1	B5-1	B5-2
11	B5-2	C1-1	C2-1	C3-1					B1-1	B1-2	B3-1	B5-1
12	B5-1	B5-2	C1-1	C2-1	C3-1					B1-1	B1-2	B3-1
13	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1					B1-1	B1-2
14	B1-2	B3-1	B5-1	B5-2	C1-1	C2-1	C3-1					B1-1

In this example the teacher chooses experiments B1-1, B1-2, B3-1, B5-1, B5-2, C1-1, C2-1, and C3-1 for the circus. The class in this example has 23 students and therefore 12 groups, but a class of any number of students can use a similar schedule. The circus lasts for the number of weeks equal to the number of groups. Some weeks a group may have no experiment to perform. Because assembling and testing apparatus in the first week of the term is demanding, a circus of eight experiments seems the best choice in the first years when this system is used. However, a teacher may choose to give theory assignments or to assign other experiments from this book, past exam papers, or original experiments in the periods left open in the circus schedule.

Using this book students will successfully and efficiently complete a wide range of experiments in Advanced Level physics. Performing carefully prepared experiments is not only the most exciting way to learn physics, it is the best way to understand physics theory -- the same way in which that theory was first deduced!

Bob Drach & Norman Price
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Assessment of Students' Written Work

Each group of students should normally present a written report of their experiment to the teacher within a few days of doing the experiment.

If the teacher has performed the experiment in advance, marking the 8 to 10 scripts is a quick process, particularly if students are encouraged to write down only those things required by the experiment instructions, numbering their answers accordingly (This provides some training in exam technique).

Although each teacher will have their own preferences, the following is a list of points to look for when marking students' work:

<u>Readings</u>: Properly tabulated; units in headings; heading names; appropriate accuracy; repeated & averaged where necessary; accurate calculation and labelling of new quantities (eg sin x etc.).

<u>Graph</u>: Title; scales chosen to spread points diagonally right across the paper if possible; axes labels (quantity, unit, scale factor, numbers); points (accurately plotted, small dot used: $\odot$ preferred, not ⦿ or $\times$); smooth best-fit curve drawn (not a polygon); overall neatness (lines thin, in pencil).

<u>Gradient</u>: Two points chosen and clearly marked (wide apart), or a tangent accurately passing through one point (line should be long).

<u>Y-intercept</u>: (if required) Point clearly marked; must lie on paper !

<u>Working</u>: Algebra clearly laid out showing steps logically; correct substitution; (arithmetic details need not be shown); answer to sensible number of sig. figs. (3 normally suitable); number in scientific notation (1.3×10^{-6} A, or 1.3 μA, not 0.0000013 A).

Generally if an answer to a question is not of a sensible size, the student should be aware of it and comment accordingly (eg if unknown mass = 3×10^{18} kg!). The student could then be given full credit for correct working based on inaccurate data.

In the exam practicals, the marks shown for each question are for guidance only, and should not be taken to necessarily be the same as the Tanzanian Exam Council originally allocated.

Answer keys are not provided as in many cases the answers obtained depend on the particular apparatus or samples used. These can also tempt the stundent to present the answer given in the key without thinking it out for themselves !

Technicians' Notes

Each experiment's instructions give an apparatus list so that apparatus may be quickly set out at the beginning of each laboratory session.

It is reccommended that at the beginning of term, technicians and teachers together prepare the apparatus for that term's experiments. Each experiment should be tested, and sample results obtained to enable the teacher to assess the students' work.

After each session, the apparatus can be stored in one place to speed up the setting out in the following week.

It is very helpful if the technician can aid the teacher during the lab sessions, especially early in the course when students lack confidence in handling apparatus and carrying out instructions.

It is assumed that normal lab services are available, however mains electricity is rarely used, and is normally unneccessary if batteries are available. For heating, kerosene/spirit burners can replace Bunsen burners. Running water is not required, as long as clean water is available in small quantities.

The expert help of a technician can substantially reduce the workload of the teacher and greatly improve the smooth running of the circus of practicals.

APPARATUS

Microscope slide; vernier calipers; magnifying glass; micrometer; beam balance with masses; Archimedes' bridge; beaker of water (250ml); metre ruler.

PROCEDURE

For each of the following, record the observations together with the possible error (of ½ the smallest scale division), eg: 46±0.5 mm. Calculate the mean value of repeated readings together with the error. Calculate the % error.

1. Measure the slide thickness in a number of places using the metre ruler.

2. Repeat using the vernier calipers instead.

3. Measure the slide thickness in several places using the micrometer screw gauge. Record the 'zero reading' and adjust the other readings correctly.

4. Measure the length l and the width w using the metre ruler. Find the mass of the slide in air, and then its apparent mass in water.

   Then UPTHRUST = WT. OF LIQUID DISPLACED

   $$mg - m_a g = \rho_w \times \text{slide volume} \times g$$

   $$\text{slide volume} = \frac{m - m_a}{\rho_w}$$

   (where m=mass of slide, m_a = apparent mass of slide in water, ρ_w = density of water)

   Then calculate the slide thickness d since:

   $$w \times l \times d = \text{slide volume.}$$

When you have completed the above, arrange the estimates of slide thickness in order (most accurate first). Explain carefully why some methods are more accurate than others.

A1-2 Use of Books and Graph Drawing.

APPARATUS

Selection of Physics books; 4 or 5 figure tables; 1 sheet of graph paper.

PROCEDURE

1. Use the books provided to answer the following:

a) What is rectilinear motion ?
b) Name 3 ferromagnetic materials. (is there a 4th ?).
c) What are the unit prefixes (letter and name) for:

10^{12}, 10^{9}, 10^{6}, 10^{3}, 10^{2}, 10^{-2}, 10^{-3}, 10^{-6}, 10^{-9}, 10^{-12}.

d) What are the letters of the Greek alphabet ? Give their names.
e) What does 'Non-Ohmic conductor' mean ? Give four examples.
f) What is the velocity of sound in air at 0°C ?
g) 0°C equals how many K, exactly ?
h) What are the main types of experimental error ?
i) $a = 5 \pm 0.005$m and $b = 3.5 \pm 0.01$m. What is the error in $a + b$ in metres and in %? What is the % error in ab ?
j) Define the metre, the kilogram, the second, the newton, and the joule. Which are base units and why ?

2. Use of 4 or 5 figure tables. Calculate the following:

a) 28.5×137; 0.056×55.62; $0.0335 \div 0.48$; $73500 \div 0.6885$; $(5.322)^4$; $\sqrt[3]{6.03}$; $\log 0.002$; $10^{1.3}$
b) $\sin(26° \; 36')$; $\cos^{-1} 0.391$; $\tan 53.552°$; $\tan 216°$; $\cos 126°$.
c) Convert to radians: 90° ; 72° ; 200° .
Convert to degrees: 1.12rad ; 3π rad ; $3\pi/2$ rad.
d) $\ln 7.9$; $e^{1.5}$; $\ln 0.14$; $\ln 40$; e^{15} ; $e^{0.02}$.
e) $\sqrt{553}$; $\sqrt{0.07}$

3. Graphs.
a) In an Ohm's Law experiment, where V = IR, the following readings were obtained:

V (volts)	0.69	0.90	1.11	1.32	1.57	1.80	2.00	2.20
I (amps)	3.05	4.00	5.01	5.95	7.03	8.00	9.00	9.90

Draw a graph of V against I, and hence find R.
b) A cell of internal resistance r and emf E supplies current through a resistor R. The equation which applies is:

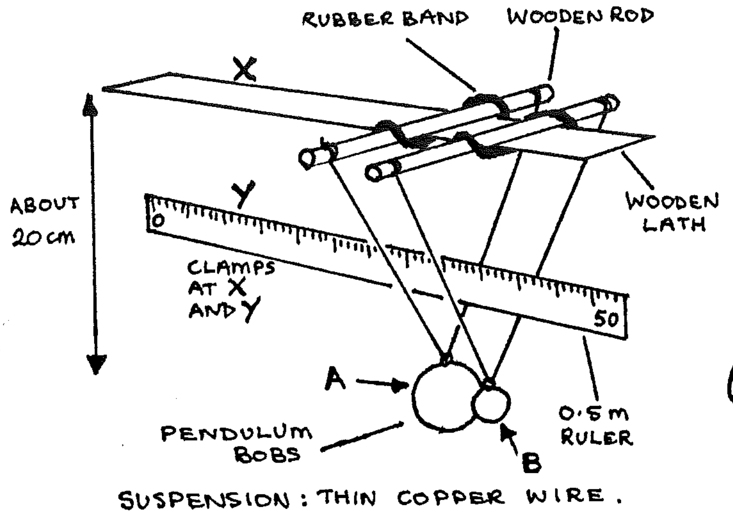
$$r = R \times \frac{E-V}{V}$$

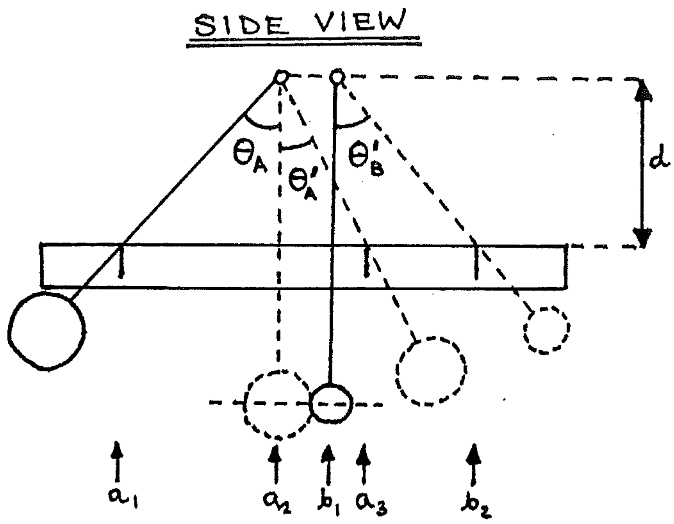
Readings of R and V are obtained, and 1/R is plotted against 1/V. Explain how the gradient and y-intercept can be used to find E and r.

Coefficient of Restitution

APPARATUS

2 wooden rods (about 20cm long); wooden lath (about 25cm long);
2 elastic bands; 2 pendulum bobs (1 large, 1 small); thin Cu wire;
2 0.5m rulers; stand; 2 bosses & clamps; G-clamp; triple beam balance.





PROCEDURE

1. Assemble the apparatus as above, ensuring that the lath and 0.5m ruler are horizontal. Make sure that the centres of the pendulum bobs are on the same level, and that the bobs just touch.
2. Pull bob A to the left and let it swing to collide with bob B, to check the operation of the apparatus.
3. With the bobs at rest, read values a_2 and b_1 on the 0.5m ruler. (Position your eye carefully to avoid parallax). Measure length d.
4. Move bob A to the left until it touches the 0.5m ruler. Read value a_1.
5. Release bob A, and note the furthest position that it reaches on the right <u>after</u> the collision (this is a_3).
6. Repeat 4 and 5 to get five readings of a_3 to average.
7. Repeat 4 , then release bob A, and note the furthest position that <u>bob B</u> reaches to the right after the collision (this is b_2).
8. Repeat 7 to get five readings of b_2 to average.
9. Measure the masses of bob A (m_A) and bob B (m_B) using the beam balance.

OBSERVATIONS

a_2 = __________, b_1 = __________, d = __________, a_1 = __________

a_3 = ______, ______, ______, ______, ______, average __________

b_2 = ______, ______, ______, ______, ______, average __________

m_A = __________, m_B = __________.

THEORY

It can be shown that a pendulum, length L, moving through an angle θ has a velocity change of:

$$v = \sqrt{(2gL(1 - \cos\theta))} \qquad \text{------ equation 1}$$

1. In the experiment there is a collision, and momentum is conserved:

$$\sum(\text{momentum before collision}) = \sum(\text{momentum after collision})$$

$$m_A v_A + m_B v_B = m_A v_A' + m_B v_B'$$

where v_A, v_B, v_A', v_B' are the velocities of bobs A and B before and after the collision respectively. However in the experiment $v_B = 0$.

$$\text{Thus} \quad m_A / m_B = \frac{v_B'}{v_A - v_A'}$$

Calculating velocities using equation 1, and substituting :

$$m_A / m_B = \frac{\sqrt{(2gL(1-\cos\theta_B'))}}{\sqrt{(2gL(1-\cos\theta_A))} - \sqrt{(2gL(1-\cos\theta_A'))}}$$

$$\text{Thus} \quad m_A / m_B = \frac{\sqrt{(1-\cos\theta_B')}}{\sqrt{(1-\cos\theta_A)} - \sqrt{(1-\cos\theta_A')}} \qquad \text{equation 2}$$

This equation can be used to calculate the ratio of the masses of the bobs.

2. To find the coefficient of restitution :

$$\text{By definition} \quad e = -\frac{\text{relative velocity after the collision}}{\text{relative velocity before the collision}}$$

Using equation 1 for these velocities;

$$e = \frac{\sqrt{(1-\cos\theta_B')} - \sqrt{(1-\cos\theta_A')}}{\sqrt{(1-\cos\theta_A)}} \qquad \text{equation 3}$$

ANALYSIS

1. Complete the following table to obtain values of θ_A, θ_A', and θ_B' .

			x	$\theta = \tan^{-1}(x/d)$ (this means arctan)
Bob A before collision	$a_2 =$	$a_1 =$	$a_2 - a_1 =$	$\theta_A =$
Bob A after collision	$a_3 =$	$a_2 =$	$a_3 - a_2 =$	$\theta_A' =$
Bob B after collision	$b_2 =$	$b_1 =$	$b_2 - b_1 =$	$\theta_B' =$

2. Substitute the values of θ_A, θ_A', and θ_B' calculated in the above table into equation 2 to calculate the ratio of the masses of the two pendulum bobs. Check the accuracy of the method using the readings of mass obtained directly using the beam balance. Comment on the differences in these ways of measuring mass, using either the ballistic balance (collision method), or the beam balance.

3. Substitute the values of θ_A, θ_A', and θ_B' from the above table into equation 3 to calculate the coefficient of restitution for these pendulum bobs.

   Comment on the elasticity of the collision in your experiment if:

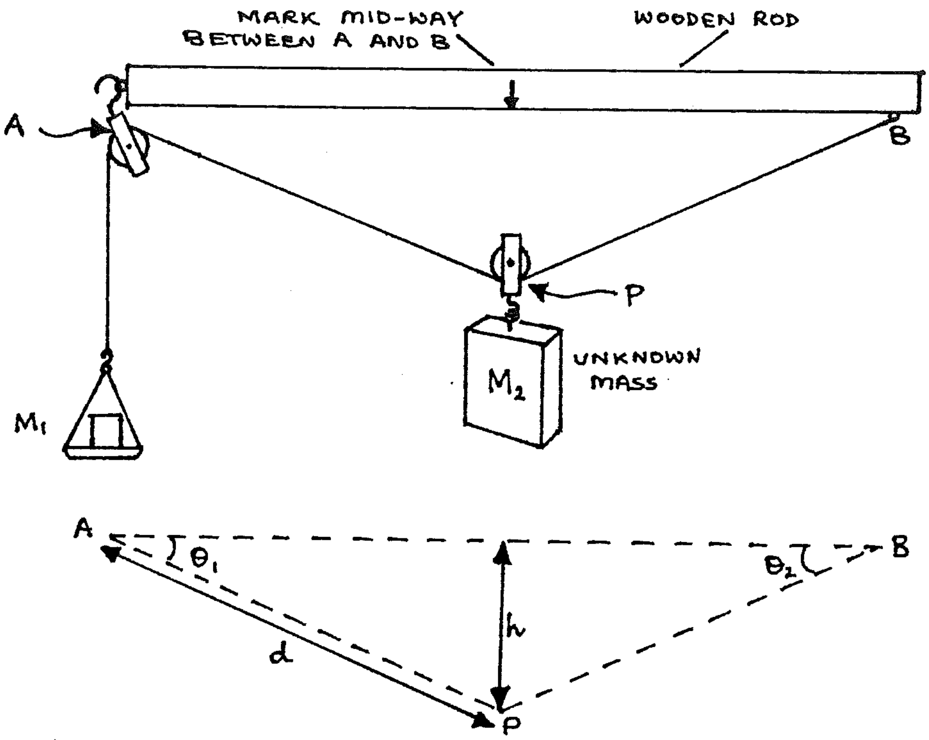
   $e = 1$ collision is perfectly elastic
   $e = 0$ collision is completely inelastic

   Give simple examples to illustrate the energy changes that occur in collisions where: i) $e = 1$ ii) $e = 0$ iii) $e =$ the value in your experiment.

Tension in a String: to Find an Unknown Mass Using Equilibrium of Forces Theory.

APPARATUS

Wooden rod about 1m long, with eyelets as shown; about 1.7m good-quality cord; 2 single pulleys; 2 × 50g masses; 5 × 100g masses; scale pan; unknown mass; 2 clamps & stands; 2 G-clamps; triple beam balance; metre ruler; 1 sht. graph paper; spirit level.



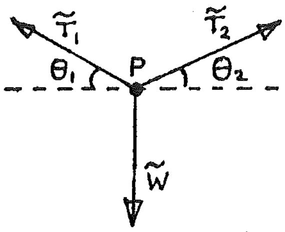
PROCEDURE

1. Clamp the wooden rod firmly and horizontally, so that there is space for the scale pan and unknown mass to move a large distance vertically without touching any object. Assemble the apparatus as above, placing m_1 = 200g in the scale pan. Measure and record AB.

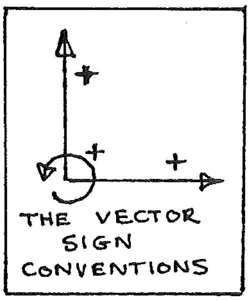
2. Move m_1 up and down, finally placing it in the middle of the range of possible equilibrium positions. Ensure that pulley P is directly under the mid-way mark on the rod. Measure and record values of m_1 , h, and d.

3. Repeat 2. with m_1 = 250, 300, 350, 400, 500, 600g, each time recording m_1, h, and d. Check that the pulley P remains under the mid-way mark on the rod.

THEORY



VECTOR DIAGRAM



Since point P is in equilibrium (Newton's 1st Law) :

$$\text{Resultant} \quad \tilde{R} = \tilde{T} + \tilde{T} + \tilde{W} = \tilde{0}$$

Therefore horizontally: $\Sigma F_x = 0$

$\therefore \; T_2 \cos\theta_2 - T_1 \cos\theta_1 = 0$
but $\theta_1 = \theta_2$ (observation) $\therefore \; T_1 = T_2$.

And vertically: $\Sigma F_y = 0$

$\therefore \; T_1 \sin\theta_1 + T_2 \sin\theta_2 - W = 0$
but $\theta_2 = \theta_1$ and $T_2 = T_1$

$2T_1 \sin\theta_1 - W = 0$ ---------equation (1)

but $T_1 = m_1 g$, $\sin\theta_1 = h/d$ and $W = m_2 g$,

Hence $h/d = m_2/2m_1$.

ANALYSIS

1. Plot a graph of h/d against $1/m_1$, and find the gradient.

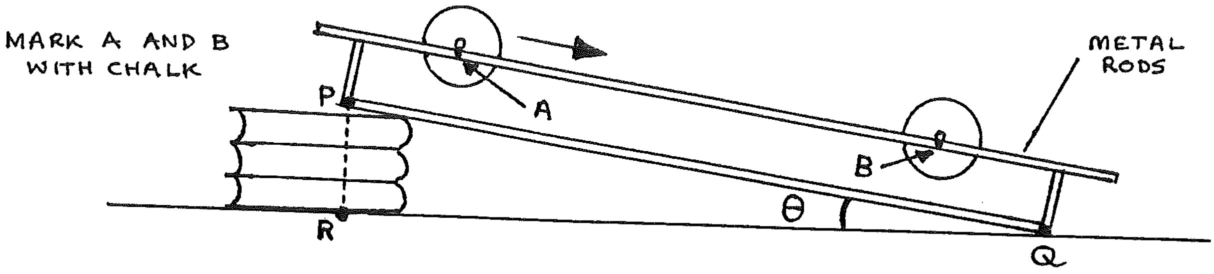
2. Use only the gradient and the formula given at the end of the theory to calculate the unknown mass m_2 .

3. Measure the mass of m_2 on the beam balance, and assuming this is accurate, calculate the % error in the value obtained in 2. above.

4. a) Use the value of h/d when m = 400g, to calculate θ_1 at this point. Calculate $W = m_2 g$.

   b) m_1 is suddenly increased to 500g. Assuming that at this moment $\theta_1 = \theta_2$ = the value in a), find the initial upward acceleration of m_2, as it heads towards a new equilibrium position.
   (Hint: find T and use part of equation (1) to find the net upward force on m_2.)

