A LABORATORY MANUAL OF PHYSICS

FOR ADVANCED LEVEL CERTIFICATE, SCHOLARSHIP AND INTERMEDIATE SCIENCE STUDENTS

BY

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Miscellaneous

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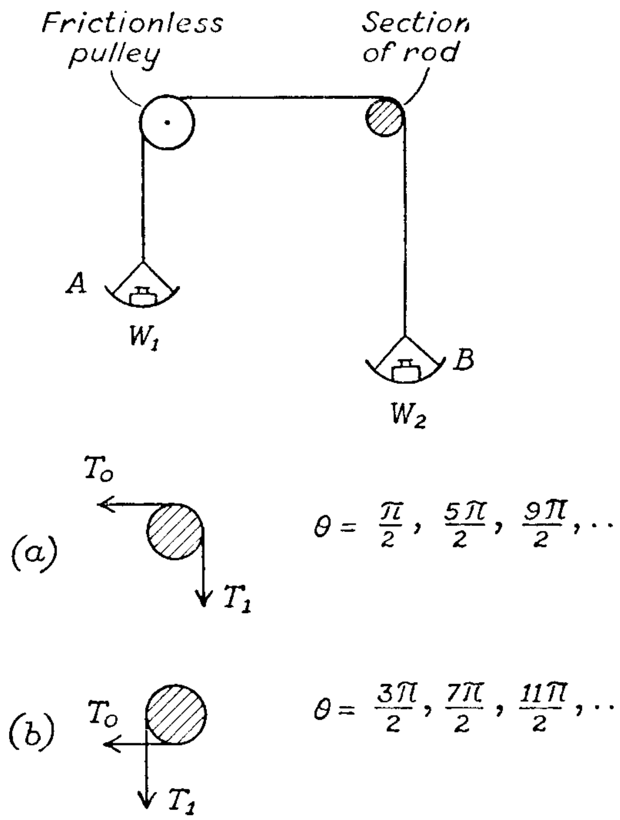
EXPERIMENT 99

TO OBTAIN THE COEFFICIENT OF FRICTION FOR A LAPPED STRING



Apparatus

Frictionless pulley, suitable rod—e.g. glass, ebonite or wood—of about 2 cm. diameter, thin string—or nylon fibre—capable of taking strain up to about 4 kgm., two scale pans with weights, two stands fitted with clamps to support pulley and rod.

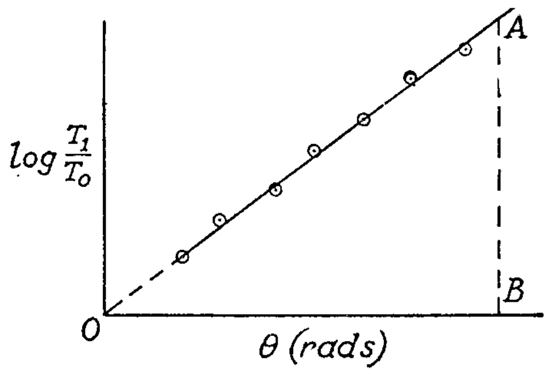
Method

Fix up the apparatus as indicated in the diagram. Place a given weight in scale pan *A* and add weights to scale pan *B* until the string just begins to slip. Note the weights in pan *B* when this occurs. Keeping the same weights in *A*, repeat the experiment with the string lapped round the rod once, twice, three times, etc., firstly as indicated in (*a*), and then as indicated in (*b*). Obtain the minimum weights added to *B* which will cause slipping in each case.

Results

The backward tension $T_0 = W_1$ gm. wt. + weight of scale pan *A*; the applied tension T_1 when slipping occurs $= W_2$ gm. wt. + weight of scale pan *B*.

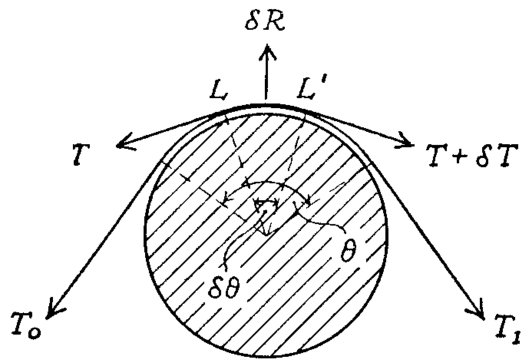
θ rads.	T_0 gm. wt.	T_1 gm. wt.	$\log_e \frac{T_1}{T_0}$



If $T_1 = T_0 e^{\mu\theta}$ (see theory), then $\log_e \frac{T_1}{T_0} = \mu\theta$.
Thus a plot of $\log_e \frac{T_1}{T_0}$ against θ will be a straight line the gradient of which is μ.
Thus the required coefficient of friction

$$\mu = \frac{AB}{OB} = \underline{\qquad\qquad}$$

Theory



Consider a small element LL' of the lapped. The forces acting on this element are as shown. The normal reaction (δR) of the rod on the element of string $= (2T + \delta T)\sin\frac{\delta\theta}{2} = T\delta\theta$ and the frictional force δF for the element $= \delta T$. But $\delta F = \mu\delta R$, $\therefore \delta T = \mu T\delta\theta$ giving, in the notation of the calculus, $\mu d\theta = \frac{dT}{T}$.

Integrating this last equation for the effect on the total lapped length of the string, we have—

$$\int_{T_0}^{T_1} \frac{dT}{T} = \mu \int_0^{\theta} d\theta$$

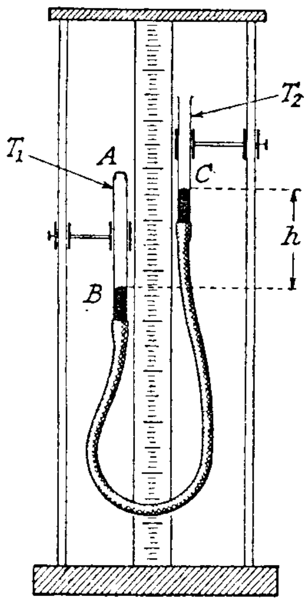
i.e.

$$\log_e \frac{T_1}{T_0} = \mu\theta$$

or

$$T_1 = T_0 e^{\mu\theta}.$$

TO DETERMINE THE ATMOSPHERIC PRESSURE USING A BOYLE'S LAW APPARATUS



Apparatus

Conventional Boyle's law apparatus such as that shown in the diagram.