The Moment of Inertia of a Cylinder



Apparatus

2 mounted rails, 2 different cylinders with axles, metre rule, micrometer screw gauge, stack of books, stopwatch, piece of chalk, triple beam balance, graph paper

Procedure

1. Set up the apparatus as shown above with PR small. Measure s = AB and measure PQ. Record s and PQ.

2. Measure and record PR. Calculate $\sin\theta = \frac{PR}{PQ}$.

3. Place a cylinder at A. Record the time, t, for the cylinder, starting from rest, to roll from A to B.

4. Determine the linear acceleration, a, of the cylinder using your readings of s and t.

5. Increase PR and repeat steps 2, 3, and 4. Increase PR three more times, repeating steps 2, 3, and 4 to obtain in all five sets of readings.

6. Measure the axle diameter and find the axle radius, r_a. Measure the mass, M, of the cylinder and axle.

7. Repeat steps 2 to 6 for the second cylinder.

Observations

For each cylinder: M = ___ kg
r_a = ___ m
r = radius of the cylinder = ___ m

PR (m)	PQ (m)	$\sin\theta = \frac{PR}{PQ}$	s (m)	t (s)	a (ms^{-2})

Theory

The cylinder loses PE and gains KE as it moves from A to B:

$$\text{Loss of PE} = Mgh = Mgs\sin\theta$$

Ignoring friction this becomes the KE of the cylinder where the total KE is:

KE = KE (linear) + KE (rotational)

Therefore:

$$Mgs\ \sin\theta = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$$

But $\omega = \frac{v}{r_a}$ and $v^2 = 2as$. Therefore:

$$a = \left(\frac{Mgr_a^2}{Mr_a^2 + I}\right)\sin\theta \qquad \text{(check this yourself)}$$

Analysis

1. Plot a graph of a against $\sin\theta$ for each cylinder on the same sheet of graph paper. Find the gradient of each line.

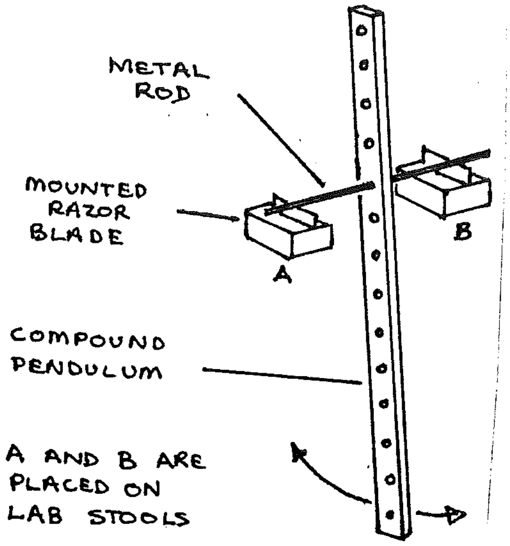
2. Given that $a = \left(\frac{Mgr_a^2}{Mr_a^2 + I}\right)\sin\theta$ find I for each cylinder.

3. From theory $I = \frac{1}{2}Mr^2$ where r = cylinder radius. Calculate I using this to check your value from (2.) above. Give the % error for your value from (2.).

4. If $I = Mk$, find the radius of gyration, k, for each cylinder.

5. Caculate the torque necessary to steadily accelerate each cylinder from rest to an angular velocity of 30 radians s^{-1} in 2s.

Determining g Using a Compound Pendulum



Apparatus

Long uniform stick with holes at regular intervals, stiff 25cm long wire, 2 razor edges mounted on blocks, 4 lab stools, stopwatch, graph paper, triple beam balance

Procedure

1. Suspend the stick as shown starting with the wire in the hole nearest the end of the stick. Record the time required for 20 oscillations of small amplitude. Repeat for every hole from one end of the stick to the other. Record the distance, d, from each hole to the end of the stick you started near and record the time for 20 oscillations of small amplitude for each hole.

2. Measure and record the mass, M, of the stick.

3. Graph T against d. This graph will be a pair of roughly parabolic curves symmetric about a line parallel to the y - axis.

4. Select 6 values of T and draw lines parallel to the x - axis through those values. These lines should cross each curve two times. Find the distance along the x - axis from left to right between the first point of intersection with the left hand curve and the first point of intersection with the curve on the right. Call this value L and tabulate it with the corresponding values of T and T^2.

Observations

M = mass of the stick = ___kg

d (m)	Time for 20 oscillations	Period T (s)

T (s)	T^2 (s^2)	L (m)	$\frac{L}{T^2}$ (ms^{-2})

Average value of $\frac{L}{T^2}$ = ___ms^{-2}

Theory

For a small displacement, θ, the equation of motion of the stick executing simple harmonic motion is:

$$\text{Torque} = I\alpha = -Mgh\theta \quad \text{or} \quad \alpha = -\frac{Mgh}{I}\theta$$

where M = mass of the stick, h = distance from the axis of rotation to the center of mass, θ = angular displacement in radians, I is the moment of inertia of the stick about the axis of rotation, and α = angular acceleration = $\frac{d^2\theta}{dt^2}$. From the theory of simple harmonic motion the angular frequency, ω, is:

$$\omega = \sqrt{\frac{Mgh}{I}} \quad \text{and the period,} \quad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{Mgh}}$$

By the parallel axis theorum and definition of radius of gyration, k, $I = Mk^2 + Mh^2$, and therefore:

$$T = 2\pi\sqrt{\frac{Mk^2 + Mh^2}{Mgh}} = 2\pi\sqrt{\frac{k^2 + h^2}{gh}}$$

The period of a simple pendulum is $T = 2\pi\sqrt{\frac{L}{g}}$. L is equivalent to the expression $\frac{1}{h}\sqrt{k^2 + h^2}$, which has a value found graphically as explained in procedure (4.) above. Using this value for L compute $\frac{L}{T^2}$ and find g from the expression:

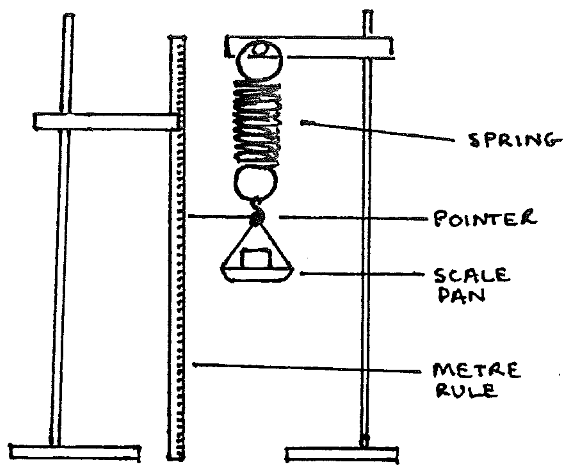
$$g = 4\pi^2\frac{L}{T^2}$$

Analysis

1. What is the value of g which you obtain using the average value of $\frac{L}{T^2}$?

2. The moment of inertia of the bar can be found from the graph T against d. The radius of gyration, k, is one half the distance along the x - axis from the point where the slope of the left curve is zero to the point where the slope of the right curve is zero. Use this value of k and the mass of the stick to determine the moment of inertia of the stick.

Experiments Using a Spiral Spring



Apparatus

2 stands with clamps, metre rule, spiral spring, scale pan with attached pointer, stopwatch, assorted masses 5g to 100g, 2 sheets of graph paper, triple beam balance

Procedure

1. Measure and record the mass of the scale pan and attached pointer. Attach the pan and pointer to one stand and place the metre rule in the other stand such that the end of the pointer moves lightly over it. Read and record the pointer position. This is the zero position.

2. Put 5g in the pan and record the total load (including the mass of the pan and pointer) and the pointer position.

3. Put 10g more into the pan and record the position of the pointer and the total load on the spring. Continue adding 10g increments of mass until 95g has been added. Record the total load and pointer position each time.

4. Once you have reached 95g remove 10g at a time and record the total load and the pointer position each time. This will give you two readings for every load except at 95g.

5. Use the readings in your data table to find the total mean extension for each load by subtracting the zero position pointer reading (from 1.) from the average pointer reading for each load. Write this in your table.

6. Put 50g into the scale pan then set it in vertical

oscillations by lifting it slightly above the equilibrium position then quickly letting go. Time 20 complete oscillations to find the periodic time, T, where

$$T = \frac{\text{time for 20 oscillations}}{20}.$$

7. Repeat procedure (6.) with 100, 150, 200, and 250g. Be certain to include the mass of the pan and pointer in your tabulation of total load on the spring.

Observations

Mass of scale pan and pointer = ___g
Zero position of pointer = ___cm (also record in data table)

Load	Pointer reading load increasing	Pointer reading load decreasing	Average pointer reading	Total mean extension

Total load	Time for 20 oscillations	T	T^2

Theory

Hooke's Law predicts that when the spring experiences elastic deformation due to a load the extension is linearly proportional to the load: $F = -kx$. When a mass, M, is attached to the spring and the spring is extended a distance, x, there is a restoring force $\frac{x}{n}g$, where $n = \frac{\text{extension}}{\text{load}}$ (n is the slope of the first graph you will draw), and g is the acceleration due to gravity.

The oscillations of the spring are simple harmonic and obey the equation of motion $Ma = -\frac{x}{n}g$, or, $a = -\frac{g}{Mn}x$. Hence:

$$\omega^2 = \frac{g}{Mn} \quad \text{and,} \quad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{Mn}{g}}$$

The above assumes that the spring is weightless. In reality the spring has an effective mass, m, which changes the equation for T:

$$T = 2\pi \sqrt{\frac{(M + m)n}{g}}$$

From a graph of T^2 vs. load g and m can be found:

$$\frac{T^2}{\text{load}} = \frac{4\pi^2 n}{g} = \text{(slope of the second graph you will draw)}$$

$$g = 4\pi^2 n \frac{1}{\text{slope of the second graph}}$$

The x - intercept of the T^2 vs. load graph gives the effective mass, m, of the spring.

Analysis

1. Plot a graph of total mean extension vs. load. Find the slope, n, of the graph and the x - intercept. Use SI units.

2. Does this first graph verify Hooke's Law?

3. Plot a graph of T^2 vs. load. Find the slope and x - intercept.

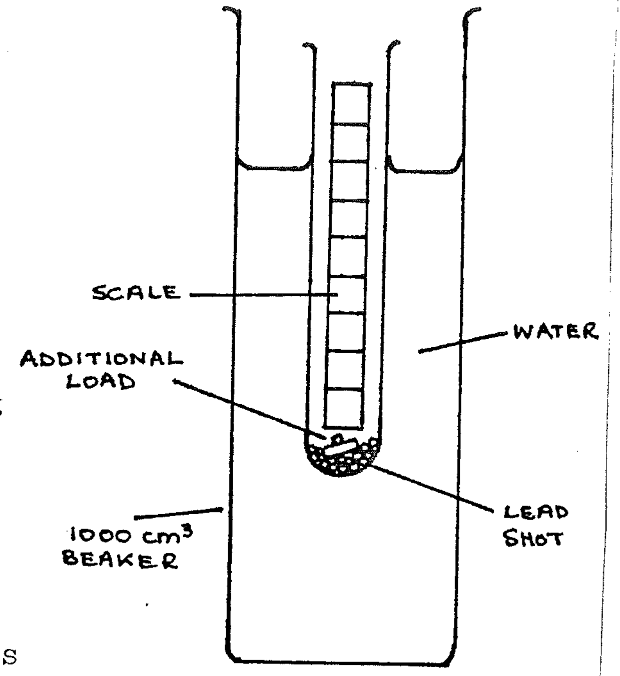
4. Use the slope of your graph to solve for g. Does the value you obtain for g agree with your expected value of nearly $9.8 ms^{-2}$? If there are differences try to explain them.

5. What is the value you predict for m? The value determined by considering kinetic energy is about 2g.

Finding g Using a Loaded Test Tube

Apparatus

A wide test tube with a millimetre scale inside, a deep 1000ml beaker, some lead shot, two 2g masses, two 5g masses, triple beam balance, stopwatch, water or other liquid, graph paper



Procedure

1. Use the triple beam balance to find the mass of the test tube filled with some lead shot. Add or subtract lead shot to make the total mass 50g.

2. Place the tube in the liquid filled beaker. The tube should float vertically. If it does not, add more lead shot until the tube floats vertically and record the new mass of the tube and lead shot. Record the initial scale reading of the liquid relative to the tube as measured on the scale inside the tube. At this point the total additional load is 0.

3. One at a time add the additional loads of 2g and 5g to the tube. After adding each mass record the liquid level on the scale inside the tube and record the total additional load.

4. Take out the 2g and 5g masses. Lift the tube 1.5cm above its equilibrium position then drop it to start it oscillating. Measure the time for 5 oscillations. This is easiest if you start the stopwatch at the top of the oscillation and count "zero" when you start the stopwatch.

Count each oscillation and stop the watch on "five."
Do this six different times and find the average result.

Observations

M = mass of the tube + lead shot = ____kg

Total additional load (kg)	Scale reading (m)	Change in scale reading (m)

6 measurements of time for 5 oscillations:

Average time of 5 oscillations: ___s

$$\text{Period of oscillation} = T = \frac{\text{Average time for 5 oscillations}}{5}$$

Theory

The upward force on the tube when it is pushed a distance x below the equilibrium position is $\frac{x}{n}g$, where n is the depth of immersion per load you will graph, and g is the acceleration due to gravity. When the loaded test tube of total mass M is oscillating the equation of motion is:

$$Ma = -\frac{g}{n}x \quad \text{or,} \quad a = -\frac{g}{Mn}x$$

From the general equation for simple harmonic motion, $a = -\omega^2 x$, $\omega^2 = \frac{g}{Mn}$, and the period of motion is:

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{Mn}{g}}$$

Analysis

1. Graph the change in level of the tube vs. total additional load. Find the slope, n, of the graph.

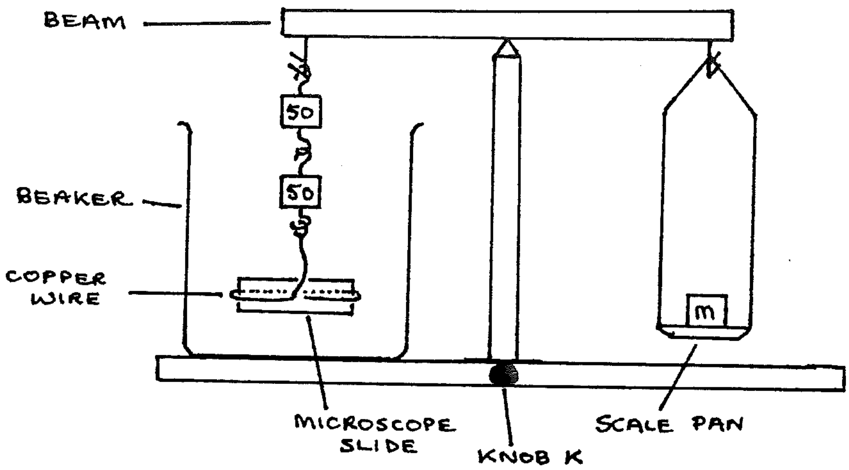
2. Show your calculation for g.

3. Does your value for g seem correct? If not, account for errors in your experiment.

Finding the Surface Tension of Water.

APPARATUS

Beam balance with two boxes of masses; tweezers; 2 × 50g masses with hooks; microscope slide with copper wire to support it; wide 1 L beaker; 1 L beaker of clean water; For cleaning slide: teat pipette; small beaker; dilute alkali; dilute acid; distilled water.
Vernier calipers; magnifying glass; thermometer (0-100°C).



PROCEDURE

1. Attach the copper wire to the slide as shown. Clean the lower half of the slide by running liquid from the pipette over it into an empty beaker: first alkali, then acid, then distilled water.

2. Assemble the apparatus as above using the empty, clean 1L beaker.

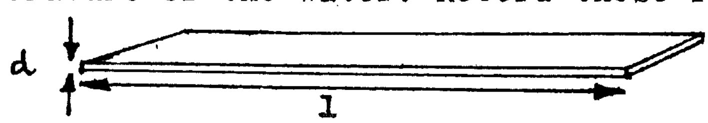
3. Raise the beam, using knob K, and carefully add masses m using the tweezers, until it is perfectly balanced. Note the total mass m_1 .

4. From now on, leave the beam raised, do not lower it. Carefully pour water into the beaker until the water surface touches the whole bottom edge of the slide.

5. Add more masses to m, little by little, until the slide just breaks away from the surface. Note the total mass in the scale pan now m_2 .

6. Reduce m until the slide touches the surface again. then repeat section 5. Repeat again to get three readings of m_2 . Note the readings and average them.

7. Use the Vernier calipers to measure the length (l) and thickness (d) of the slide. Measure the temperature of the water. Record these readings.



THEORY

The surface tension pulling force of the water exerted on the slide $\propto$ the length of the line of contact between the water and the slide.

$\therefore$ Surface tension force = $\gamma \times$ perimeter of the slide.

In the experiment, the surface tension force = the upward force exerted by the beam on the slide. (because the slide is in equilibrium). This is true at the point just before the slide leaves the water.

Force exerted by the beam = $(m_2 - m_1)g$. $(g = 9.8 Nkg^{-1})$

The slide perimeter = $2l + 2d$.

Thus $(m_2 - m_1)g = \gamma(2l + 2d)$

γ is a constant called the surface tension of water.

ANALYSIS

1. Use your readings to find the surface tension of water γ, stating the temperature at which it was measured.

2. Use a method of dimensions to find the unit of γ (Greek: gamma).

3. Draw a diagram to show the molecular forces acting on: a) the slide and b) the water.

4. What effect on γ would the following have ?

   a) Raising the water temperature.
   b) Mixing impurities into the water.

5. If the slide is greasy, how will this affect:

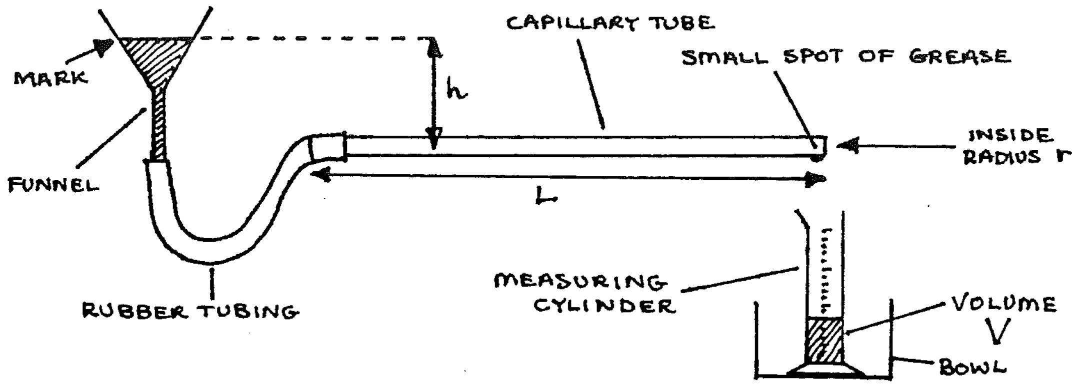
   a) The angle of contact of the water ?
   b) The downward force on the slide ?

6. Use your value of γ to calculate the capillary rise up a glass tube of internal diameter 0.2mm, if the angle of contact of the water on the glass is assumed to be $0°$.

The Viscosity of Water Using Flow Through a Capillary Tube.

APPARATUS

Funnel with connecting tube to capillary tube (int. dia. approx. 1mm, length approx. 30cm); stopclock; 0.5m ruler; 25ml & 50ml measuring cylinders; thermometer; ½ L water in beaker; bowl; spirit level; 1 sht. graph paper; stand & 2 clamps. To measure dia.: 20cm approx. of the same capillary tubing; beam balance & masses.



PROCEDURE

1. Set up the apparatus as above. Throughout the experiment keep the funnel topped up to the level of the mark. Check that the capillary tube is horizontal (use the spirit level), and that drops fall from the tip (if necessary, lower the tip <u>a little</u>). Set h to 5 cm. Measure L.

2. Collect water drops for t = 120s, measuring the volume V collected. Repeat with h = 7cm, 9cm, 11cm, 13cm.

3. Tabulate values of h (in m), V (in m^3), and V/t calculated for every value of h.

4. To find the inside radius of the capillary tube:

   a) Fill the short capillary tube with water, and dry the outside. Find its mass m_1, and the length l of water in the tube.

   b) Shake the water out of the tube and dry it. Find its new mass m_2.

   c) Then mass of water = $(m_1 - m_2)$
   = volume × density of water
   Thus $m_1 - m_2 = \pi r^2 l$ × density of water.

   Solve this to find the radius of the capillary tube.

   d) Check your result by using a ruler to find the radius. If the result from c) is very inaccurate use the estimate using the ruler.

5. Plot a graph of h against V/t and find the gradient.

6. Calculate the viscosity of water η (unit Nsm^{-2}) using:

$$\eta = \frac{\pi r^4 \rho g}{8 L} \times \left(\frac{h}{V/t}\right)$$

(ρ = density of water)
(η is Greek eta)

THEORY

Poiseuille's formula for liquid flow through a tube states:

Flow Rate $\propto$ pressure difference between ends of the tube.

The constant of proportionality depends on the radius and length of the tube, and the viscosity of the liquid:

Flow Rate $= \frac{\pi r^4}{8 \eta L} \times$ pressure difference.