Method

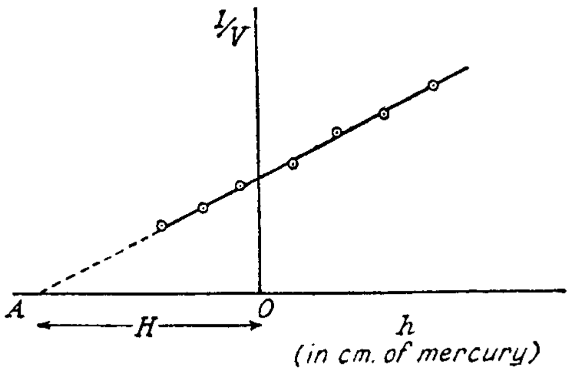
The experiment is commenced with the open tube T_2 well raised and the closed tube T_1 containing the gas (air) as low as possible. Then, by gradually lowering T_2 and raising T_1 until the positions of the two tubes are interchanged, a series of readings for pressures and volumes can be obtained extending over a wide range. At each stage the position of A (top of T_1) and the mercury surfaces at B and C are read against the scale, a small time-interval being allowed between each set of readings to ensure that the gas in T_1 is at the temperature of its surroundings. The volume (V) of the gas may be taken as proportional to the length AB of the tube (assumed uniform), whilst the difference (h) between the readings at B and C gives the excess pressure of the gas above the atmospheric pressure (H). (If the level of the mercury at C is below that at B, h will be negative.)

Results

Level A	Level B	Level C	h $(C - B)$ cm. of mercury	V $(A - B)$ Scale units	$\frac{1}{V}$

Theory

Boyle's law states that for a given mass of gas maintained at constant temperature, the volume (V) is inversely proportional to the pressure (P), or PV = const. A plot of $\frac{1}{V}$ against P will thus yield a straight line graph passing through the common zero. Now if H is the atmospheric pressure in cm. of mercury, and h the difference in the mercury levels in tubes T_2 and T_1, then $P = H \pm h$.

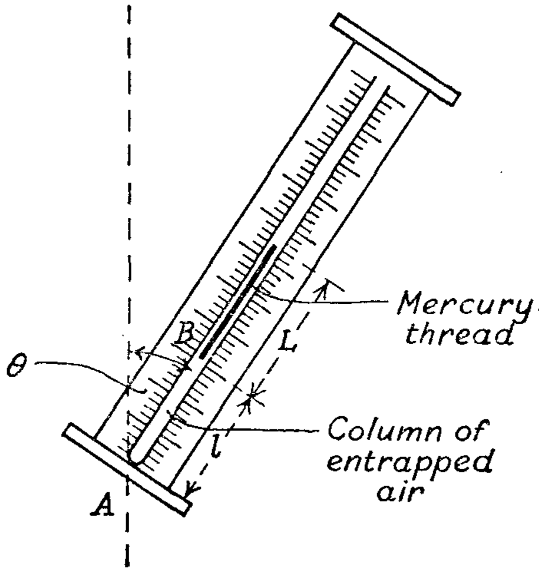


Thus the plot of $\frac{1}{V}$ against h when extrapolated to cut the h-axis will locate the common zero, and the intercept OA (disregard the negative sign) is evidently the atmospheric pressure H.

$\therefore H = OA =$ ______________ cm. of mercury.

Experiment 101

TO DETERMINE THE ATMOSPHERIC PRESSURE FROM MEASUREMENTS OF AN ENTRAPPED AIR COLUMN



Apparatus

Uniform glass tube, about 70 cm. long and with internal 2 mm., closed at one end and containing a column of air entrapped by a mercury thread approximately 20 cm. long. The position of the mercury thread should be such that, when the tube is stood vertically on its closed end (A), the length of the air column is about 20 cm. The tube is then mounted on a wooden stand (see diagram) on which is pasted a paper cm. scale.

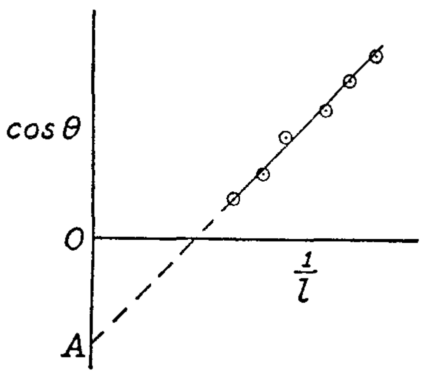
Method

The tube is placed in a vertical position with the open end uppermost, and the position of the lower end (B) of the mercury thread is measured against the scale. The tube is now tilted at various angles (θ) with the vertical and the position of B is measured against the scale in each case. (Positioning the edge of the stand against direction lines ruled on a sheet of white paper pinned against the laboratory wall is a convenient way of placing the tube at measured angles with the vertical.) Finally the length (L) of the mercury column is measured.

Results and Theory

Length (L) of mercury column = cm.

Angle of tilt θ	$\cos\theta$	Length of air column (AB) l cm.	$\frac{1}{l}$



Let H = atmospheric pressure in cm. of mercury. Then, when the tube is inclined at an angle of θ with the vertical, the total pressure of the entrapped air $= H + L\cos\theta$ cm. of mercury. Now since the volume of the air is proportional to the length (l) of the air column, we have, applying Boyle's law to the mass of air,

$$(H + L\cos\theta) \times l = \text{const. } (k)$$

Rearranging we get

$$\cos\theta = \frac{k}{L}\cdot\left(\frac{1}{l}\right) - \frac{H}{L}$$

Hence a plot of $\cos\theta$ against $\frac{1}{l}$ gives a straight line, the intercept OA on the $\cos\theta$ axis being $\frac{H}{L}$.

Thus $\frac{H}{L} = |OA|$ or $H = L \times |OA| =$ cm. of mercury.

Another Method

Place the tube in a vertical position with the open end uppermost. Measure the length (l_1) of the air column under the pressure ($H + L$) cm. of mercury. Now invert the tube and measure the length (l_2) of the air column under the new pressure ($H - L$) cm. of mercury. Apply Boyle's law and get $l_1(H + L) = l_2(H - L)$ from which

$$H = L\left(\frac{l_2 + l_1}{l_2 - l_1}\right)$$

EXPERIMENT 102

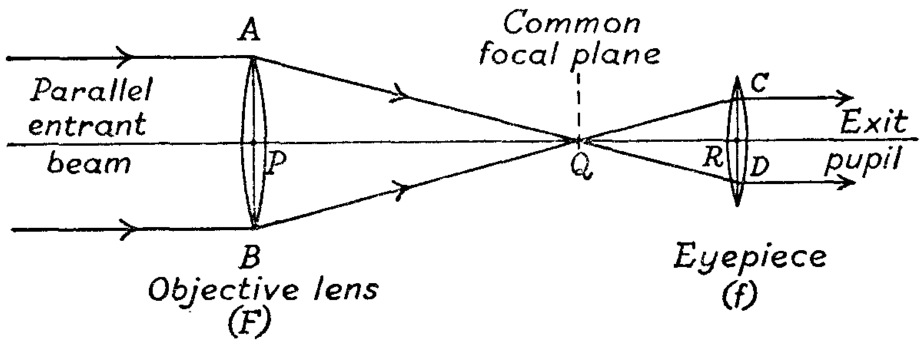
TO DETERMINE THE MAGNIFYING POWER OF A TELESCOPE

Apparatus

Small telescope in stand, vernier reading microscope.

Method

First focus the telescope on a very distant object and ensure that it is in normal adjustment. Now place the telescope in its stand and point it to the light from the laboratory



windows. On looking through the telescope the exit pupil can be seen as a small illuminated disc just behind the eyepiece. Measure the diameter of the exit pupil using the vernier reading microscope. Also measure the diameter of the objective lens of the telescope.

Theory

The diagram above shows an axial beam passing through the telescope when in normal adjustment. The magnifying power for normal adjustment

$$= \frac{\text{focal length of objective}}{\text{focal length of eyepiece}} = \frac{F}{f}$$

Now from the geometry of the figure it will be seen that—

$$\triangle ABQ \;|||\; \triangle CDQ$$

and accordingly
$$\frac{AB}{CD} = \frac{PQ}{QC}.$$

But $PQ = F$ and $QC = f$,

$$\text{hence magnifying power} = \frac{F}{f} = \frac{AB}{CD} = \frac{\text{Diameter of objective}}{\text{Width of exit pupil}}$$

Results

Diameter of objective = cm., width of exit pupil = cm.

∴ Magnifying power = ——— = ______

Note on the Resolving Power of a Telescope

The resolving power of a telescope may be defined as the angle subtended at its objective by two point objects, the images of which in the telescope can just be separately distinguished. A simple method of finding the resolving power of a laboratory reading telescope is as follows:

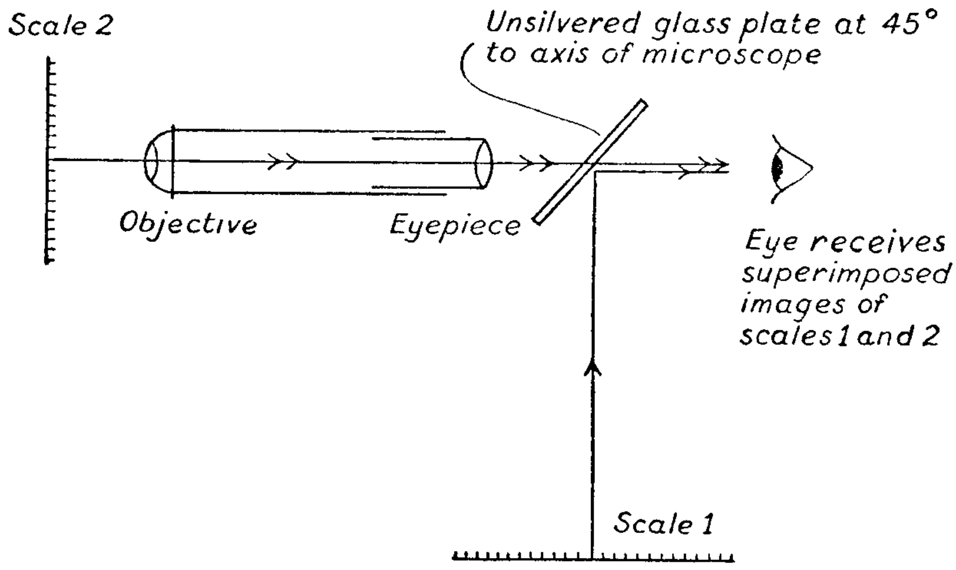
Two fine holes, a few mms. apart, are pierced in a metal sheet which is mounted in front of a sodium lamp. The two holes are then viewed through the telescope mounted some distance away—the telescope being adjusted in position until the holes just cannot be separated. The distance L of the telescope from the metal sheet is now measured—as is the distance d (by vernier microscope) between the two holes. The resolving power is then $\frac{d}{L}$ rads. The student should compare the result thus obtained with the theoretical value $1{\cdot}22\,\frac{\lambda}{D}$ where λ is the wavelength of the light used and D is the diameter of the objective of the telescope.