In the experiment, the flow rate is V/t, and the pressure difference is $h\rho g$.

QUESTIONS

1. Use the theory to show that the formula given in 6. is correct.

2. What is viscosity ? (Use Nelkon & Parker, and explain in words only).

3. What changes would occur in the experiment if oil were used instead ? Explain why.

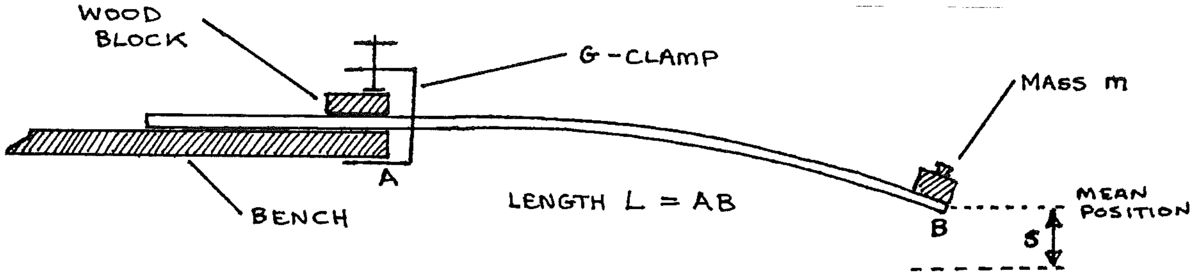
4. What energy changes occur when a liquid moves along a horizontal tube ?

5. Check the formula in 6. by using a method of dimensions.

Determining the Young's Modulus of Wood Along the Grain Using a Cantilever

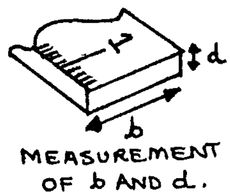
Apparatus

Wooden metre rule, 100g mass, elastic band, G-clamp, block of wood, vernier calipers, stopwatch, graph paper



Procedure

1. Clamp the loaded metre rule firmly to the end of a bench with a definite length, L, projecting from the edge of the bench.



2. Start the metre rule vibrating vertically and find the periodic time, T, for one complete oscillation. Do this by timing 20 oscillatioms and dividing by 20. Find T for the folling lengths, L: 0.5, 0.6, 0.7, 0.75, 0.8, and 0.9m. Tabulate your readings of L and T.

3. Using the callipers measure the dimensions b and d of the metre rule. Take six readings for each dimension at different positions along the rule. Record the readings, then calculate the mean values of b and d.

Observations

M = mass at end of the metre rule = ___kg
6 readings for b: __, __, __, __, __, __ Average: ___m
6 readings for d: __, __, __, __, __, __ Average: ___m

Length (L)	Time for 20 oscillations (t)	Period $(T = \frac{t}{20})$	T^2	L^3

Theory

Bending theory gives $s = \frac{4FL^3}{b\,d^3E}$ where F is a force applied to the end of the metre rule (reference Scholarship Physics by Nelkon, fifth edition, p44). Thus if the rule is depressed a distance, s, from equilibrium the restoring force is:

$$F = -\frac{b\,d^3Es}{4L^3} = -ks \quad \text{where } k = \frac{b\,d^3E}{4L^3}$$

This force acts on the mass at the end of the rule. Ignoring the mass of the metre rule itself the following is derived:

$$F = Ma = -ks \quad \text{and therefore} \quad a = -\frac{k}{M}s$$

The solution to this equation comes from the theory of simple harmonic motion. The equation describes an oscillation with $\omega^2 = \frac{k}{M}$. In terms of the period this is:

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{M}{k}}$$

Therefore: $T^2 = \frac{4\pi^2M}{k} = \frac{16\pi^2M}{b\,d^3E}L^3$

Analysis

1. Plot a graph of T^2 against L^3 and find the gradient.

2. From the equation $T^2 = \frac{16\pi^2M}{b\,d^3E}L^3$ and the gradient of your graph determine E, the Young's modulus of the wood along the grain.

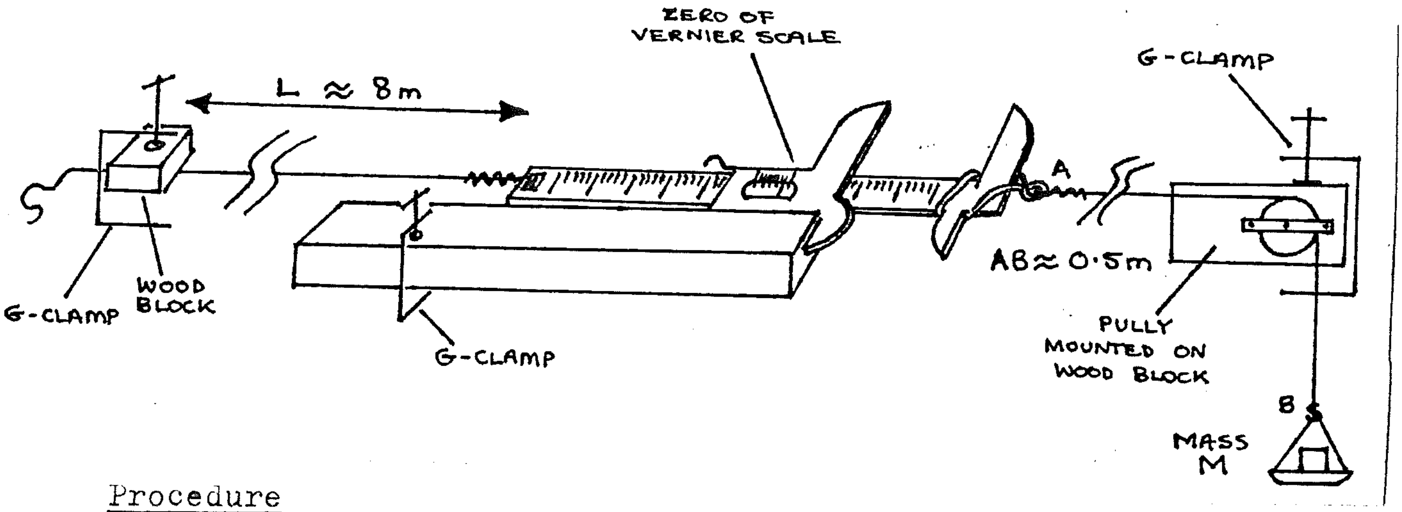
3. The Young's modulus across the grain is about 0.5GPa. Compare this with your value of E from (2.) and give a reason for the difference.

4. Calculate the longitudinal tension that would stretch the metre rule by 0.1mm. Use the dimensions of the rule, your calculated value for E, and the relation $E = \frac{\text{stress}}{\text{strain}}$.

Determining Young's Modulus for a Wire

Apparatus

Mounted vernier scale, mounted pully, about 8m copper wire of diameter about 0.3mm, 3 G - clamps, six 100g masses with loops to hang from an S - hook, 0.5m of wire with an S - hook at one end, wooden block or metal strip to protect wire from G - clamp, metre rule, micrometer, magnifying glass, graph paper



Procedure

1. Clamp the apparatus in place on the longest table in the lab as shown above. Be certain the vernier scale is about half - way along the sliding metal ruler. The ruler should slide freely or friction will ruin your results. Ask for some lubricating oil if the ruler is dry or binding in the vernier scale.

2. Gently add the masses to the S - hook, one at a time, until all masses are on the hook. One at a time take the masses off the hook until only one 100g mass remains on the S - hook. Repeat this process once. This will assure your wires are straight and tight.

3. Measure and record the length of the wire from clamp to vernier. Measure and record the diameter of your wire in 6 different places.

4. Starting with 100g add loads in increments of 100g to the wire up to 600g total load. Take the loads off 100g at a time until only 100g remains on the S - hook. Load and unload the wire a second time in this manner. Each time you add or take off 100g record the vernier scale reading. Tabulate your results. Find the extension, L, by subtracting the mean reading when load = 0.1kg from the mean reading at other loads.

Observations

L = length of the wire = ___m

6 readings of diameter: __, __, __, __, __, __ average =___m

r = radius = ___m

Load (kg)	Vernier scale reading (m)					ΔL (m)
	Adding load	Reducing load	Adding load	Reducing load	Mean	
0.1 0.2 0.3 0.4 0.5 0.6						

Theory

$$\text{stress} = \frac{\text{force}}{\text{area}} = \frac{\text{load}}{\pi r^2} = \frac{\text{mass} \times g}{\pi r^2}$$

$$\text{strain} = \frac{\Delta L}{L}$$

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}} = \frac{MgL}{\pi r^2 \Delta L}$$

Analysis

1. Graph load against ΔL. Use the slope to find Young's modulus for the wire.

2. Find the elastic modulus for copper in a reference book. What is the difference between the value you determined and that in the book? Explain any difference in terms of the numerical errors in your experiment.

Physical Properties of Solid Materials

APPARATUS

A large selection of different solid materials; 1.5V cell; ammeter (0-1A); voltmeter (0-3V); 5 connecting leads; magnet; compass needle; triple beam balance; overflow can; 1L and 100ml measuring cylinders filled with water; small beaker; optical pin; 0.5m ruler; Physics reference books.

PRECAUTIONS

1. Some materials shatter if stressed. Take care to protect your eyes!

2. Do not damage samples in the box marked 'DO NOT DAMAGE'. Any other materials can be bent or damaged if you wish.

PROCEDURE

1. Choose 8 different materials for testing. For each of the materials, perform the following tests. Tabulate the results in a large table. Use words and/or numbers in the table, do not just use ✓ or ✗.

2. Name the material. Describe its molecular structure, giving the constituent elements.

3. Find its density. Is the material porous ?

4. Find its resistance between two chosen points (in Ω)

5. When illuminated with white light:
   a) What intensity and colours of light are reflected ?
   b) What intensity and colours of light are transmitted ?
   c) Is it opaque, translucent, or transparent ?
   d) Is the reflection regular or diffuse ?

6. Is the material a good or poor thermal conductor ?

7. Are there ferromagnetic elements in the material ?

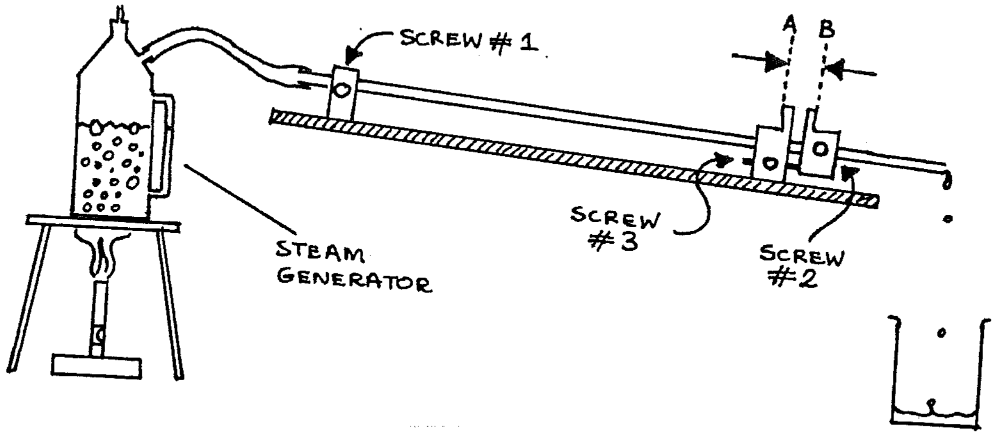
8. Mechanical tests: (approximate only)
   a) Elasticity: is it a stiff material ?
   b) Strength: is the material strong or weak ?
   c) Hardness: is the material hard or soft ?
   d) Is the material ductile or brittle ?

NOTE: The underlined words in sections 3 to 8 have exact meanings in Physics. Make sure that you know these meanings. (Refer to text books for help).

Linear Expansivity

Apparatus

Gas burner or a stove, heating stand, steam generator, expansion sample, small beaker or dish, meter stick, micrometer, theremometer, stack of books, table of linear expansivities of common materials



Procedure

1. Set up apparatus as shown above. Be sure the sample slopes away from the steam generator, screw #1 is very tight, and screw #3 is very loose. Be certain there is water in the steam generator.

2. Loosen screw #2 and push the sliding metal piece up against the leg which holds the sample. Tighten screw #2 to lock the sliding metal piece in this position. Measure the distance AB with a micrometer. NOTE: The metal faces at A and B are not perfectly flat or parallel. You musr measure AB at the very edge of the metal pieces and then use the exact same location for all future measurements.

3. Measure the length, L_o, of the sample. Measure from the centers of the tightinid screws.

4. Measure the room temperature.

5. Light the gas burner or stove. After steam begins flowing steadily through the tube wait 3 minutes and then measure AB again.

Observations

AB before heating = ___m, AB after heating = ___m
ΔL = change in length = ___m
L_0 = length of sample between screws 1 and 2 = ___m
θ_T = room temperature = ___C
$\Delta\theta$ = change in temperature of the sample = ___C

Theory

The coefficient of linear expansion is determined from the relation $\Delta L = L_0 \alpha \Delta\theta$ where α is the average of the coefficient of linear expansion over the temperature range.

Analysis

1. What is the coefficient of linear expansion of the sample?

2. What material is the sample? Explain your choice by refering to a table of linear expansivities of common materials.

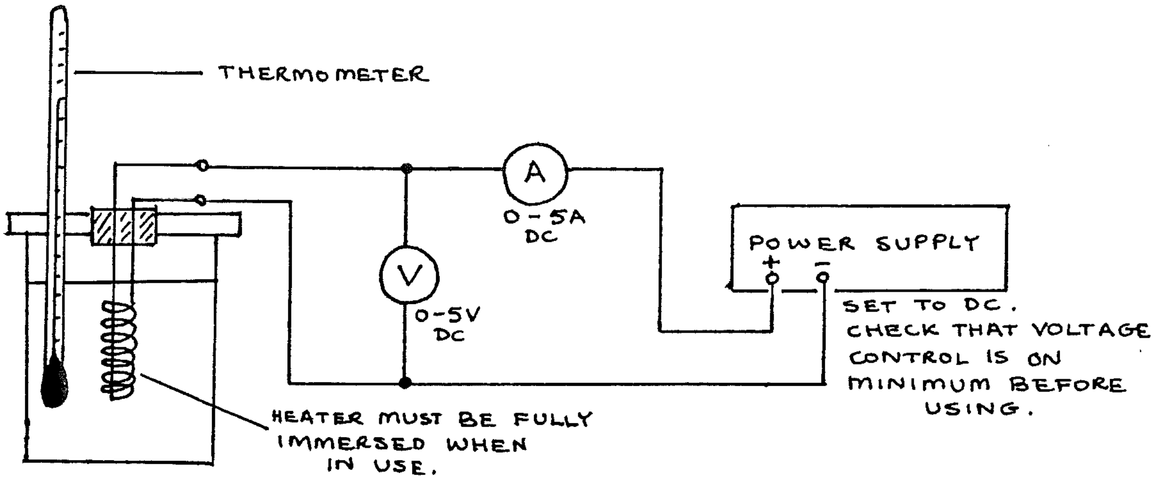
3. List 4 assumptions you made in determining the coefficient for the sample. For each assumption justify it or account for error.

D2-1 Specific Heat Capacity of water: Electrical Method

NB: This experiment requires mains electricity.

APPARATUS

Copper calorimeter (unlagged, with fitted lid and electrical heater); thermometer (0-100°C); voltmeter (0-5Vdc); ammeter (0-5Adc); power supply (dc); stopclock; measuring cylinder (100ml with 100ml water); triple beam balance; 5 connecting leads; 1 sheet graph paper.



PROCEDURE

1. Find the mass of the calorimeter. Pour in 100 cm³ water. Record the calorimeter mass m_c, and the mass of water m_w.

2. Assemble the apparatus as above. Switch on, and quickly adjust the voltage so that A reads 4A. Switch off.

3. Shake the calorimeter gently to stir the water, then record the starting temperature θ_1 .

4. Switch on and start the stopclock. Record readings of current and p.d. After 30s read the temperature, and continue reading time and temperature every 30s. Occasionally shake the calorimeter gently.

5. When the temperature has risen about 15 °C, note the time t, and switch off the heater. CONTINUE TIMING, BUT DO NOT TURN ON THE HEATER AGAIN. Continue recording temperature and time every 30s for a further time of t seconds.

6. Plot a graph of temperature θ against time. From the graph read: initial temperature θ_1 , highest temperature θ_2 , the time t' taken to reach θ_2 (may not equal t), and the temperature fall x during a period $\frac{1}{2}$t' after time t'.

THEORY

The 'cooling correction' to allow for heat loss = x °C.

Then: Electrical energy supplied = Heat gained by water and calorimeter.

Thus $VIt = (m_c c_c + m_w c_w)((\theta_2 + x) - \theta_1)$

Where c_c = specific heat capacity of copper
= 3.8×10^2 $Jkg^{-1}K^{-1}$

And c_w = specific heat capacity of water

(The theory of the cooling correction can be found in 'Practical Physics' - Armitage)

QUESTIONS

1. Use the above equation and the readings from your graph to determine the specific heat capacity of water.

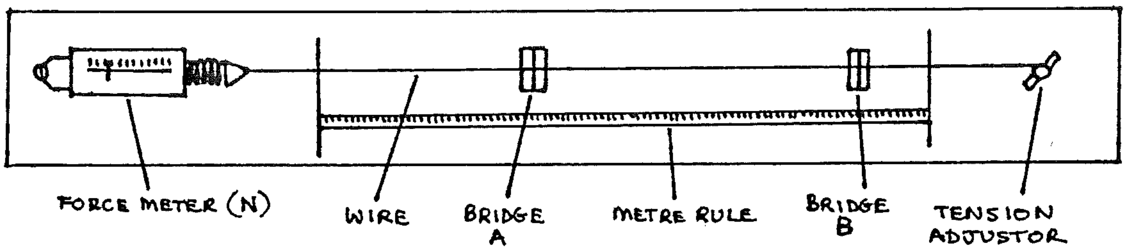
2. If an accurate value of c_w = 4190 $Jkg^{-1}K^{-1}$, calculate the % error in your value.

3. Explain the most likely sources of error in your experiment, and for each source give a suitable precaution to reduce its effect.

The Frequency of Vibration of a Stretched String : Variation with Length and Tension.

APPARATUS

Sonometer with two bridges; set of tuning forks (frequencies 256 to 512 Hz); 5m sample of sonometer wire; tuning fork hammer; sounding box; beam balance with masses; 2 shts. graph paper.



Precaution: do not exceed the maximum tension (see label beside force meter).
Place bridge A near the right hand end. Do not move it again.

EXPERIMENT 1 : PROCEDURE

To study how frequency varies with length and thus calculate the mass per unit length of the sonometer wire.

1. Set the tension to 20 N; throughout this experiment ensure that this remains constant. Record this value of tension.

2. Strike the 256 Hz tuning fork with the hammer, and press the tip hard against the sounding box. (Do not touch the arms of the fork). Listen carefully to the note produced.

3. Pluck the string between bridges A and B, then move bridge B until the string makes exactly the same note as the fork. (Repeat step 2. to help the comparison).

4. Record the frequency and the length AB.

5. Repeat 2., 3., and 4., using all the other forks in turn, up to 512 Hz.

EXPERIMENT 1 : THEORY

For a string under tension, secured at both ends:

$$f = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

Where f = frequency(Hz), m = mass per unit length (kg m^{-1}),
l = length (m), T = tension (N).

If T and m are constant, then $f = k \times \frac{1}{l}$, where the constant k is $\frac{1}{2}\sqrt{\frac{T}{m}}$.

EXPERIMENT 1 : ANALYSIS

1. Plot a graph of f against 1/l and find the gradient.

2. Use the gradient, the value of tension and the theory to find the value of m, the mass per unit length of the wire.

EXPERIMENT 2 : PROCEDURE

To study how frequency varies with tension, and thus calculate the mass per unit length of the wire.

1. Place bridge B so that length AB is 20 cm. Record this length.
2. Adjust the tension so that the string frequency is 256 Hz. (use the tuning fork as described in experiment 1 step 2.)
3. Record the values of tension and frequency.
4. Adjust the tension so that the string produces the frequencies of each of the other tuning forks. For each fork record the values of tension and frequency. Ensure that length AB remains constant throughout.
   NB: DO NOT EXCEED THE MAXIMUM TENSION ALLOWED.