EXPERIMENT 103

TO DETERMINE THE MAGNIFYING POWER OF A MICROSCOPE

Apparatus

Compound microscope—e.g. standard laboratory vernier reading microscope, unsilvered glass plate, two millimetre scales (mounted white paper scales are suitable), lamps to illuminate the scales.



Method

Set up the arrangement sketched in the figure, placing scale 1 a distance of 25 cm. from the eye, and scale 2 in front of the objective of the microscope as shown. Adjust the position of scale 2 until there is no parallax between the magnified image produced of it by the microscope and the superimposed image of scale 1 viewed directly. The magnifying power is then obtained by counting the number of millimetre divisions contained in one division of the magnified scale.

Theory and Results

The magnifying power of a microscope

$$= \frac{\text{visual angle subtended by the final image seen at the nearest point of distinct vision through the microscope}}{\text{visual angle subtended by the object when seen directly at the nearest point of distinct vision by the unaided eye}}$$

$$= \frac{\text{width of final image seen in microscope}}{\text{width of object}}$$

= (in this case) relative width of mm. divisions in the two scale images

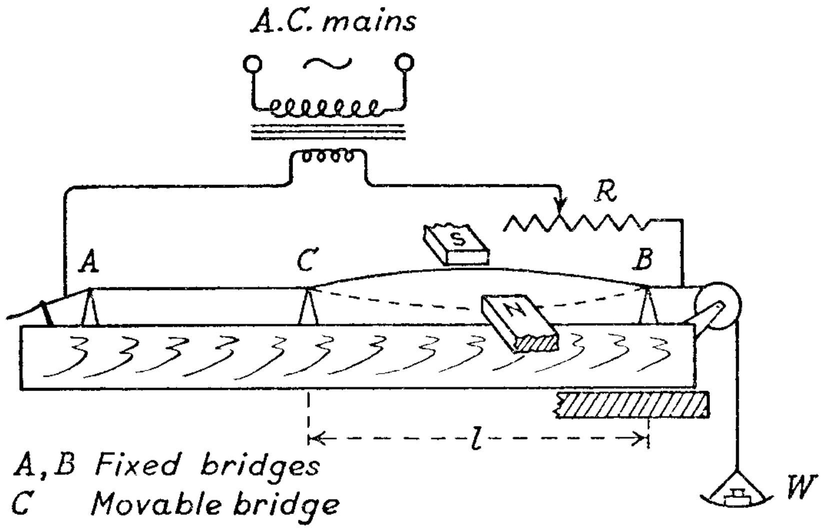
= ______________

EXPERIMENT 104

TO DETERMINE THE FREQUENCY OF THE A.C. MAINS USING A SONOMETER

Apparatus

Transformer to step down the A.C. mains voltage to 20 volts, rheostat, sonometer fitted with fine steel wire, scale pan and weights (to 1000 gm.), two powerful bar magnets clamped



on either side of the sonometer wire with unlike poles facing each other so as to produce a magnetic field perpendicular to the wire.

Method

The low voltage side of the transformer is connected, through the rheostat *R*, across the sonometer wire. The movable bridge *C* is now adjusted so as to obtain a given length *l* of the wire, and the magnets are placed mid-way between the bridges *B* and *C*. The weights are adjusted in the scale pan until the vibrations of the wire *BC* show a maximum amplitude, indicating that full resonance has been obtained. Note the weights in the pan. The position of *C* is readjusted (and appropriately that of the magnets) to obtain another measured length *l* and the weight required to produce resonance is again found. This is done for several values of *l*. Finally the mass of a measured length of the wire is found.

Theory and Results

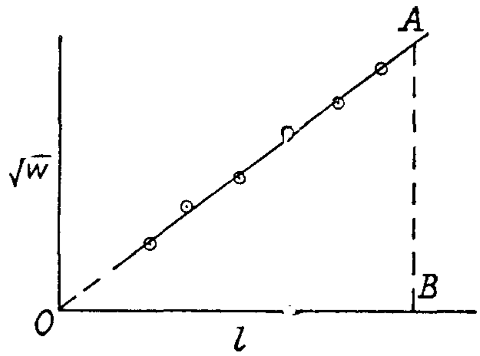
The transverse magnetic field produces a force on the current-bearing sonometer wire which is perpendicular to the direction of both the magnetic field and the current. The magnitude of this force varies at the mains frequency and the wire is thus forced to vibrate at this frequency. If the length and tension of the wire are such that its natural frequency is equal to the mains frequency, then resonance occurs. Hence at resonance the mains

frequency $= \frac{1}{2l}\sqrt{\frac{Wg}{m}}$ (see p. 109).

l cm.	W gm. (including mass of scale pan)	$\sqrt{W}$

mass of   cm. of wire =   gm.,

$\therefore$ mass (m) per cm. of wire = ____________ gm.



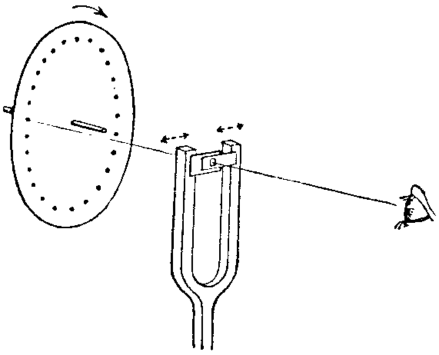
Mains frequency = frequency of resonant wire

$$= \frac{1}{2l}\sqrt{\frac{Wg}{m}} = \frac{1}{2}\sqrt{\frac{g}{m}} \cdot \frac{\sqrt{W}}{l}$$

$$= \frac{1}{2} \cdot \sqrt{\frac{981}{m}} \times \frac{AB}{OB} = \underline{\qquad\qquad} \text{ c.p.s.}$$

TO DETERMINE THE FREQUENCY OF A TUNING-FORK USING A STROBOSCOPIC DISC

Apparatus



A circular white cardboard disc about 10 cm. in diameter, and having a number of equidistant black dots marked in a circular row near its periphery, is mounted to the spindle of a small electric motor so that the card can be rotated about a horizontal axis through its centre. The motor is powered by an accumulator battery and its speed regulated by a suitable rheostat included in the electrical circuit. In front of the disc is placed an electrically maintained tuning-fork to the prongs of which are attached two strips of aluminium with a narrow slit in each such that, when the fork is at rest, the dots on the disc can be seen. The revolutions of the disc are counted by a revolution counter or commercial tachometer, or by improvising a simple revolution counter—as by using a worm gear with suitable step-down ratio attached to the spindle of the motor. A stop-watch is also needed for timing the revolutions.

Method

Steadily increase the speed of the motor to find the slowest speed at which the dots on the disc appear to be at rest when viewed through the attachments on the prongs of the vibrating fork. Keep the speed of the wheel steady at this stage and find the time for a counted number of revolutions.

Theory

When the fork is vibrating the prongs move outwards and inwards together and thus the slits will be in line twice—giving the observer two glimpses of the disc—during each vibration of the fork. The disc will appear to be stationary if each dot has travelled to the exact position occupied by another dot during the interval between two glimpses. Hence if the disc has m dots it will have rotated through $\frac{1}{m}$th of a revolution during half a vibration of the fork. Thus if the speed of the disc in revs per sec. is N, the time for $\frac{1}{m}$th of a revolution of the disc is $\frac{1}{Nm}$ sec. and this is equal to $\frac{1}{2n}$ where n is the fork frequency. Accordingly, $n = \frac{Nm}{2}$.

Results

Number (m) of dots round disc = .

Time for revs of disc at slowest speed for stationary pattern = sec.

$\therefore$ $N =$ revs. per sec.

Hence fork frequency $(n) = \frac{Nm}{2} = \frac{\quad \times \quad}{2}$

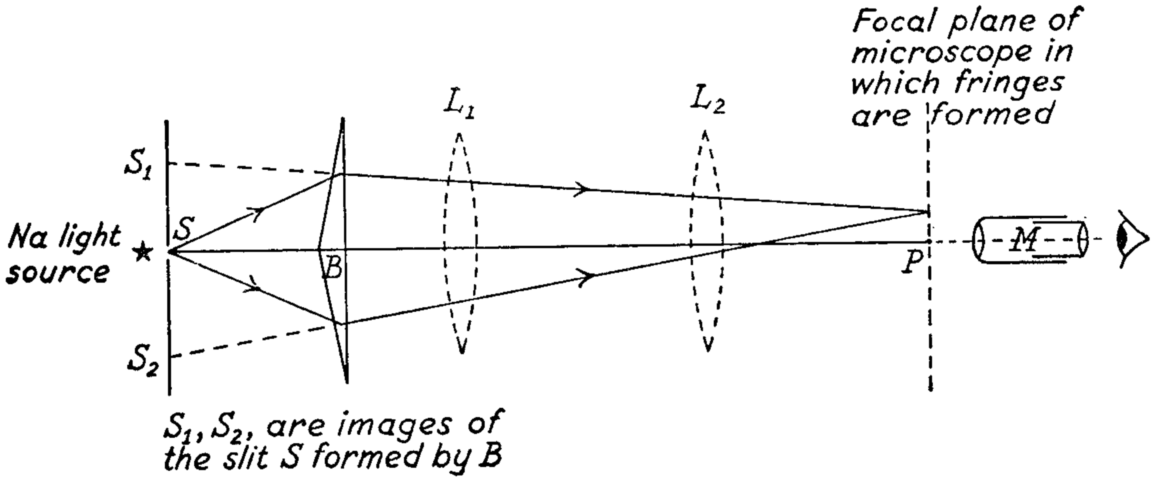
$= \underline{\hspace{4cm}}$ c.p.s.

Note. The above result is the frequency of the loaded fork and to obtain the **true** frequency a correction must be applied as in Expt. 51.

TO DETERMINE THE WAVELENGTH OF SODIUM LIGHT USING A FRESNEL'S BIPRISM

Apparatus

Source of sodium light, adjustable narrow slit (S), biprism (B) with obtuse angle not less than 179°, vernier reading microscope, convex lens with focal length about 10 cm., suitable stands or optical bench for mounting above components.



Method

Arrange the components in optical alignment on the dark room bench as shown in the sketch plan above. Suitable distances for SB and BP are respectively 5 cm. and 30 cm. (P is the point of intersection of the optical axis of the arrangement with the focal plane of the microscope M—found by moving a pin into sharp focus in front of M.) Interference fringes formed from light proceeding from the refracted images S_1, S_2 of the slit S can now be seen in the plane through P. By adjusting the width of the slit, and by slightly rotating the biprism about its vertical axis, obtain the clearest definition of the fringes. Now, by moving the microscope in lateral traverse in one direction only, obtain the width of a counted number of fringes. Taking measurements along the bench, obtain the distance between S and P; and finally, to obtain the distance separating S_1 and S_2, place the convex lens between B and P and move it into the two positions L_1 and L_2 in which it produces sharp images of S_1S_2 in the focal plane of M. Measure the distances y_1 and y_2 between these images in the two cases by means of the vernier microscope.

Theory

From the theory of Young's double-slit method (on which the present experiment is based), the fringe width $(\omega) = \frac{D\lambda}{2d}$, where λ is the wavelength of the light used, D the distance between the plane of the slits and that of the fringes, and $2d$ the inter-slit width.