EXPERIMENT 2 : THEORY

In this experiment, l and m are constant, therefore:

$$f = k\sqrt{T} \quad \text{where the constant } k = \frac{1}{2l\sqrt{m}}$$

EXPERIMENT 2 : ANALYSIS

1. Plot a graph of f against $\sqrt{T}$, and find the gradient.

2. Use the gradient, the value of length, and the theory, to find the value of m, the mass per unit length of the wire.

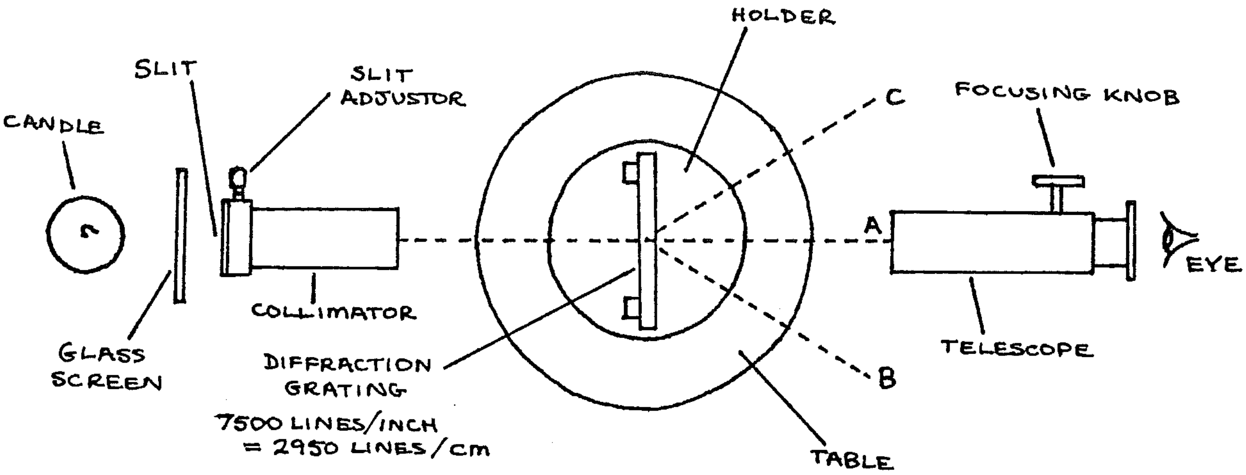
CONCLUSION

Use the beam balance to measure the mass of the 5m length of sonometer wire supplied. From this value calculate the mass per unit length of the wire. Assuming that this value is very accurate, calculate the % error in the values obtained from experiments 1 and 2.

Finding the Wavelength of Sodium Light Using a Diffraction Grating and Spectrometer.

APPARATUS NB A darkened room is required.

Spectrometer (set up and adjusted); diffraction grating; glass screen; candle in holder; matches; wire loop and a Sodium salt.



PROCEDURE

1. Essential precautions: Do not touch the collimator or telescope lenses or the glass of the diffraction grating. Keep the glass screen between the candle flame and the slit. Take care with this delicate apparatus.

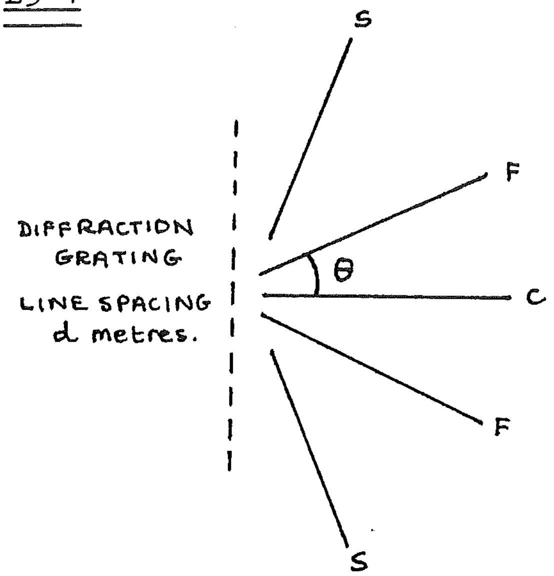
2. Without the grating on the table, place the telescope at A. Adjust focusing and candle position until the slit is visible through the telescope.

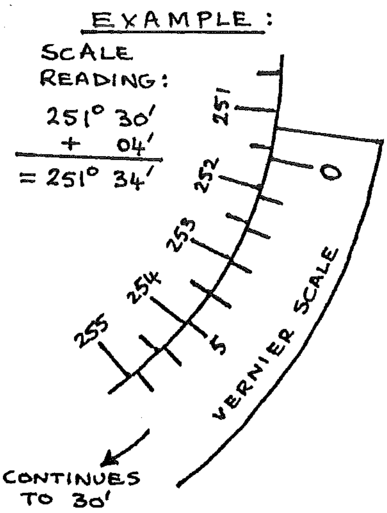
3. Replace the grating as above. The slit should still be visible through the telescope. Move the telescope towards B until a spectrum is seen. If none is seen check that little direct light is falling on the apparatus. Otherwise seek help.

4. Burn some Sodium salt in the candle flame using the wire loop. Move the telescope to place the cross-wires on the bright yellow (Sodium) lines. Read the angle on one of the vernier scales θ_1.

5. Move the telescope towards C. Repeat step 4. reading the angle from the same vernier scale θ_2.

OBSERVATIONS θ_1 = ______ ° ' ; θ_2 = ______ ° ' .





THEORY

In the above diagram:

C = central bright line
F = first order spectra n=1
S = second order spectra n=2
θ = angle of F from C

From the readings: $\theta = \dfrac{\theta_2 - \theta_1}{2}$

Take care to calculate θ correctly if your vernier scale moved through 0° when moving from θ_1 to θ_2.

Then $\lambda = \dfrac{d \sin\theta}{n}$

ANALYSIS

Use your observations and the theory to find λ of Sodium light. Read 'Fundamentals of Senior Physics' Book II pp140-144. Find λ of sodium light from p 142 and compare this with your value. Use the average λ of the two brightest yellow lines.

QUESTIONS

1. Why did you see the Sodium spectrum and a continuous spectrum ?

2. Calculate the energy of a photon of yellow light from hot sodium.
   ($h = 6.6 \times 10^{-34}$ Js ; $c = 3 \times 10^{8}\ m s^{-1}$).

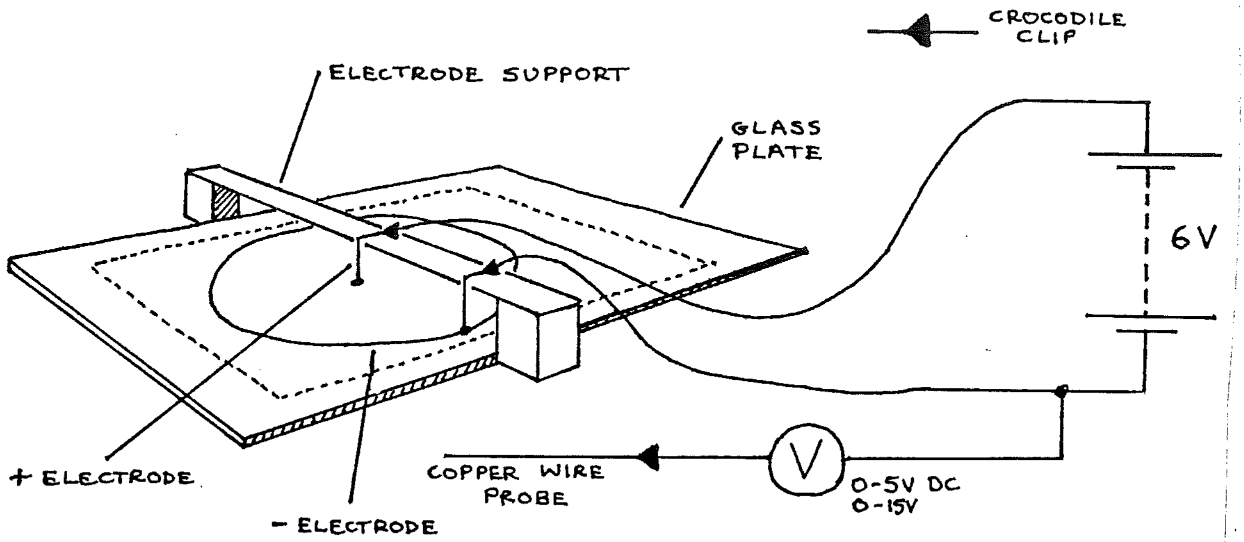
3. An electric Sodium lamp, rated at 40 W is approx. 20 % efficient in producing visible light. Assuming that all the light produced is at the wavelength you calculated above, how many photons per second are given out by the lamp ?

4. Draw a diagram to illustrate the change in energy state of a Sodium atom when emitting a photon of yellow light. If the lower energy state is x eV, what is the upper energy state in eV ?
   ($e = 1.6 \times 10^{-19}$ C).

Investigation of Electric Fields

APPARATUS

Glass plate with graph paper on the underside; probe ; electrodes; electrode support; 100ml copper sulphate solution; syringe; spirit level; 4 connecting leads; voltmeter (0-5 & 0-15Vdc); 6V battery; 2 sheets graph paper.



PROCEDURE

1. Pour enough copper sulphate solution onto the glass plate to form a thin layer. Level the glass carefully so that the pool is of uniform depth.

2. Arrange the apparatus as above, checking that the electrodes are clean (if necessary clean with sand paper).

3. On a sheet of graph paper mark X and Y scales similar to the sheet under the glass plate. Draw a point and a circle to show the positions of the electrodes.

4. Holding the probe vertically, touch the tip onto the copper sulphate solution between the electrodes. Move the probe until a point is found where V = 1 V. Read the X and Y coordinates. Mark this point on your graph paper.

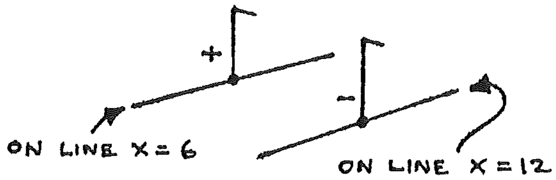
5. Find another point about 2cm from the first, where V = 1 V. Mark this point on the graph paper. Continue this process until either the line of points forms a closed loop or goes off the area of the solution.

6. Join the points with a smooth curve and label it +1V.

7. Repeat 4, 5, and 6 with V = 2V, 3V, and 4V.

8. Touch the probe onto each electrode in turn, read V, and mark these values on the graph paper beside the electrodes.

9. Change the electrodes to these shown below :



The wires are parallel and 6cm apart.

Draw two parallel lines on a new sheet of graph paper to show these electrodes. Now repeat steps 4 to 8, but placing the probe tip onto positions in the <u>whole area</u> of the copper sulphate solution.

10. Use the syringe to replace the copper sulphate solution into its container. Wash the glass plate (top surface only!) the electrodes and the probe in clean water.

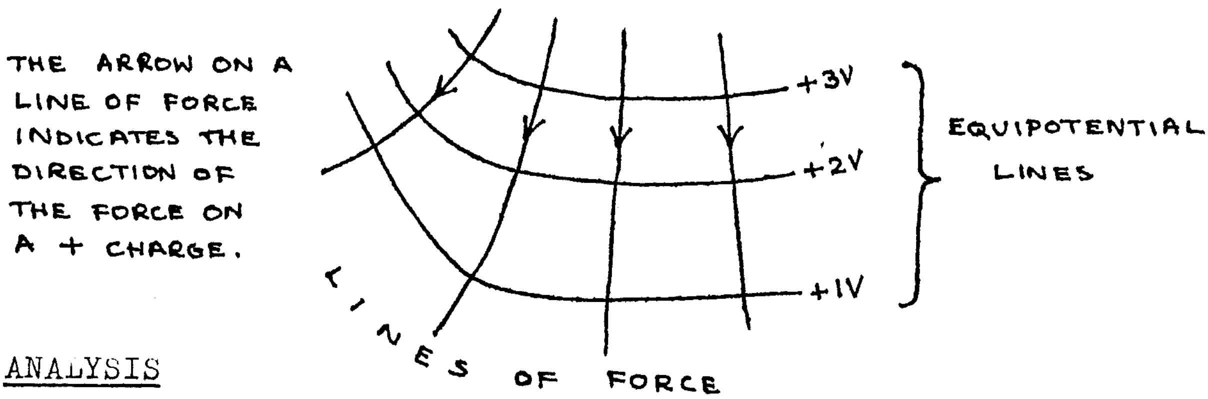
<u>THEORY</u>

The reading on the voltmeter was the value of electric <u>potential</u>, relative to the negative electrode. Thus the curves that you plotted were <u>equipotential lines</u>, that is lines drawn linking points at the same electric potential.

If an electric charge moves between points at different electric potentials, it moves through a <u>potential difference</u>, and work is done. If a charge moves perpendicular to an equipotential line, work is done at a maximum rate (per unit distance), and the charge is moving along a <u>line of force</u>.

A line of force is a line drawn to indicate the direction of the force on a unit positive charge placed at one of the points on the line. A charge free to move would move along the line of force, so that work is done at a maximum rate (per unit distance).

Example:(Note that the lines always cross perpendicularly)



<u>ANALYSIS</u>

1. Sketch on your graph papers the <u>lines of force</u>, which are perpendicular to the equipotential lines (use a different colour pen).

2. Use the graph paper obtained in 1 to 8, to find the approx. potential difference between points A(9,15) and B(8,10).

3. Calculate the work done if a charge of +2C moves from point A to point B. Describe the energy change if the charge is acted on by no forces other than that exerted by the electric field.

4. How much work is done if the +2C charge moves along an equipotential line ?

5. Look at the pattern of lines of force from steps 1 to 8. What formula is used to find the force on a charge in this field ? (in terms of the size of the charge, the charge on the central electrode, and the distance from the central electrode).

6. Look at the lines of force from step 9. What formula can be used to find the force on a charge between the electrodes ? (in terms of p.d. between the electrodes, distance between electrodes, and the charge).

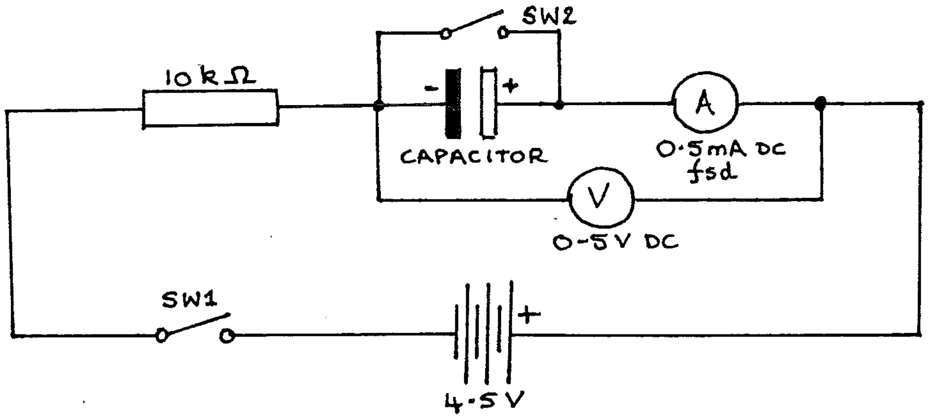
7. Calculate the work done if a -4C charge moves between the electrodes (from the + to the - electrode), in both of the fields studied.

Charging Capacitors

APPARATUS

Capacitors (2 × 1000 μF, electrolytic); voltmeter (high resistance, 0-5Vdc eg multimeter); ammeter (0.5mA fsd); resistor (10kΩ); 4.5V battery; 2 switches; stopclock; 9 connecting leads; 2 blocks with crocodile clips; 2 shts. of graph paper.

IMPORTANT The battery must not be connected until your circuit has been checked by a teacher. (an error could seriously damage the ammeter).



PROCEDURE

1. Construct the circuit as above, using one capacitor. Connect the battery after the circuit has been checked.

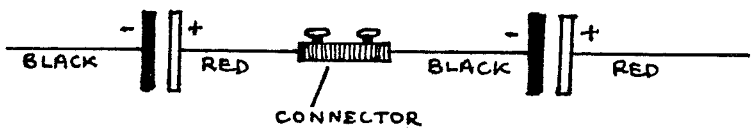
2. Leave SW2 open. Close SW1 and notice how V and I change as the capacitor charges. Open SW1. Close SW2 briefly to discharge the capacitor again.

3. Close SW1, and start the stopclock at the same moment. Note readings of V at t = 0, 10, 20, ... up to 100s. Open SW1. Discharge the capacitor by closing SW2 briefly.

4. Close both SW1 & SW2, and note the value of I at t = 0. Open SW2 (to allow charging to start), starting the stopclock at the same moment. Note readings of I at time t = 10, 20, 30, ... up to 100s.

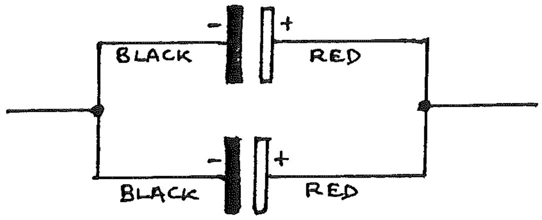
5. Tabulate your readings of V, I, and t.

6. Replace the single capacitor by two capacitors in series:



Repeat steps 2 to 5.

7. Replace the series capacitors by two in parallel:



Repeat steps 2 to 5.

ANALYSIS

1. Plot a graph of V against t, for all three arrangements of capacitors, on the same sheet of graph paper. Label each line clearly.

2. Plot a graph of I against t on another sheet, labelling the three lines clearly.

3. Find the area under the I against t curve for the single capacitor, using the axes scales. This is the total charge stored in coulombs. (Ask for help if you have not done this before).

4. From the V curve for the single capacitor read the maximum value V_{MAX}.

5. Calculate the capacitance using:

$$C = \frac{Q}{V}$$

Thus here: $C = \dfrac{\text{Total charge stored}}{V_{MAX}}$

6. Repeat 3, 4, and 5 for the capacitors in series and in parallel.

7. Assuming that each capacitor has value 1000 μF $\pm$ 10%, and using the formulae for capacitors in series or in parallel, calculate the range of possible values for each of the three arrangements in the experiment. If your values from step 5 lie outside these ranges, suggest possible reasons for error.

8. Draw a line on the V graph, parallel to the x-axis, at $V = (5/8) \times V_{MAX}$. For each of the three curves read the time when $V = (5/8) \times V_{MAX}$.

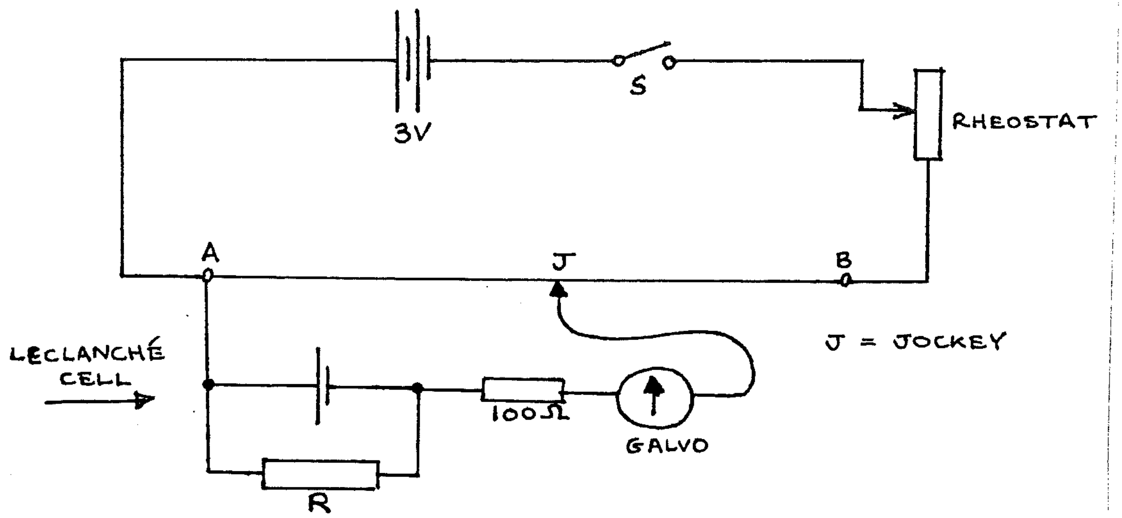
9. τ = RC is called the time constant of the circuit. (τ is Greek tau). This is the time taken for the p.d. to rise to 5/8 of its final value (approx.).
   Calculate the values of RC using the values of capacitance found in step 5.
   Compare these calculated times with the times obtained directly from experiment in step 8.

10. V_{MAX} should equal the battery voltage, but in the experiment it is lower. Why ?
(Hint: take into account the resistance of the voltmeter).

Determination of the Internal Resistance of a Cell Using a Potentiometer.

APPARATUS

Leclanché Cell (filled to bottom of paint line with saturated Ammonium Chloride solution); metre bridge board; 3V battery (fresh cells); jockey; switch; galvanometer with 100Ω series resistor; rheostat (≈ 15Ω resistance); resistors values: 5Ω, 10Ω, 20Ω; block with crocodile clips (for resistor); connecting leads (3 long, 7 short); 1 sht. graph paper.



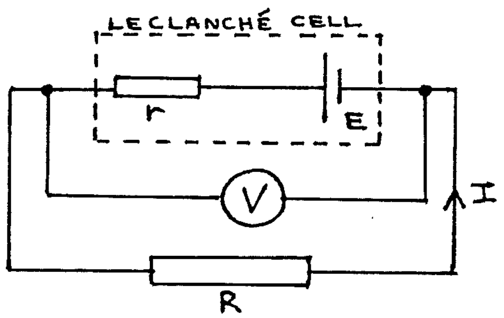
PROCEDURE

1. Construct the above circuit, with R = ∞ Ω. Close S, and placing J 5cm from B, adjust the rheostat until the galvanometer reads zero (balance point). Note the length l_∞ = AJ. Open S.