Hence $$\lambda = \frac{2d \times w}{D}.$$

In the above experiment $D = SP$ and $2d = S_1S_2$. Now, by referring to the " displacement method " for convex lenses on p. 82, it will be seen that

$$\frac{S_1S_2}{y_1} = \frac{y_2}{S_1S_2} \quad \text{giving } S_1S_2 = \sqrt{y_1y_2}$$

Accordingly $$\lambda = \frac{w\sqrt{y_1y_2}}{SP}.$$

Results

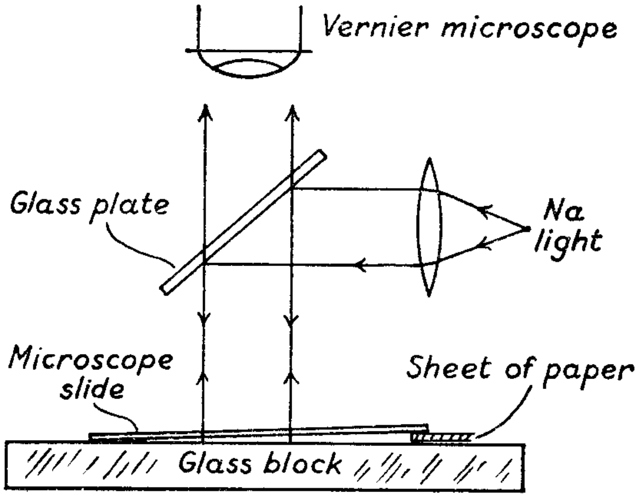
Width of fringes = cm.

$\therefore$ fringe width ω = cm.

SP = cm., y_1 = cm., y_2 = cm.

Hence λ = ______________ cm.

TO DETERMINE THE THICKNESS OF PAPER BY MEASUREMENTS ON THE INTERFERENCE FRINGES IN AN AIR WEDGE

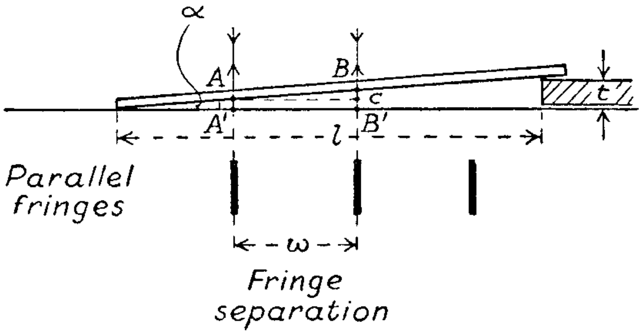


Apparatus

Piece of thin paper (e.g. cigarette paper), microscope slide, glass block of good optical quality, piece of unsilvered glass sheet, convex lens, Na light source, vernier reading microscope.

Method

Arrange the apparatus as shown in the diagram with the edge of the paper inserted under one end of the microscope slide on the glass block. Adjust the lens and glass plate until the parallel interference fringes formed in the air wedge can be seen to the best advantage. Using the vernier-reading microscope find the distance of traverse to cover a given number of interference fringes. Now measure (again with the vernier microscope) the distance (l) of the edge of the paper from the line of contact of the microscope slide with the glass block.



Theory

The fringe at A (see figure) is caused by interference between the light beams reflected at A (the point at the bottom of the microscope slide) and at the point A' immediately below A across the air film. The next fringe (at B) will be formed when the air film has increased in thickness by an amount BC equal to half a wavelength. Thus, if α is the angle of the air wedge, we have from $\triangle ABC$,

$$\tan \alpha = \frac{BC}{AC} = \frac{BC}{A'B'} = \frac{\lambda}{2}/\omega$$

where ω is the fringe separation. But also $\tan \alpha = \frac{t}{l}$ where t is the paper thickness.

Hence $$\frac{t}{l} = \frac{\lambda}{2\omega} \quad \text{or} \quad t = \frac{\lambda l}{2\omega}$$

Results

λ (sodium light) $= 5893 \times 10^{-8}$ cm.

$l =$ cm.

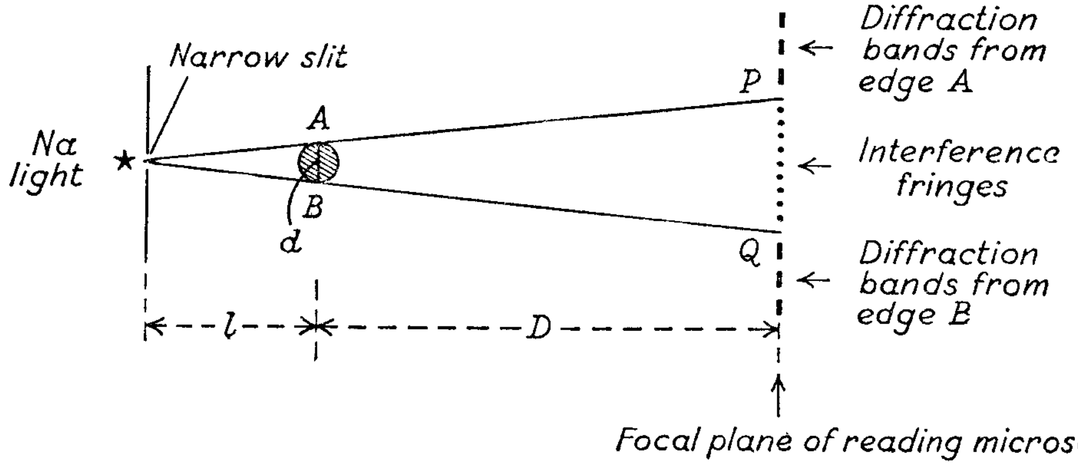
Distance of traverse for fringes = cm., ∴ fringe separation (ω) = cm.

Hence $t = \frac{5893 \times 10^{-8} \times \quad}{2 \times \quad} =$ ________ cm.

TO DETERMINE THE DIAMETER OF A FINE WIRE BY INTERFERENCE FRINGE MEASUREMENTS

Apparatus

Adjustable narrow slit illuminated by Na light (sodium lamp or flame), length of fine wire—e.g. No. 36 S.W.G. copper wire—suspended from a stand and held tautly vertical by attaching a small weight at the lower end, vernier reading miscroscope.



Method

Place the vertical wire at a distance (l) of approximately 5 cm. from the narrow slit and, with the vernier microscope in accurate optical alignment with the slit and wire, take observations on the interference fringes formed in its focal plane (determined by preliminary sharp focusing of a pin or other fine object). Taking readings with the microscope travelling in one direction only, obtain the width of as many fringes as can be clearly discerned when the distance (D) between the wire and the focal plane of the microscope is about 20 cm. Measure the distance D along the bench using a metre rule or against the scale of an optical bench—if used.

Theory

PQ (see figure) is the geometrical shadow of the wire AB. The effects observed outside P and Q are due to diffraction effects at the edges A and B respectively. The bands between P and Q are due to interference between wavelets which originate at A and B (first half-period strips): A and B act as a pair of Young's slits to give interference fringes between P and Q. Now from the theory of Young's experiment, the fringe width (ω) is given by $\frac{D\lambda}{d}$ where D is as given, d is the diameter of the wire and λ is the wavelength of the light used. Hence diameter (d) of the wire $= \frac{D\lambda}{\omega}$.

Results

$D =$ cm., $\lambda = 5893 \times 10^{-8}$ cm.

Width of fringes = cm., $\therefore$ fringe width (ω) = cm.

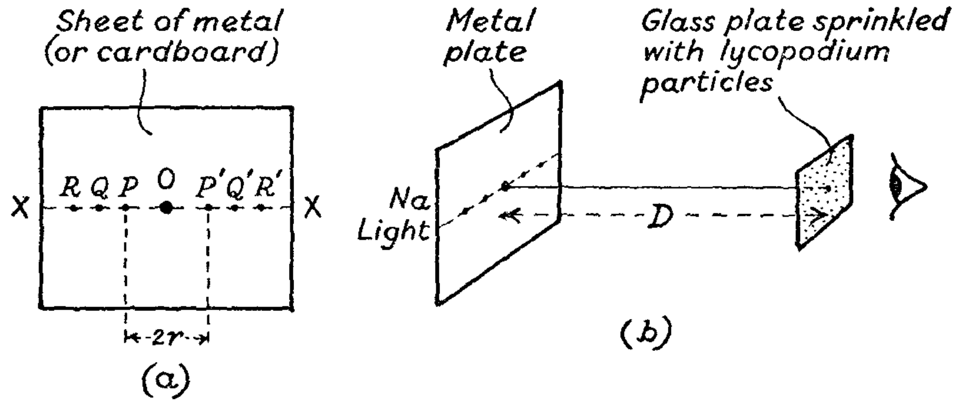
Hence diameter (d) of wire $= \frac{D\lambda}{\omega} = \frac{\quad \times 5893 \times 10^{-8}}{\quad}$

$=$ cm.

Note. From the geometry of the figure above the width of the shadow $PQ = \left(\frac{D+l}{l}\right)AB$. Now the fringe width is $\frac{D\lambda}{AB}$, accordingly the number of fringes visible in the region PQ

$$= \left(\frac{D+l}{l}\right)AB \Big/ \frac{D\lambda}{AB} = \left(\frac{D+l}{Dl}\right)\frac{(AB)^2}{\lambda}.$$

TO DETERMINE THE DIAMETER OF SMALL PARTICLES BY DIFFRACTION HALO MEASUREMENTS



Apparatus

Na light source, metal sheet pieced with holes $PP'QQ'$, etc., as indicated in Fig. (*a*), glass plate, stands to mount metal and glass plates, lycopodium powder, metre rule.

Method

Arrange the apparatus as shown in Fig. (*b*). Looking through the powdered glass plate, view the diffraction haloes produced and adjust the distance D between the metal and glass plates until the first dark ring fits on the pin holes PP'. Measure the corresponding distance D. Now move the glass plate away from the metal plate until the first dark ring fits on the pin holes QQ'. Again measure the distance D when this occurs. Continue and obtain similar coincidences for as many holes as are pierced on the metal sheet—taking the appropriate reading of D in each case.

Results

r cm.	D cm.

$$\lambda = 5893 \times 10^{-8} \text{ cm.}$$

From graph, slope

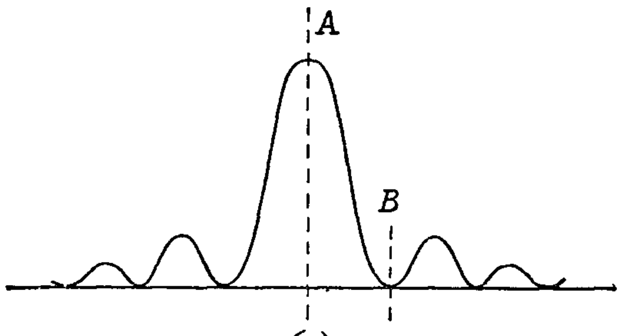
$$= \frac{AB}{OB} = \frac{1{\cdot}22\lambda}{d}$$

$$\therefore\ d = 1{\cdot}22 \times 5893 \times 10^{-8} \times \frac{OB}{AB}$$

$$= \underline{\hspace{3cm}} \text{ cm.}$$

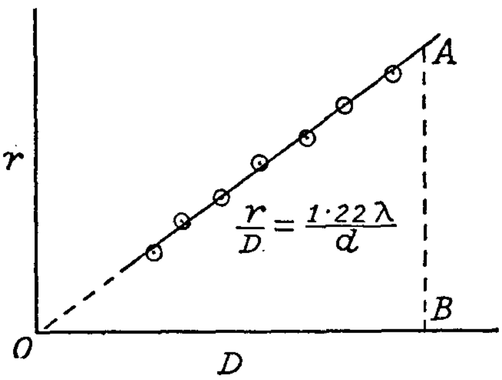
Theory

Fig. (*c*) shows the intensity curve of the diffraction pattern of a small circular aperture or obstacle. The angle (θ) between the principal maximum A and the first minimum B can be shown to be $\frac{1{\cdot}22\lambda}{d}$, where d is the diameter of the body. For a number of such bodies scattered over a glass plate the pattern is the same as for a single body but is more



(*c*)

intense. The complete pattern results from a rotation of the glass plate about its normal so that a series of concentric diffraction rings is seen.