2. Connect R = 30Ω, close S, and find the balance point. Read l = AJ. Repeat with R = 25, 20, 15, 10, and 5Ω. Tabulate R and l. Open S.

THEORY

Consider the lower branch of the circuit when the galvanometer reads zero. It is effectively disconnected from the top branch of the circuit:



$$I = \frac{E}{r + R} = \frac{V}{R}$$

$$\therefore ER = Vr + VR$$

$$\therefore r = \frac{R(E - V)}{V}$$

However the length l ∝ the p.d. V, and when R = ∞ Ω, V = E.

Thus let V = kl and E = kl_∞ ,where k is a constant:

$$\therefore \quad r = \frac{R(kl_{\infty} - kl)}{kl} = \frac{R(l_{\infty} - l)}{l}$$

$$\therefore \quad \frac{1}{R} = \left(\frac{l_{\infty}}{r} \times \frac{1}{l}\right) - \frac{1}{r}$$

ANALYSIS

1. Plot a graph of $1/R$ against $1/l$, and find the gradient.

2. Use the gradient, the value of l_{∞}, and the last equation in the theory only, to find the internal resistance of the cell, r.

QUESTIONS

1. a) In the theory why is the lower branch 'effectively disconnected' from the top branch of the circuit ?

   b) If the resistance of wire AB is 2Ω, and its length is 100 cm, find an expression for k in terms of V_{AB} only.

2. List a) the similarities and b) the differences between the Leclanché Cell and the modern Dry Cell.

3. Define a) internal resistance and b) electromotive force, and thus explain carefully why, in the theory, when $R = \infty\,\Omega$, then $V = E$.

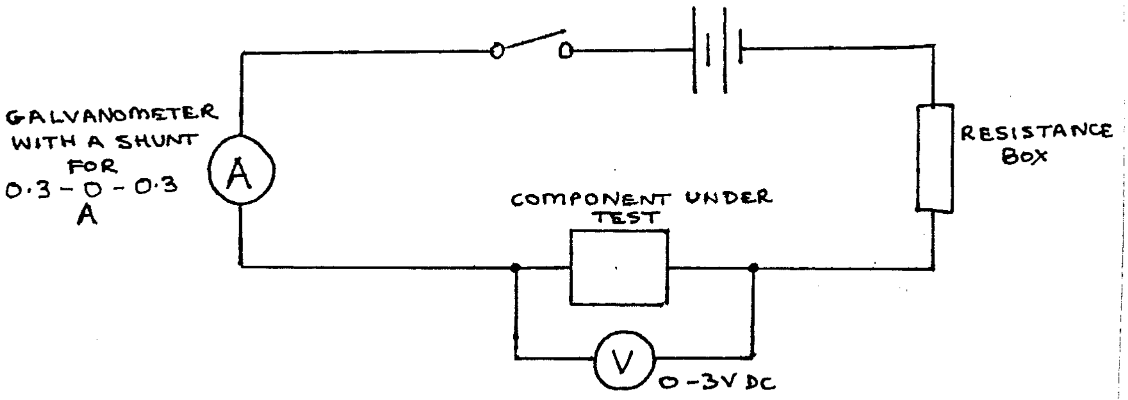
NOTE: After the experiment, empty the Ammonium Sulphate solution out of the Cell again, to ensure a maximum lifetime for the solution.

Ohmic and Non-Ohmic Conductors

APPARATUS

3V battery; galvanometer with shunt for 0.3-0-0.3 A; voltmeter (0-3Vdc); resistance box; switch; block with crocodile clips to hold component; 7 connecting leads; 1 sht. graph paper;

COMPONENTS UNDER TEST:
A. Resistance wire
B. 6V bulb in holder
C. Copper Sulphate solution with copper electrodes
D. Semiconductor diode.



PROCEDURE

1. Set up the circuit as above, using component A.

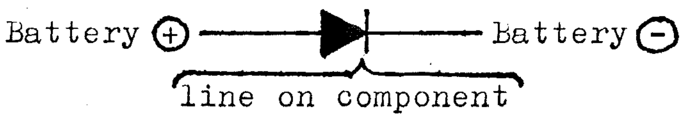
2. Set the resistance box to 5 Ω, close the switch, and read V and I.

3. Increase the resistance box resistance to 10, 20, 50 Ω , and then ∞ Ω, in each case reading V and I. Tabulate the readings of V and I.

4. Reverse the connections to the component. Repeat steps 2 and 3, recording the values of V and I as NEGATIVE values.

5. Repeat steps 2, 3, and 4, using components B, C, and D in turn.

   Note that the diode should first be connected into the circuit as follows:



ANALYSIS

1. Plot all the readings on the same sheet of graph paper, labelling the lines carefully. (V against I)

2. Calculate resistance from lines where $V \propto I$.

3. The lines on your graph all follow different paths. For each of the conductors in turn, explain why the line for the conductor has the shape it does.
(You should refer to the internal structure and properties of the component when you answer this, and use text books for reference).

QUESTIONS

1. What are the properties required of a material used to make resistors ?

2. Draw a circuit to show how semiconductor diodes can be used to rectify an AC supply.

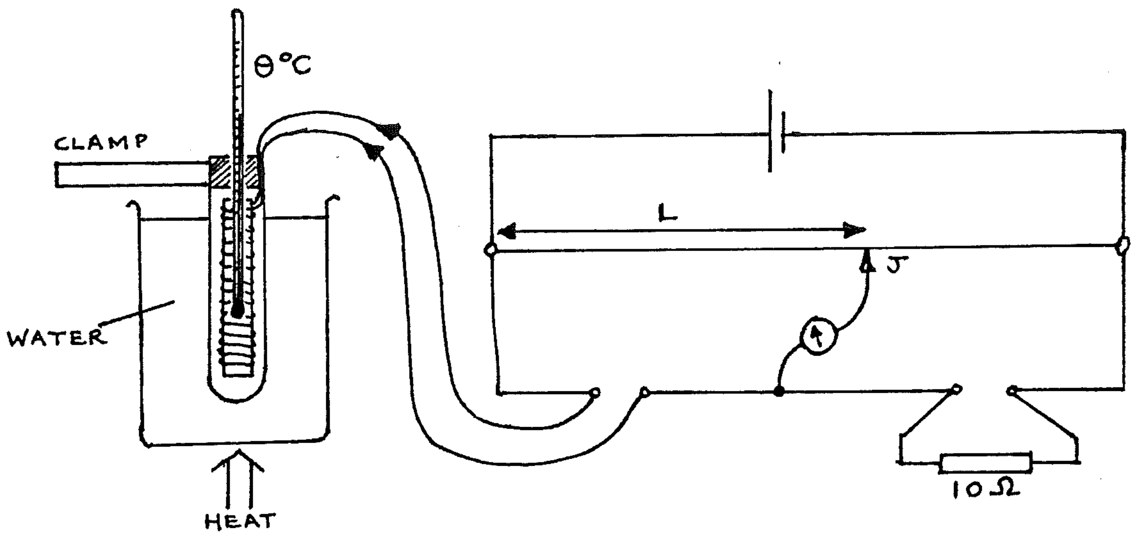
3. Why does a tungsten-filament bulb have such a low efficiency ?

4. Find the resistance of the shunt in parallel with the galvanometer if the galvanometer alone has a full-scale deflection of 3mA, and an internal resistance of 10Ω.

The Temperature Coefficient of Resistance of Copper

APPARATUS

Metre bridge board; 1.5V cell; galvanometer; jockey; standard resistor 10Ω; copper wire & thermometer in a test tube; 1L beaker of water; Bunsen burner (or other heat source); 8 connecting leads (5 long, 3 short); 1 sht. of graph paper. Clamp and stand.



PROCEDURE

1. Set up the apparatus as above. Do not begin heating yet. Check carefully that all connections are secure. Find the balance point length L where the galvanometer reads zero. Disconnect the battery. Read temperature θ.

2. Begin heating the water. At temperatures approximately 30, 35, 40, 45,....... up to 90 °C, reconnect the battery, find L, and read θ (to the nearest 0.1 °C). Disconnect the battery between readings.

3. Tabulate the readings of L and θ.

THEORY

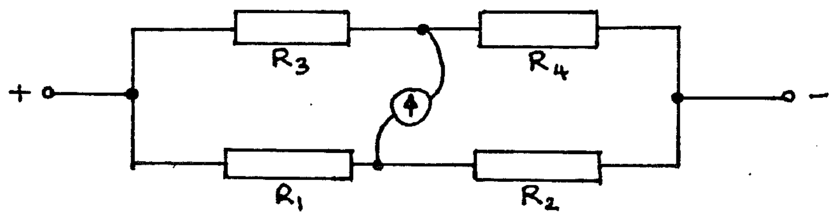
1. Resistivity varies with temperature, therefore the resistance of a given sample varies with temperature. This is given by:

$$R_\theta = R_0(1 + \alpha\theta + \beta\theta^2)$$

R_θ = R at θ °C
R_0 = R at 0 °C
α, β are constants

β is very small, and is usually neglected. In this experiment assume that β = 0.

2. The circuit is a Wheatstone Bridge:



When the galvanometer reads zero:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \text{-------- equation 1}$$

And therefore in this experiment: $R_\theta = 10\left(\frac{L}{100 - L}\right)$ -equation 2

ANALYSIS

1. For each value of L, calculate a value of R_θ using the above formula. (equation 2)

2. Plot a graph of R_θ against θ °C. Find the gradient and the y-intercept. (NB: it is not necessary for the R_θ axis to extend down to zero).

3. Use the formula given in 1 of the theory, together with the gradient and y-intercept only, to calculate α, the temperature coefficient of resistance of copper.

QUESTIONS

1. Use equation 1 above to prove equation 2.

2. Calculate the expected resistance of the copper wire when its temperature is 300 °C.

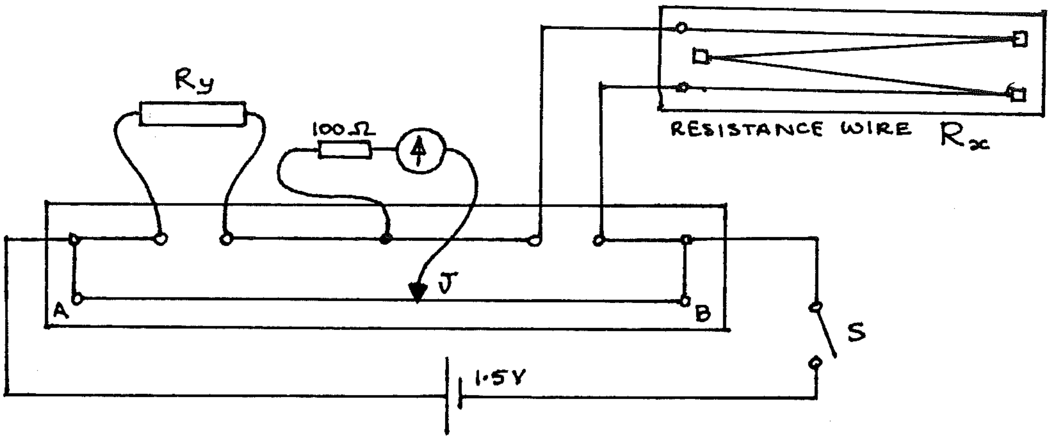
3. If copper has a resistivity of 1.7×10^{-8} Ωm at 293K, find the resistance of a sample of copper length 5cm, uniform cross-sectional area 10^{-6} m², at:

   a) 0 °C
   b) 100 °C.

Determination of the Resistivity of the material of a Wire.

APPARATUS

Metre Bridge board; resistance wire board (R_x, may include wires of several materials); galvanometer with 100Ω protection resistor; resistor R_y of 10Ω; 1.5V cell; switch; micrometer screw gauge; jockey (J); connecting leads (3 long, 6 short).



PROCEDURE

1. Set up the apparatus as above.

2. Close S, and place J at the 50cm mark. Move J until the galvanometer reads zero. Record the length AJ. Open S.

3. Measure the length of R_x. Very gently lift the wire R_x, and measure its diameter in 5 different positions.

4. If there are wires of other materials, repeat steps 2. and 3. for these wires.

OBSERVATIONS

For each wire: Wire number ________

AJ = ______cm ; JB = ______cm ; R_y = ______Ω;

Length L of R_x = __________m ;

Diameter of R_x :

d_1 = ______mm; d_2 = ______mm; d_3 = ______mm; d_4 = ______mm;

d_5 = ______mm.

Average value of d = __________mm.

THEORY

This circuit is a Wheatstone Bridge. Thus $AJ/JB = R_y/R_x$, and R_x can be found.

Now $\rho = \frac{RA}{L}$, where here $R = R_x$, A = cross-sectional area of wire R_x, L = length of R_x, and ρ is the resistivity of the material of the wire.

ANALYSIS

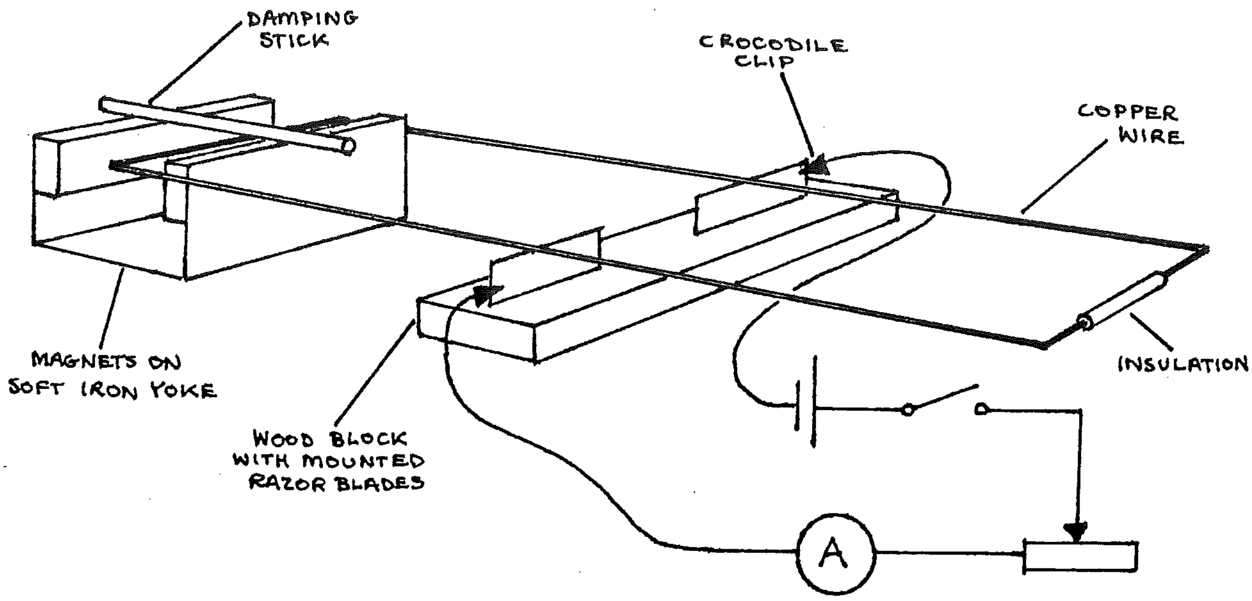
1. Use the theory to find ρ of the material of each type of wire tested.

2. Look at the table on p477 of 'University Physics' or other reference book, and try to deduce the type of material of each wire. Calculate the % error in each of your results.

3. Choose a suitable material or materials, giving reasons, for the construction of the following:

   a) a fixed resistor of 10000Ω
   b) a variable resistor of 5Ω
   c) a lamp filament
   d) a thermistor
   e) a junction diode
   f) a connecting wire
   g) a long-distance power cable in a National Grid.
   h) a lightning conductor.

Measuring the Magnetic Flux Density of a Permanent Magnet Using a Current Balance



Apparatus

Magnets mounted on a soft iron core, rectangular copper wire coil, mounted razor blades, plastic dampening stick, 5 connecting wires, 1.5V dry cell, key switch, 15Ω rheostat, ammeter with 0 to 0.3mA scale, metre stick, callipers, triple beam balance, 5m of ticker tape, about 0.4m piece of extra ticker tape, tweezers, scissors

Procedure

1. Set up the apparatus as shown above. Be certain the wire coil is level with the smooth end of the coil in the exact center of the magnetic field.

2. Measure and record the horizontal length of the magnets. Neglecting edge effects this is the length of the magnetic field the current passes through.

3. Measure and record the mass of 5m of ticker tape. Use this to determine the linear density (μ) of the tape.

4. Place the key in the switch and allow 0.05mA of current to pass through the circuit by adjusting the rheostat. The end of the coil between the magnets should deflect down. If the end of the coil between the magnet deflects up reverse the direction of the dry cell in the circuit to make the end of the coil between the magnets deflect down. From the short extra piece of ticker tape cut lengths of tape 0 to

4cm long, fold them in half, and using the tweezers place them on the end of the coil opposite the magnets. Add or remove tape until the coil is again level.

5 When the weight of the tape pieces balances the force on the current carrying end of the wire switch the current off and remove the pieces of tape. Measure the lenth of this tape and using μ determine the weight of the pieces of tape.

6 Repeat steps 4 and 5 above for currents 0.10, 0.15, 0.20, 0.25, and 0.30mA. Tabulate your results.

Observations

L = length of magnet = ___m
M = mass of 5m of ticker tape = ___kg
μ = linear density of ticker tape = ___kg m^{-1}

Current (I)	Length of balancing tape	Mass of balancing tape	Weight of balancing tape (W)	Magnetic flux density $B = \frac{W}{IL}$

Theory

For a current flowing perpendicular to a magnetic field the force exerted on the current carrier is $F = BIL$ when F is in newtons, B is in tesla, I is in amperes, and L is the length in metres of the wire in the magnetic field. In this experiment the coil experiences a torque due to the force on the end of the wire which runs through the magnetic field. $\tau = FR$ where R is the distance from the end of the coil to the pivot on the ravor blades. The coil is uniform and the distance, R, to each end is the same. When the coil is level the weight of the tape on one end is equal to the force of the magnetic field on the current at the othe end of the coil. The magnetic flux density is found from: $B = \frac{F}{IL} = \frac{W}{IL}$

Analysis

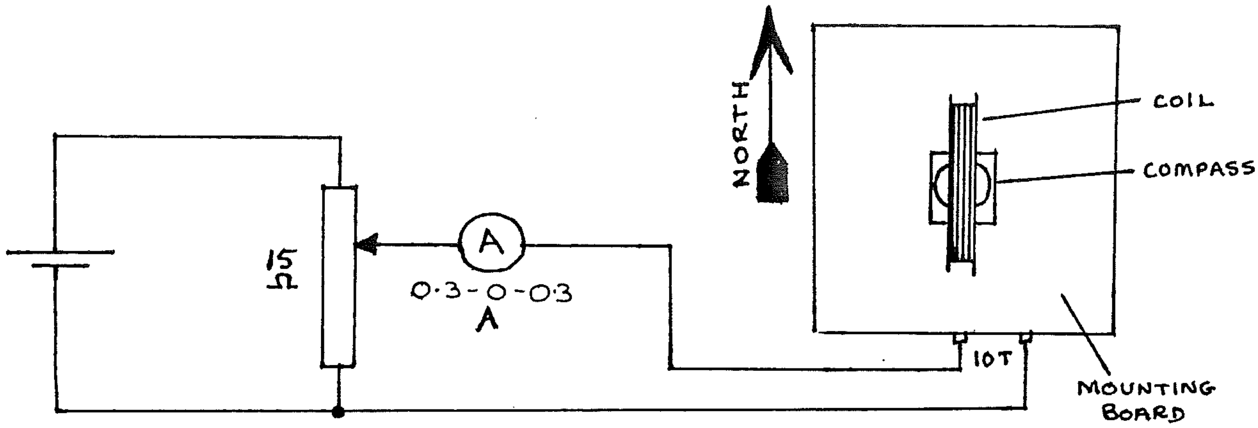
1 Use your measurements to find the magnetic flux density of the magnet for each value of I and then find an average value for B.

2 Explain why the end of the coil in the magnetic field is deflected down when the current is increased Use Advanced Level Physics by Nelkon and Parker (fourth edition), pp 775 and 776, or University Physics by Sears, Zamansky, and Young (fifth edition) pp 520 - 524 as a reference.

Measurement of the Horizontal Component of Earth's Magnetic Field.

APPARATUS

1.5V Cell; 15Ω rheostat (approx.); galvanometer with shunt for 0.3-0-0.3 A; mounted coil; magnetic compass; 5 wires (3 long, 2 short); 0.5m ruler.



PROCEDURE

1. Set up the apparatus as above, but do not connect the battery. To avoid errors due to extra magnetic fields, the wires from the coil to the ammeter & rheostat should be long and twisted together. Arrange the compass accurately at the centre of the coil.

2. Turn the plane of the coil so that it lies accurately North-South (magnetic).

3. Connect the battery and adjust the rheostat until the compass needle points NW or NE (at exactly 45° to North). Read the ammeter.

4. Reverse the battery, and repeat step 3. Average the two readings of current.

5. Measure the coil across several diameters. Average these readings and thus find the average radius of the coil.

THEORY

There are two forces acting on the compass needle:

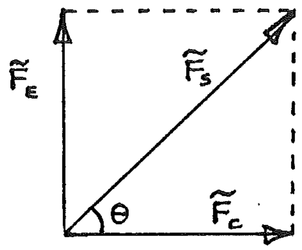
$\tilde{F}_E$ due to the Earth's magnetic field

$\tilde{F}_C$ due to the magnetic field of the current.

The compass needle points along the direction of the vector sum of these two forces.

When $F_C = 0$, the needle points North, along $\tilde{F}_E$.

When $F_C \neq 0$, then the needle points along the sum $\tilde{F}_S$, as shown on the vector diagram:



VECTOR DIAGRAM

From the diagram, when $\theta = 45°$, $F_E = F_C$. In this case, the magnetic fields of the coil current and the Earth are equal. The field produced by the coil current can be calculated from:

$$B = \frac{\mu_0 N I}{2 r}$$

B = magnetic field (tesla, T)
$\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}
N = number of coil turns
I = current (A)
r = coil radius (m)

And in the experiment this has the same value as the horizontal component of the Earth's magnetic field.

ANALYSIS

1. Calculate the horizontal component of the Earth's magnetic field.

2. Draw a diagram of the Earth showing the magnetic lines of force.

3. Use the diagram to explain why the experiment measures the horizontal component of the field. (Hint: consider the difference if the experiment is done first in Tanzania, then in Canada).

4. If in the experiment, the electric current is doubled, calculate the angle (from magnetic North) along which the compass needle points.

Self Inductance in AC Circuits

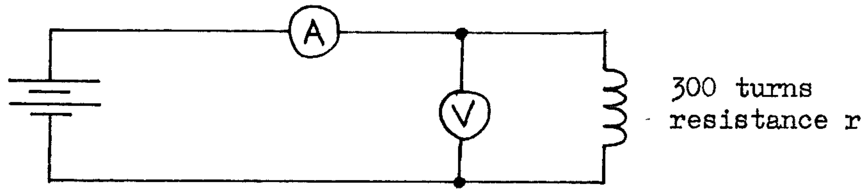
NB: This experiment requires mains electricity.

APPARATUS

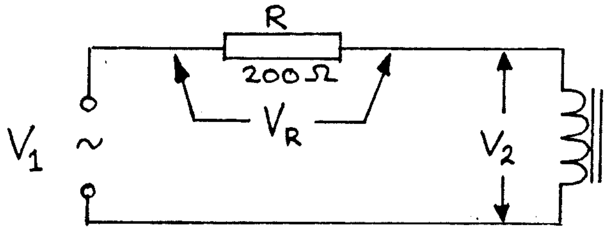
300 turn coil; 2 iron C - cores; C - core clip; ammeter (0 - 1 Adc); voltmeter (0 - 5 Vdc); battery (3V); 2 x 100Ω resistors; CRO (oscilloscope); AC power supply; 0.5m ruler; connecting leads (5 short); 1 sht graph paper.

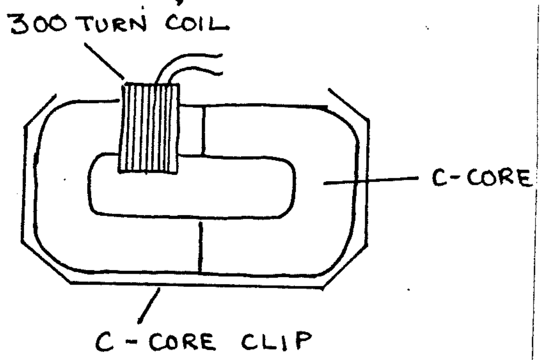
PROCEDURE

1. To find the resistance r of the coil. Connect the following circuit and use the readings to calculate r :

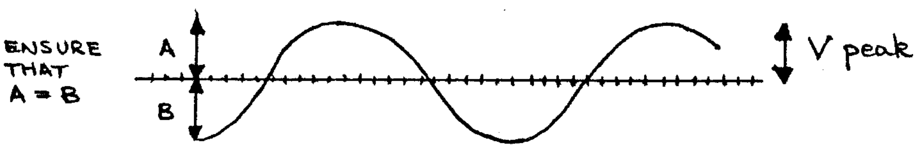


2. To find the inductance L of the coil with an iron core, connect the following circuit:





a) Connect the CRO input to V_1. Adjust the power supply so that V_1 is about 4V, the supply being switched to AC. Adjust the CRO so that the AC waveform is clearly seen:



Now carefully adjust the power supply so that the peak value of V_1 as seen on the screen is 4V peak.

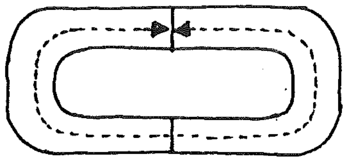
b) Now connect the CRO to measure V_R peak. Use this, and the value of R to calculate the value of I peak for the circuit.

c) Use the CRO to measure V_2 peak.

d) Repeat a), b), and c), but using V_1 of 3.5, 3, 2.5, 2, 1.5, 1, 0.5, and 0 volt peak each time.

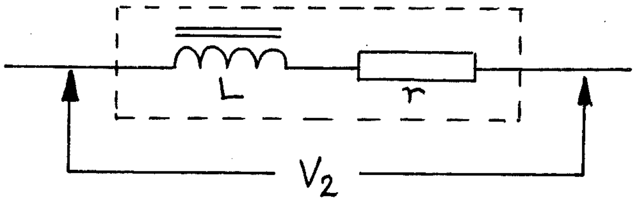
e) Tabulate the values of V_R peak, V_2 peak, and I peak.

f) Measure the cross - sectional area of the iron core and the distance l around the centre of the pair of cores as shown below:



THEORY

The coil with its iron core has an inductance L, and the copper wire of the coil has a resistance r. An equivalent circuit for the coil is:



The impedance of this combination of r and L is given by:

$$Z = \sqrt{r^2 + \omega^2 L^2} \qquad \text{equation 1}$$

Where $$Z = \frac{V_2 \text{ rms}}{I \text{ rms}} = \frac{V_2 \text{ peak}}{I \text{ peak}} \qquad \text{equation 2}$$

and $$\omega = 2\pi f$$

It is also possible to calculate L using data about the coil and its core:

$$L = \frac{\mu_o \mu_r N^2 A}{l} \qquad \text{equation 3}$$

Where $\mu_o = 4\pi \times 10^{-7}\ Hm^{-1}$

μ_r = relative permeability of the iron

N = number of coil turns

A = core cross - sectional area

l = distance around core

ANALYSIS

1. Plot a graph of V_2 peak against I peak, and find the gradient.
2. Use the gradient and equation 2 to find the value of Z.
3. Use equation 1 to find the inductance of the coil, L.
4. Use this value of L, together with the other measured values, and equation 3, to find the relative permeability of this type of iron, μ_r.
5. Look up values of μ_r for different types of iron in a data book (eg Nelkon & Parker), and try to deduce the type of iron alloy used in your iron cores.

QUESTIONS

1. Use the values of R, r, and L above to calculate the current I peak, if V_1 = 8 V peak, and f = 1 kHz.
2. Use equation 3 to estimate L if the iron core is removed. Show that in this case $Z \approx r$. Repeat Q1 using L for the coil without an iron core.
3. Briefly explain the energy changes in r and L when:

   (i) The current is + and rising
   (ii) The current is a maximum +, and constant
   (iii) the current is + and falling

4. How can an inductor be constructed so that power losses are kept to a minimum ? (consider both the design of the coil and the core).
5. Why is it desirable to keep power losses to a minimum in an inductor used in the tuning circuit of a radio reciever ?
6. Prove that: $$\frac{V_2 \text{ rms}}{I \text{ rms}} = \frac{V_2 \text{ peak}}{I \text{ peak}}$$ (from equation 2)

   Why in the experiment is V peak measured rather than V rms ?
7. Sketch on the same graph curves of V and I for an inductor (with r = 0) which is connected to an AC power supply.
8. Explain carefully why V_1 peak $\neq$ V_R peak + V_2 peak .

Mutual Inductance : Transformers

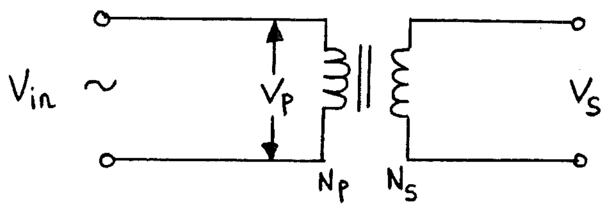
NB: This experiment requires mains electricity. Students are advised to perform experiment F6-1 Self Inductance before attempting F6-2.

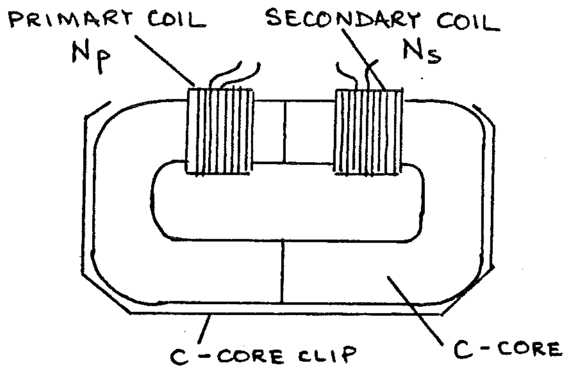
APPARATUS

Coils 300 turns & 150 turns; wire for 20 turn & 10 turn coils; 2 iron C - cores; C - core clip; 10 Ω and 5 Ω resistors; CRO (oscilloscope); AC Power supply; connecting leads (5 short).

PROCEDURE

1. Construct the following :





a) Using N_p = 150 turns, N_s = 10 turns. Measure and set $V_{in} = V_p$ = 4V peak. Measure V_s peak. Calculate V_p / V_s and N_p / N_s and compare their values.

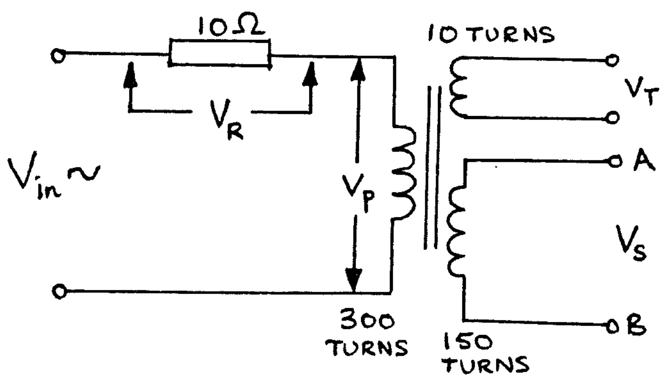
b) Repeat a) with the following numbers of turns :

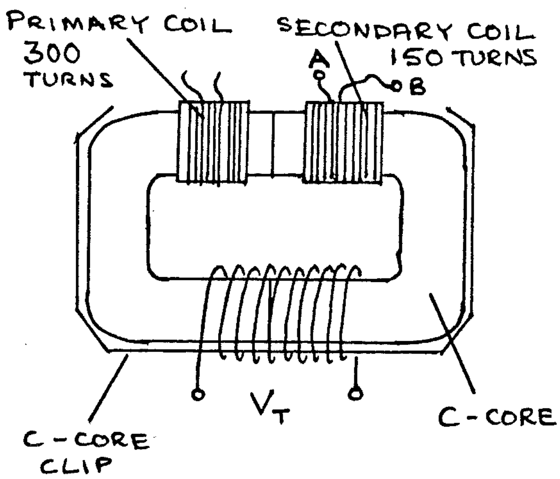
N_p	N_s
150	20
300	150
150	300

c) Keeping N_p = 150 turns and N_s = 300 turns, reduce $V_{in} = V_p$ to 2V peak. Measure V_s peak, and calculate and compare V_p / V_s and N_p / N_s .

d) Remove the clip from the iron cores, and remove one C - core. Place the two coils as in c), one on each arm of a single C - core. Set $V_{in} = V_p$ = 4V peak. Measure V_s.

2. Construct the following with N_p = 300 turns, N_s = 150 turns, and an extra test coil of 10 turns as shown





a) Connect the CRO to measure V_p peak, and set V_{in} so that $V_p = 4V$ peak.

b) Measure V_R peak, and thus calculate I_p peak, the current in the primary circuit.

c) Measure V_T peak, across the 10 turn test coil.

d) Connect a $5\,\Omega$ resistor between A and B, across the 150 turn secondary coil. Connect the CRO to measure V_p and adjust V_{in} so that $V_p = 4V$ peak.

e) Measure V_R peak, and thus calculate I_p peak.

f) Measure V_T peak again. This should be about the same size as the value measured in c) above.

THEORY

1. Flux Φ and induced emf E are related by the following:

$$E_p = -N_p \frac{d\Phi_s}{dt} \quad \text{equation 1A, and} \quad E_s = -N_s \frac{d\Phi_p}{dt} \text{ equation 1B}$$

When Φ_s , the flux through the secondary coil = Φ_p , the flux through the primary coil (unit weber, Wb),

$$\text{Then} \quad \frac{d\Phi_s}{dt} = \frac{d\Phi_p}{dt} \quad \text{therefore} \quad \frac{E_s}{N_s} = \frac{E_p}{N_p}$$

$$\text{Thus} \quad \frac{E_p}{E_s} = \frac{N_p}{N_s}$$

If the resistances of the primary coil and the secondary coil are both low and the currents flowing through them are not too large, then:

$$V_p \approx E_p \quad \text{and} \quad V_s \approx E_s$$

2. The 10 turn coil is used to detect if the flux Φ in the iron core changes in the experiment. If $\Phi = \Phi_{peak} \sin\omega t$, then equation 1B can be used to show that V_T peak $\propto \Phi_{peak}$, provided that ω is constant.

ANALYSIS

1. Why, in experiment 1 a) to c), are the two ratios calculated not exactly equal? (Hint: use the theory, and the fact that the primary coil has some resistance).

2. Use the theory to explain the result of 1 d)

3. According to Lenz's Law, the induced current in the secondary coil in the experiment part 2 d) is in such a direction so as to reduce the flux in the core. However part 2 f) shows that the flux remains approximately constant. How is this possible ? (Hint : consider the primary coil).

4. Give an explanation in terms of power flow for the change in I_p produced as a result of connecting the $5\,\Omega$ resistor to the secondary coil.

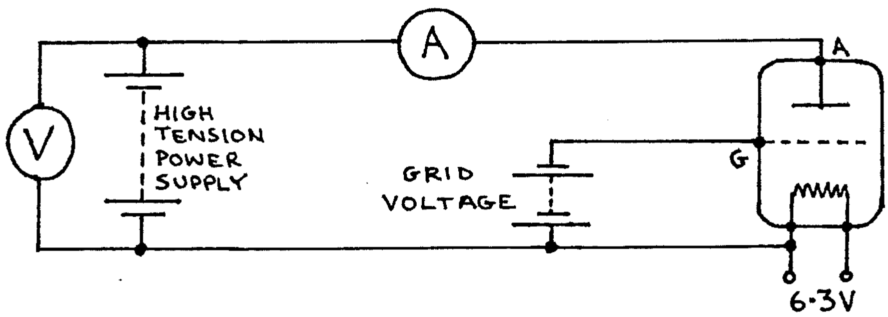
6. a) What are the causes of power loss in a transformer, and how can they be minimised ?

   b) All Electricity Supply Companies use transformers in their power distribution systems. Explain, giving reasons, how they are used.

Measuring Triode Characteristics

Apparatus

DC power supply 0 - 800V, voltmeter 0 - 800V, cathode heater circuit (in power supply), planar triode (TEL 521), 6 dry cells as grid voltage source, sensitive ammeter 0.01 - 0.8mA, 9 connecting wires, 2 sheets of graph paper



Procedure

1. Check the circuit to see it agrees with the drawing above. The power supply is off. Always be certain the power supply is off before you change circuit connections. Failure to do this may cause injury or damage to the equipment.

2. Set the grid voltage at -9V (six dry cells in series). Set the power supply dial at zero. Turn on the power supply and slowly increase the anode potential by turning the power supply dial until the voltmeter shows 100V. Record anode potential, V_a, and anode current, I_a, for V_a = 100, 200, 300, 400, 500, and 600V. NOTE the ammeter while you increase the anode potential. If the ammeter goes off scale STOP increasing the potential difference and go on to the next step. Turn the power supply off.

3. Change the grid potential, V_g, to - 6V then repeat procedure (2.).

4. Change V_a to $-4.5V$ and repeat procedure (2.).

5. Change V_a to $-3V$ and repeat procedure (2.).

6. Change V_a to $-1.5V$ and repeat procedure (2.).

7. Make 5 more data tables of V_g and I_a, with V_a constant. Use the data from the procedure above for V_a = 100, 200, 300, 400, and 500V.

Observations

5 tables of I_a and V_a, V_g constant

V_g = ___V

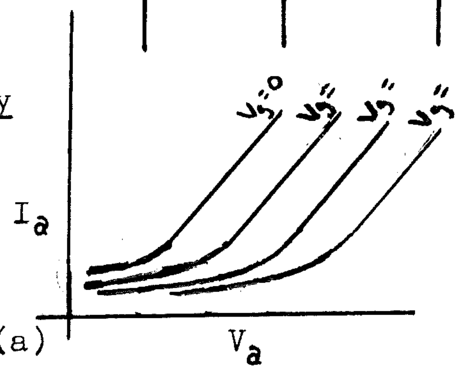
I_a mA	V_a volts

5 tables of I_a and V_g, V_a constant

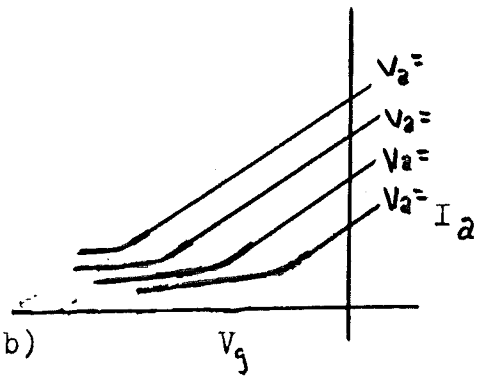
V_a = ___V

I_a mA	V_g volts

Theory



(a)



(b)

From the slope of the linear part of graph (a) the anode resistance is:

$$R_a = \frac{\delta V_a}{\delta I_a} \quad \text{when } V_g \text{ is constant}$$

From the linear part of graph (b) the mutual conductance, g_m, is:

$$g_m = \frac{\delta I_a}{\delta V_g} \quad \text{when } V_a \text{ is constant}$$

The amplification factor, μ, can be found by comparing V_a

and V_g over similar intervals of I_a on the graphs.

$$\mu = \frac{\delta V_a}{\delta V_g} \text{ over the same interval } I_a$$

Or:

$$\mu = g_m R_a$$

Analysis

1. Plot I_a against V_a for all values of V_g on the same axes.

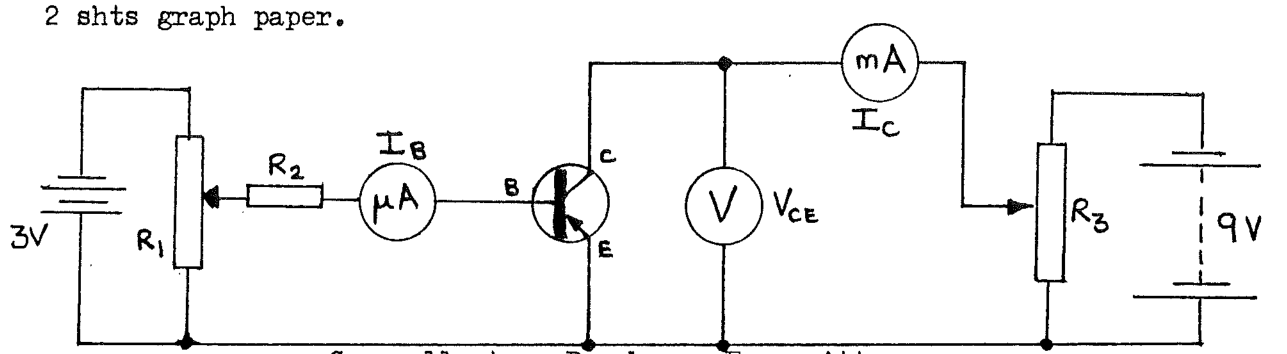
2. Plot I_a against V_g for all values of V_a on the same axes.

3. From your graphs find R_a, g_m, and μ.

Transistor Characteristics

APPARATUS

3V battery; 9V battery; 2 rheostats (high resistance); resistor R_2 (approx. 50 kΩ); voltmeter (0-5 Vdc); ammeter (approx 50 μA fsd); ammeter (approx 3 mA fsd); transistor (pnp); connecting leads (12 short); 2 shts graph paper.



C = collector, B = base, E = emitter.

INSTRUCTIONS

Set up the circuit as above, but do not connect the batteries until a teacher has checked the circuit (to avoid damaging the ammeters or transistor). In the experiment, when not taking readings, leave the batteries disconnected.

EXPERIMENT 1

To investigate the ' transfer characteristics ' of the transistor. The transistor acts as a current amplifier: the size of the large current I_C depends on the size of the small current I_B. The circuit used above is called a ' common emitter ' circuit.

EXPERIMENT 1: PROCEDURE

1. Set V_{CE} to 4V using rheostat R_3. Ensure that this remains constant (adjust R_3 again later as necessary).
2. Set I_B to 0 using R_1. Read and note I_B and I_C .
3. Increase I_B a little using R_1, and read and note I_B and I_C . Continue increasing I_B and reading the ammeters until I_C = 3 mA.
4. Tabulate the readings of I_B, I_C, and the value of V_{CE}.

EXPERIMENT 1: ANALYSIS

1. Plot a graph of I_C against I_B, labelling the curve with the value of V_{CE} used.
2. Find the gradient of the straight-line section of the curve.

Then Current Gain $\beta = \dfrac{\Delta I_C}{\Delta I_B}$ = gradient.

EXPERIMENT 2

To study how I_C varies when V_{CE} is changed, for certain fixed values of I_B. The graph obtained is called the 'output characteristic' of the transistor.

EXPERIMENT 2: PROCEDURE

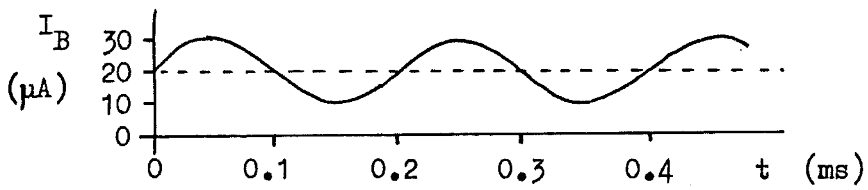
1. Set $I_B = 0$ using R_1 . Starting with $V_{CE} = 0$, and little by little increasing V_{CE} up to 5V, take a set of readings of I_C and V_{CE}, and note the value of $I_B = 0$.
2. Increase I_B to 10 µA, and obtain another set of readings of I_C and V_{CE} as in step 1.
3. Repeat the procedure with I_B = 20 µA then 30 µA.
4. Tabulate the sets of readings of I_C and V_{CE}, noting the value of I_B for each set.

EXPERIMENT 2: ANALYSIS

Plot a graph of I_C against V_{CE} , to obtain four curves. Label each curve with the appropriate value of I_B used.

QUESTIONS

1. When $I_B = 0$, I_C should be zero for all V_{CE}. However all transistors have some 'leakage current'. What is the value of the leakage current I_C when V_{CE} = 4V ?
2. What is the approximate minimum V_{CE} so that a variation in I_B between 0 and 30 µA produces a large change in I_C ? (In practice the supply voltage is usually set to between this value and a certain maximum. The maximum depends on the 'breakdown voltage' of the junctions).
3. In use as an amplifier, an AC input voltage makes I_B vary with time: For example:



   (i) Use the value of β to make a graph of I_C against time.
   (ii) If a resistor R = 1 kΩ is connected in series with the collector C, so that I_C flows through it, draw a graph of the pd across this resistor against time.
   (iii) What is the frequency of these AC currents and pd ?
4. Draw a diagram to show, when the pnp transistor is conducting:
   (i) Electron flows and conventional currents through the three terminals.
   (ii) Electron & hole movements inside the transistor (may be simplified).

Radioactive Decay

APPARATUS

About 200 small cubes, marked ⊡ and ⧈ on two faces; two trays; 2 × 500ml beakers; periodic table of the elements; 2 shts. graph paper.

INTRODUCTION

In this model of radioactive decay, the cubes represent atoms. They are either parent (undecayed) atoms or daughter (decayed) atoms. When a cube is thrown at random, if a certain face of the cube faces up, then the atom has decayed.

DECAY MODEL 1 (uses 1 tray & 1 beaker only)

Reaction: $$\underbrace{{}^{12}_{5}B}_{\text{in the tray}} \rightarrow \underbrace{{}^{A}_{Z}X + \beta^-}_{\text{discarded}}$$

1. Count the cubes. This is number N_0, the number of parent atoms of ${}^{12}_{5}B$ at time t = 0.

2. Place all the cubes in a beaker and empty the beaker into a tray. Shake the tray until all the cubes lie flat (do not touch any cubes).

3. Each time you empty a beaker into a tray, 0.01s has elapsed. Record the time t = 0.01s. Discard cubes showing ⊡ or ⧈ (these are atoms of ${}^{A}_{Z}X$, the daughter atoms). Count and record the number N of cubes left in the tray.

4. Place the cubes now in the tray into the beaker. Empty the beaker into the tray and shake as before. Record t = 0.02s. Discard decayed atoms. Record the new number N of cubes left in the tray.

5. Continue for t = 0.03, 0.04, 0.05, ... 2.5s, or until N = 0.
6. Tabulate your readings as follows:

t /s	0	0.01	0.02	0.03			
N	N_0 =						

etc.

ANALYSIS

1. Plot a graph of N against t. From the graph find the half life $T_{1/2}$.

2. Using the formula : $\frac{dN}{dt} = -\lambda N$, calculate the decay rate when t = 0. (λ is given by $\ln 2/T_{1/2}$).
   Find the graph's gradient at time t = 0; is this the same (approx) as the calculated value ?

3. On the same sheet of graph paper, plot another curve showing the number of daughter atoms.

4. Find A, Z, and X. Is this atom stable ?

DECAY MODEL 2 (uses 2 trays & 2 beakers)

In this experiment, tray #1 contains $^{227}_{90}Th$ atoms, and tray #2 contains $^{A1}_{Z1}X$ daughter atoms. These daughter atoms decay again and are discarded.

Reactions: $^{227}_{90}Th \rightarrow {}^{A1}_{Z1}X + \alpha$ Half life $T_{1/2}$

$^{A1}_{Z1}X \rightarrow {}^{A2}_{Z2}Y + \alpha$ Half life 11.7days.

1. Place all the cubes into tray #1, count them, and record number N_0 at time t = 0. Record for tray #2 that N_0 = 0 at t = 0.

2. Place tray #1 cubes into beaker #1, return to tray #1 and shake tray to settle the cubes. Move cubes showing ▣ into tray #2. Record N for tray #1 and tray #2 at this time t = 5 days.

3. FIRST: Place cubes from tray #2 into beaker #2. Return to tray #2 and shake. Discard cubes showing ▣ .

   SECOND: Place cubes from tray #1 into beaker #1. Return to tray #1 and shake. Move cubes showing ▣ to tray #2.

   THEN: Count and record N for trays #1 and #2 at t= 10 days.

4. Continue repeating step 3., letting t = 15, 20, 25, ... up to 200 days. (Each time you perform step 3., t advances by 5 days).

5. Tabulate your readings as follows :

t /days		0	5	10	15	20	25	
tray #1	N	N_0 =						
tray #2	N	N_0 = 0						

etc.

ANALYSIS

1. On the same piece of graph paper plot N against t for trays #1 and #2, to obtain two curves.

2. Using the #1 curve, find $T_{1/2}$ for $^{227}_{90}Th$. Calculate λ and thus find N at t = 40 days (use $N = N_0 e^{-\lambda t}$). Check that the value of N at t = 40 days is about the same, using the graph, and note this value.

3. Explain carefully why the curve #2 has the shape that it does.

4. Use the reaction equations given above to determine A1, Z1, X and also A2, Z2, and Y.

QUESTIONS

1. ${}^{A2}_{Z2}Y$ is unstable and decays. There follows a whole series of decays, ending with a stable atom, as follows:

${}^{A2}_{Z2}Y$	$\rightarrow$	?	+	α	$T_{1/2} = 3.92s$
?	$\rightarrow$	?	+	α	$T_{1/2} = 1.8 \times 10^{-3}s$
?	$\rightarrow$	?	+	β^-	$T_{1/2} = 36.1$ min
?	$\rightarrow$	?	+	α	$T_{1/2} = 2.15$ min
?	$\rightarrow$	?	+	β^-	$T_{1/2} = 4.8$ min.

Write down the above set of reactions, deducing each of the ?s, giving atomic mass, atomic number, and symbol in each case.

2. A sample of ${}^{227}_{90}Th$, when left for 30 days, is found to contain a lot of ${}^{227}_{90}Th$, ${}^{A1}_{Z1}X$, and the final, stable, isotope, but very little of ${}^{A2}_{Z2}Y$ and the four intermediate isotopes. Why ?

3. Draw an A-Z Map to illustrate the complete series of seven decays from ${}^{227}_{90}Th$ to the stable isotope.

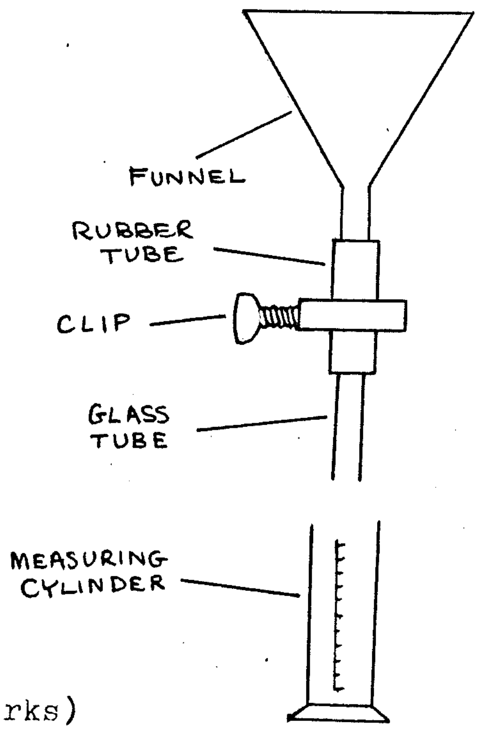
Surface Tensions by Rayleigh's Formula. Time $1\frac{1}{2}$ hr.

APPARATUS

Beaker of liquid A, beaker of liquid B, stand and clamp, funnel, rubber tube, clip, glass tube, measuring cylinder, graph paper, stopclock, small empty beaker, beam balance

You are required to determine the surface tensions γa of liquid A and γb of liquid B. Proceed as follows:

Set up the apparatus shown in figure 2. With the clip closed, fill the funnel with the liquid A. Adjust the gripping of the clip so that the rate of issuing of the drops at the lower open end is between 20 and 30 drops per minute initially. When making the adjustments the drops may be collected in the measuring cylinder.



Starting with a convenient reading V_0 of the volume of liquid already collected in the measuring cylinder, observe the new volume V of the liquid in the measuring cylinder when a known number n of drops has been collected. Without losing the sequence of count of n, observe six series of pairs of V and n. Tabulate your observations.(6 marks)

Plot a graph of $V - V_0$ (vertical axis) against n (horizontal axis).(18 marks)

Assuming that the drops are spherical determine from the resulting graph the diameter d and the mass m_a of one drop. Hence using Lord Rayleigh's formula

$$m_a = \frac{1.9\, d\, \gamma a}{g}$$

where g is the acceleration due to gravity which may be taken as $9.8\,ms^{-2}$, calculate γa. You may assume that the density of the liquid A is $1.0\,g\,cm^{-3}$. (10 marks)

Now empty the entire apparatus and refil it with the liquid B. Adjust the rate of flow as before. Collect 20 drops of the liquid B into the small beaker which you should first weigh empty. Reweigh the beaker and contents so as to obtain the mass of 10 drops of the liquid. From your observations determine the mass m_b of one drop. (6 marks)

Calculate the surface tension of the liquid B given, as before,

$$m_b = \frac{1.9\, d\, \gamma b}{g}$$

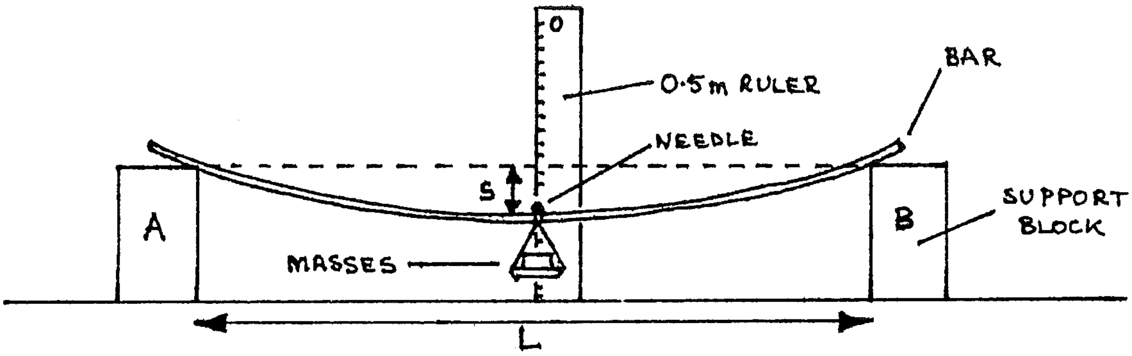
where g and d have the same values as above. (10 marks)

Young's Modulus by Bar Bending
Time: 1½ hr.

APPARATUS

Wooden bar (thin metre rule is suitable); supporting blocks; 0.5m rule held by clamp & stand; needle & plasticene; scale pan with loop; 3 X 100g and 1 X 50g masses; 1 sht. graph paper.

The aim of this experiment is to determine the Young's Modulus of the material of the bar. Proceed as follows:



(a) Place the wooden bar symmetrically on the supports A and B. Keep the distance L between the blocks about 90cm. Record the distance L, and this should not be changed during the experiment; also ensure that the protruding lengths of the bar are equal. The vertical metre rule should be placed in line with the centre of the bar. The pointer needle is attached to the bar at its centre. Record the pointer reading on the vertical metre rule when the bar is unloaded, and call this reading X_0. (2 marks)

With mass m, say 50g, on the scale pan, record the resulting pointer reading X on the vertical metre rule, and hence determine the sag, $s = X - X_0$. Repeat this procedure for 5 other readings of m (see diagram) (10 marks)

(b) Measure the breadth b and thickness d of the bar. (8 marks)

(c) Plot a graph of m against s. (10 marks)

(d) Calculate the Young's Modulus, E, of the bar given that:

$$E = \frac{g L^3 m}{4 b d^3 s}$$ (11 marks)

(e) (i) State any sources of errors and precautions taken in this experiment. (5 marks)

(ii) Determine the order of accuracy of your results. (4 marks)

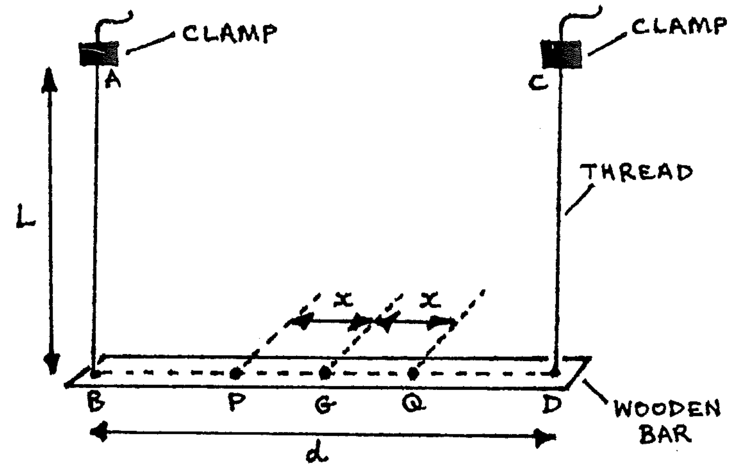
$(g = 9.8 \text{ ms}^{-2})$

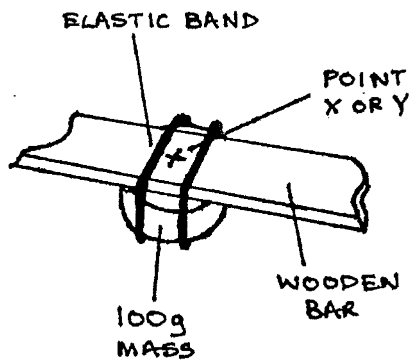
Moment of Inertia of a Bar
Time: $1\frac{1}{2}$ hr.

APPARATUS

Bifilar pendulum (wooden bar or metre rule with holes 0.5cm from ends); 2 threads ($\approx$ 1.2m long); 2 $\times$ 100g masses (shape: ); 2 elastic bands; metre rule; stopclock; 2 clamps & stands; 2 G-clamps; piece of chalk; 1 sht. graph paper. (OPTIONAL: spirit level).

The aim of this experiment is to determine the moment of inertia I of a wooden bar acting as a bifilar pendulum. Proceed as follows:





(a) Determine the centre of mass G of the wooden bar, and draw the horizontal axis of the bar (from B, through G, to D).

(b) Using the pieces of thread provided, suspend the wooden bar as shown above, such that L = d = CD $\approx$ 100cm. Measure and record L and d. (2 marks)

(c) Make adjustments so that the bar is horizontal.

(d) Measure distance x = 5cm from each side of G to the variable positions P and Q as shown above.

(e) Place the 100g masses at positions P and Q simultaneously. Set the wooden bar oscillating about a vertical axis through G. Record the time t for 10 complete oscillations and calculate the corresponding periodic time T. (2 marks)

(f) Move the 100g masses along the wooden bar at increasing distance x in intervals of 5cm from each side of G. At each stage measure the time t for 10 complete oscillations and determine the corresponding periodic time T. Tabulate your results. (10 marks)

(g) Plot a graph of T^2 (vertical axis) against x^2 (horizontal axis). **(marks: table 3, graph 12)**

(h) Given that:

$$T^2 = \frac{16\pi^2 IL}{(M+m)\,g\,d^2} + \frac{16\pi^2 m\,L\,x^2}{(M+m)\,g\,d^2}$$

Use your graph to determine I and M; where L and d are expressed in SI Units and g = 9.81 ms^{-2}. m = 0.2 kg. What does M represent ?

(marks:
use of graph 3,2
I and M 10
M ? 2)

(i) Mention any precaution(s) that you took in performing this experiment. (4 marks)

Relative Density of a Liquid

Time: $1\frac{1}{2}$ hr.

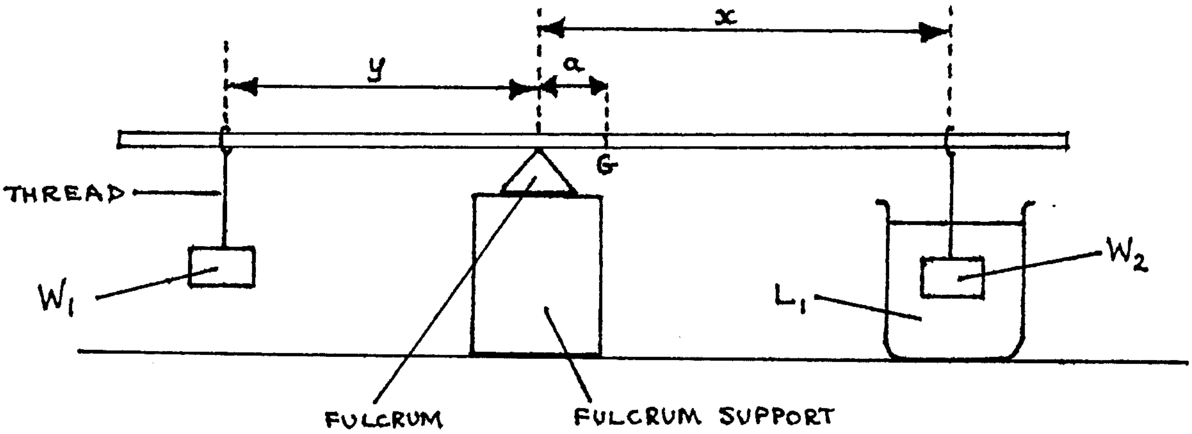
APPARATUS

Metre rule; thread ($\approx$ 50cm); fulcrum (eg prism); fulcrum support (height $\approx$ 10cm); L_1 200ml water in 250ml beaker; L_2 200ml motor oil in 250ml beaker (or kerosene); W_1 50g mass (metal); W_2 20g mass (plastic or rubber); piece of chalk; 2 shts. graph paper.

In this experiment you are required to determine the density of liquid L_2 relative to that of liquid L_1, and find the mass M of the metre rule provided. Proceed as follows:

(a) Locate and mark the centre of gravity G of the metre rule.

(b) Set up the apparatus as illustrated below, where a = 5cm, W_1 and W_2 are masses of 50g and 20g respectively.



(c) With W totally immersed in liquid L_1 and x = 10cm, balance the metre rule by adjusting the position of W_1. Read and record distance y. Repeat the process for x = 20cm, 30cm, 40cm, 50cm, and 54cm. Tabulate the values of x and y. (7 marks)

(d) Replace liquid L_1 by liquid L_2 and then repeat the procedure outlined in (c) above. (7 marks)

(e) Plot a graph of y against x using the table obtained in (c) (8 marks)
  (i) Read and record I, the value of y when x = 0. Calculate 10I, which is equal to the mass of the metre rule. (4 marks)
  (ii) Find the slope S_1 of the graph. (4 marks)
  (iii) Find the value of λ_1 given that $\lambda_1 = 0.4 - S_1$. (2 marks)

(f) Plot a graph of y against x using the table obtained in (d). (8 marks)
  (i) Find the slope S_2 of this graph. (4 marks)
  (ii) Find the value of λ_2 given that $\lambda_2 = 0.4 - S_2$. (2 marks)
  (iii) Evaluate the ratio λ_2/λ_1, which is equal to the density of liquid L_2 relative to that of liquid L_1. (4 marks)

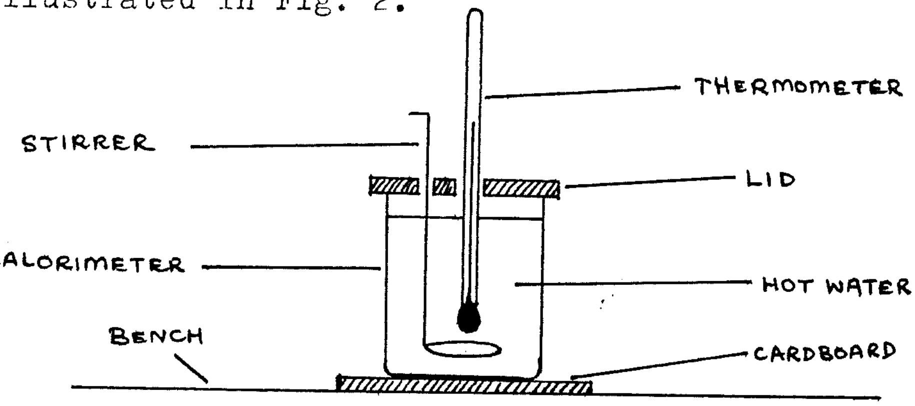
Surface Characteristics and Cooling. Time $1\frac{1}{2}$ hr.

APPARATUS

Copper calorimeter with lid, thermometer (0 - 100°C), stirrer, cardboard base, stopclock, kerosene or diesel burner, stand and clamp, graduated beaker, hot water, graph paper.

The aim of this experiment is to investigate how the nature of the surface of a calorimeter affects the rate of loss of heat. Proceed as follows:

(a) You are provided with a beaker which is nearly full of hot water and a polished copper calorimeter. Nearly fill the calorimeter with the hot water, whose temperature should initially be above 80°C, and set it up on the bench as illustrated in Fig. 2.



(b) Stir the hot water in the calorimeter constantly and record the temperature of the water after every 1.0 minute with the aid of a stop clock. Continue recording temperature θ in this way for 15 minutes and tabulate θ and time t. (6 marks)

(c) Empty the water in the calorimeter into a measuring cylinder and record the Volume V. Blacken the external surface of the calorimeter using smoke from the kerosene or diesel burner provided. Now pour volume V of hot water, whose temperature should initially be above 80°C, into the blackened calorimeter and again set it up on the bench as illustrated in Fig. 2.

(d) Repeat the procedure outlined in (b) above. (6 marks)

(e) Using the same axes, plot a cooling curve for the polished calorineter together with its contents and another cooling curve for the blackened calorimeter together with its contents. (18 marks

(f) If R_p represents the rate at which the polished calorimeter and contents lose heat and R_b represents the rate at which the blackened calorineter and contents lose heat, determine the ratio $\frac{R_p}{R_b}$ at:

(i) 78°C and
(ii) 70°C. Comment on your results.
(20 marks)

Newton's Law of Cooling
Time: $1\frac{1}{2}$ hr.

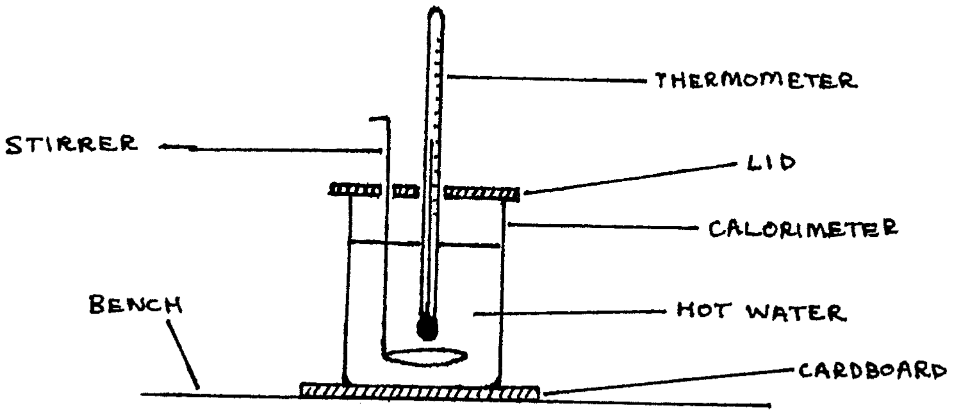
APPARATUS

Thermometer (0–100 °C); calorimeter (very small capacity), with lid & stirrer; cardboard base; stopclock; supply of boiling water; 2 shts. graph paper; clamp & stand.

The aim of this experiment is to investigate the manner in which a calorimeter containing hot water cools down.

PROCEDURE

Pour the boiling water into the calorimeter until it is about three-quarters full, and then set up the calorimeter as illustrated below. Carefully observe and record the temperature θ °C of the water inside the calorimeter after every two minutes. Continue the process while stirring the calorimeter until the temperature of the water drops to about 50 °C.



(i) Tabulate the values of θ (in °C) and the corresponding values of time t (in minutes), starting at t = 0. Also measure and record the room temperature θ_R. (Marks 8,4)

(ii) Plot the cooling curve for the calorimeter and its contents using the table in (i) above. (10 Marks)

(iii) Choose six points (θ, t) along the curve in (ii) above and at each point draw the tangent to the curve and then determine the gradient G of the curve at that point. Calculate and record the excess temperature ($\theta - \theta_R$) corresponding to each of the six points chosen. Hence make up a table that consists of values of G as well as corresponding values of ($\theta - \theta_R$). (Marks 3,6,3)

(iv) Using the results in (iii) above, draw a graph of 'Rate of cooling' against 'Excess temperature'. (10 Marks)

(v) Compare the results in (iv) above with Newton's Law of Cooling and make any relevant comments. (6 Marks)

Resistivity, Using a Wheatstone Bridge

Time: $1\frac{1}{2}$ hr.

APPARATUS

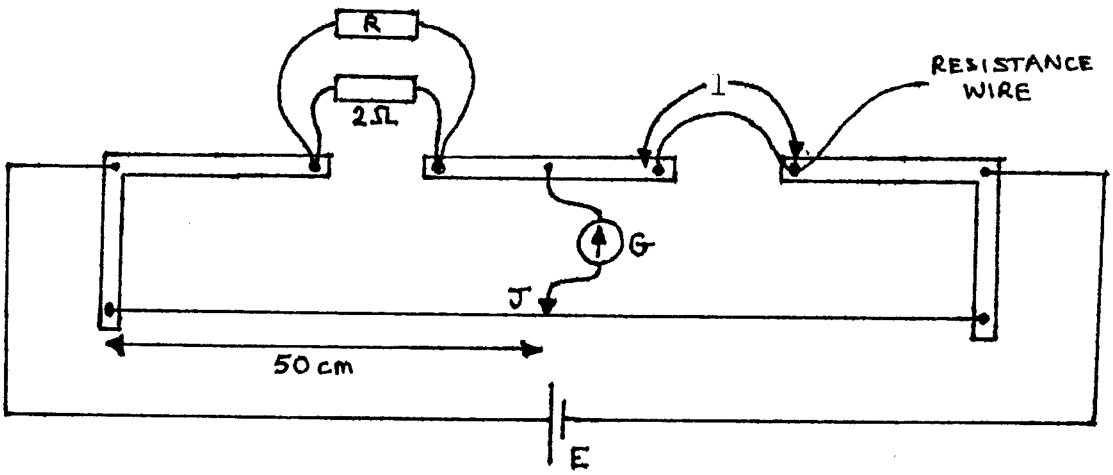
Metre bridge & jockey; resistance wire (length ≈1m, resistance ≈2Ω but not less); metre rule; resistors (0.5Ω, 1 Ω, 2 × 2 Ω, 5Ω, 10Ω, 20Ω); 1.5V cell; galvanometer; 4 connecting leads (3 long, 1 short); 1 sht. graph paper; micrometer.

The aim of this experiment is to determine the electrical resistivity of the wire provided. Proceed as follows:

(a) Set up a slide-wire metre bridge as illustrated below where E is a cell, G is a galvanometer, length l of the resistance wire is connected across the right-hand gap of the bridge, and the jockey or slider J is placed at the 50cm mark.

(b) With R = 20Ω, find the value of length l for which the galvanometer gives zero deflection when the slider is tapped onto the 50cm mark as shown below. (2 Marks)

(c) Repeat the procedure in (b) for values of R equal to 10Ω, 5Ω, 2Ω, 1Ω, and 0.5Ω. (8 marks)



(i) Calculate and tabulate the values of 1/R and 1/l for the values of R = 20Ω, 10Ω, 5Ω, 2Ω, 1 Ω, 0.5Ω obtained in (b) and (c) above. (7 marks)

(ii) By means of the micrometer screw gauge provided, measure the diameter of the resistance wire, and hence calculate its average diameter d. (5 marks)

(iii) Plot a graph of 1/R against 1/l (whose values are recorded in (i) and determine the gradient. (12,5 marks)

(iv) Determine the resistivity ρ of the resistance wire given that

$$\frac{1}{R} = \frac{A}{\rho}\frac{1}{l} - \frac{1}{2}$$

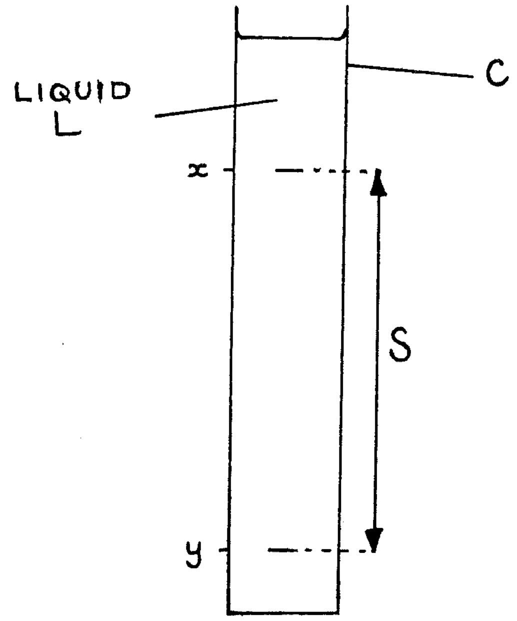
Where A is the cross-sectional area of the resistance wire. (4,7 marks)

APPARATUS

Tall burette (250ml) or 500ml measuring cylinder; 4 steel ball bearings of different diameters (between 0.2 and 0.65cm); micrometer screw gauge; liquid L; ruler; stopwatch; strong magnet; forceps; thermometer (0–100°); clamp and stand (if burette is used only); 2 small dishes; note giving values of ρ_1 and ρ_2; graph paper.

The aim of this experiment is to determine the viscosity of liquid L. Proceed as follows:

(a) Set up the apparatus as shown in Fig. 1 with burette C nearly filled with liquid L.



(b) Determine and write down the diameters of all the steel ball bearings using the micrometer screw gauge. Then wet all the balls with the liquid L by keeping them in a small dish containing the liquid. (8 marks)

(c) By using the forceps, drop the balls one by one in the liquid. Measure and record the time taken by each ball to fall the distance S between points x and y in the liquid. The point x should be chosen such that the distance from the meniscus of the liquid to x is at least 7cm. The point y should be at least 20cm away from x. Measure and record the distance S with a ruler. The bar magnet may be used to pull out the balls from the liquid L in the burette.

Make a table of results and tabulate the following: Average diameter (d) of each ball in cm, the square of the radius (r^2) of each ball in cm^2, the average terminal velocity v of each ball in cms^{-1}. Record the room temperature. (marks : t 8, s 2, r^2 2, v 4)

(d) Plot a graph of r^2 against v and draw the best line through the points. Calculate the slope of the graph. (marks 10, 3)

(e) Determine the viscosity η in SI units of liquid L using the relation:

$$\eta = \frac{2g}{9}(\rho_1 - \rho_2)\frac{r^2}{v}$$

where ρ_1 is the density of the steel balls, ρ_2 is the density of liquid L, and g (= 9.8ms^{-2}) is the acceleration due to gravity. (6 marks)

(f) Give the SI units of η and state any sources of errors in your experiment. (marks 2, 5)

Further Description of Apparatus for Teachers and Technicians

PRACTICAL EXERCISES

A1-1 A large model of a vernier scale can help students.

A1-2 Ensure that the books supplied to students contain all the required information.

B1-1 None

B1-2 Unknown mass should be about 250g.

B3-1 Height 'PR' should not exceed 10cm to avoid sliding of the axel.

B5-1 Stick should be about 1.2m long with 16 equally spaced holes.

B5-2 A spring of mass 6g will have an effective mass, m, of 2g. For a larger spring the effective mass will be greater.

B5-3 None

C1-1 Sulfuric acid and caustic soda are suitable dilute acid and alkaline.

C2-1 Other liquids, for example kerosene, may be tried but will rot the rubber tubing.

C3-1 Expected value for the Young's modulus along the grain is about 10GPa.

C3-2 Magnifying glass is to help see the vernier scale. An old callipers glued to a wood strip make a good mounted vernier scale.

C3-3 Ensure that the books supplied contain the required information. Supply the students with a box of many different materials which may be tested to destruction and a seperate box of materials to be tested labled 'Do not damage' containing samples to be kept intact.

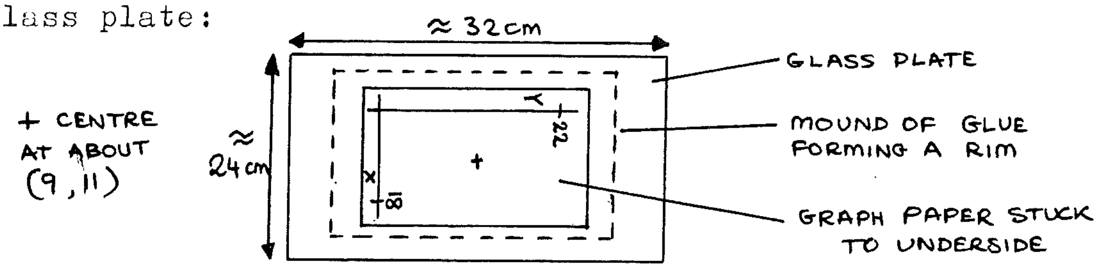
D1-1 The expansion sample is a hollow tube mounted in large metal blocks. Screws 1 and 2 fix the sample in the blocks. Screw 3 fixes the travelling block to the stationary block.

D2-1 A wooden calorimeter lid can be drilled to accept a rubber bung. The central wire should be in a glass tube through the bung extending to the bottom of the heater to avoid a short circuit. The right-hand wire should go through a glass tube through the bung to avoid melting the rubber. Uninsulated Nichrome resistance wire (Resistance about 1Ω) is suitable and should be as thick as possible. The wires can be brought out to two connectors fixed to the top of the wooden lid.

E1-1 If the sonometer has no force meter, a spring balance can be fitted. The meter should be recalibrated in newtons if it reads grams. A sticker should be put nearby giving the maximum safe tension for the wire (eg. '25N maximum'). Experiment 1, step 3, may need demonstrating if 'same note' is not understood. A sounding box can be any hollow wooden box.

E3-1 The spectrometer should be set up in advance of each session. The candle could be replaced by a sodium lamp if one is available. A darkened room is required but total darkness is unnecessary.

F1-1 Glass plate:

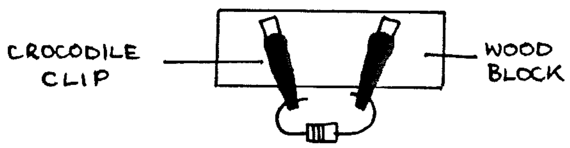


Electrodes are made of thick copper wire soldered at joints. The circular electrode should be about 8cm in diameter. The electrode support is a thin wooden strip on two wooden blocks.

F1-2 Other large value capacitors are suitable (eg. 2000μF, etc.). Do not use less than 500μF. The ammeter can be a galvanometer with a suitable resistance wire shunt. Note that many capacitors are accurate ±10% and results will reflect this.

F2-1 A Daniell cell could be substituted.

F2-2 Use a resistance wire for the galvanometer shunt. Resistors can be substituted for the resistance box.



Block with crocodile clips to hold the components can be included with the apparatus.

The components: A) resistance of about 5Ω, B) 6V bulb preferably 0.5A type, C) ensure the electrodes are clean, D) any semiconductor diode is suitable.

F2-3 For the resistor use copper wire (36SWG enamelled is suitable) wound onto a strip of cardboard and placed inside the test tube. Use about 15m of wire to give a resistance of about 10Ω. Solder insulated stranded copper wire onto the thin copper wire with the joints inside of the test tube. Make cuts in the rubber bung to allow the insulated wire to exit the tube. The thermometer with a scale 0°C to 100°C should also pass through the bung.

F2-4 A range of different material, length and thickness wires for R_X can be mounted on the same board. Provide at least three different wires to test as R_X.

F5-1 Thick copper wire formed into a rectangle 35cm long and 1cm wider than the magnets works well as the coil. Be certain the coil does not make a closed circuit through the end opposite to the magnets. For question 2 of the analysis the text available to the students should be substituted.

F5-2 The mounted coil can be easily constructed from 10 turns of stiff copper wire bound with insulating tape, placed in a slot cut in a wooden board. The coil need not be fixed to the board to allow substitution of different coils. The board needs legs to support it above the bench.

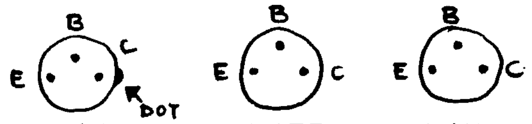
F6-1 300 turn coil: 36SWG copper on a cardboard former to be removeable from C-core. Solder on stranded insulated copper wires for connection, and cover the 36SWG wire with insulating tape. Students will need help operating the CRO, An AC voltmeter could be substituted for the CRO but the students will learn less, and the readings will be rms.

F6-2 300 turn and 150 turn coils constructed as in F6-1.

G1-1 For the ammeter a multimeter or two ammeters of different ranges can be used. The triode specified, TEL521, from Teltron LTD., London works well but any triode with clearly labeled connections is also suitable.

G2-1 Microammeter can be a Nakamura galvanometer (2.5μA per division) and the milliameter a Weir galvanometer (3mA full scale deflection). Rheostats 1kΩ to 10kΩ are preferred. A 15Ω rheostat is useable but it will run down batteries quickly.

Some common pnp transistors: (view of underside)



AC128 B475 B178

Testing old transistors:

Using:

Cell Galvo. 10kΩ

1) Find two wires of the transistor with no conduction in either direction. The base wire is the other wire. (Failure to find this: transistor broken)
2) With Base +, another wire -: conduction means that the transistor is npn.
   With Base -, another wire +: conduction means that the transistor is pnp.
   If there is conduction in both cases, the transistor is broken.
3) To distinguish C and E is difficult. Try the experiment G2-1. If $\beta > 40$ then the choice of C and E made was probably correct.

NB: npn transistors can easily be used in the experiment but the battery connections must be reversed.

H3-1 Wooden cubes are easily made (edges about 1cm each). Ensure edges are clean and even and mark the symbols ⊡ and ⧈ on opposite faces (leaving 4 blank faces).

PAST EXAM PAPERS

77 ALT A-Q2 A heavy weight must be placed on the base of the stand or it will topple over. Both liquid A and liquid B are water. Add some Potassium Permangenate ($KMnO_4$) to liqiud B to raise an element of doubt for the students.

80 ALT B-Q1 Prisms may be placed on A and B. Expected value of the Young's modulus is about 14GPa.

84-Q1 None

85-Q1 None

85-Q2 Have a thermos flask for the hot water. Pliers are useful for holding the calorimeter over the stove when blackening it.

86-Q2 A small ($25cm^3$) calorimeter is essential to ensure a measureable change in the rate of cooling.

86-Q3 None

87-Q1 The burette or cylinder must have a diameter of $\geq$3cm to avoid surface effects and must be $\geq$30cm deep. Liquid L is engine oil, SAE 40. Typical values for ρ_1 and ρ_2 are $8800kgm^{-3}$ and $900kgm^{-3}$.

GENERAL

Battery Boxes: It is worthwhile to construct a good number ranging from 1 cell to 6 cell capacity.

Connecting leads: A large number are needed, if possible with crocodile clips and/or plugs, made of stranded insulated wire. (standard useful lengths are 40cm and 60cm).