With a dark ring in coincidence with two small holes at a distance r on either side of O, the required angle θ is clearly $\frac{r}{D}$ and this, for the first dark ring, equals $\frac{1{\cdot}22\lambda}{d}$. Hence a plot of r against D is a straight line, the slope of which is $\frac{1{\cdot}22\lambda}{d}$. Whence, assuming a value for λ, d can be found.

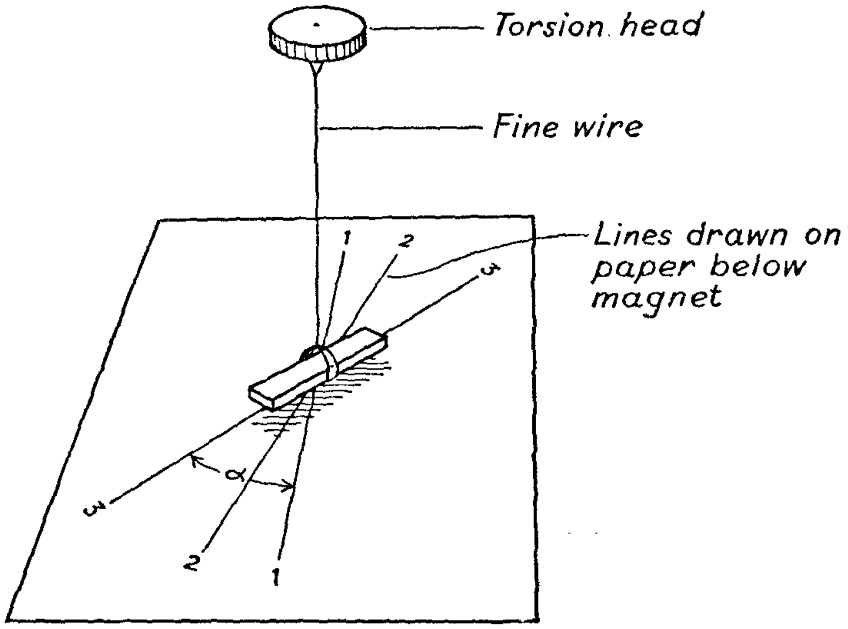
Notes

(1) Readings may also be taken on the second dark ring, in which case the angle

$$\theta = \frac{2{\cdot}23\lambda}{d}.$$

(2) Alternatively the experiment may be carried out placing the powdered plate on the spectrometer and using the telescope for the angular measurements required.

TO DETERMINE THE DIRECTION OF THE MAGNETIC MERIDIAN FROM OSCILLATIONS OF A BAR MAGNET SUSPENDED BY A WIRE AND TO FIND THE MAGNETIC MOMENT OF THE MAGNET CONCERNED



Apparatus

Bar magnet suspended in light aluminium stirrup at the end of a fine wire controlled by a torsion head, stand to support same, stop-clock, large sheet of white paper with direction lines ruled at 10° intervals.

Method

The magnet is supported so that it can freely oscillate in a horizontal plane just above that of the white paper. The time for 10 oscillations is taken with the magnet aligned parallel to each of the ruled lines in turn—the alignment being brought about by means of the torsion head.

Theory

If the magnet is inclined at an angle ϕ with the meridian, the component of the earth's horizontal intensity (H_0) along this direction is $H_0 \cos \phi$. If this is the equilibrium position, then the restoring couple (C) about this direction when the magnet (of magnetic moment M) is displaced a small angle θ from it is : $(MH_0 \cos \phi)\,\theta$ (due to the magnetic field) $+ c\theta$ (due to the twist in the suspending wire), where $c =$ the couple per unit of twist in the wire.

Now $C = I\ddot{\theta}$—when I is the moment of inertia of the bar magnet about the axis of oscillation,

$$\therefore \quad -(MH_0 \cos \phi + c)\theta = I\ddot{\theta}$$

or

$$\ddot{\theta} + \left(\frac{MH_0 \cos \phi + c}{I}\right)\theta = 0.$$

Hence the oscillations are simple harmonic for which the time period

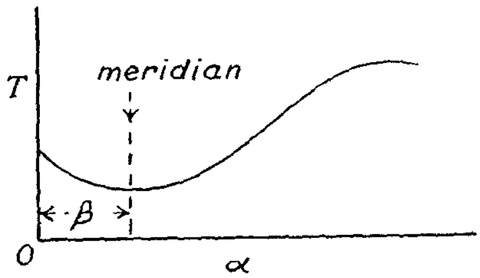
$$T = 2\pi\sqrt{\frac{I}{MH_0 \cos \phi + c}}.$$

We thus see that the time period is a minimum when the magnet lies along the meridian with its n-pole pointing northwards, and a maximum in the anti-parallel position. Thus a plot of T against α (the angle between a position line and the original reference line) enables the angle β (see graph 1) of the meridian direction from the reference line to be ascertained.

Results

α	Time for 10 oscillations	T (for 1 osc.) sec.

Graph 1.



Angle β gives the inclination of the reference line with the meridian—hence find the meridian direction.

Having determined the meridianal line the angles α can be converted into angles ϕ (angles between direction lines and meridian); then, since

$$T = 2\pi\sqrt{\frac{I}{MH_0 \cos\phi + c}}$$

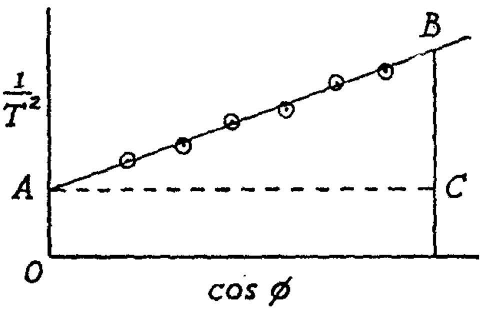
we have—

$$\frac{1}{T^2} = \left(\frac{MH_0}{4\pi^2 I}\right)\cos\phi + \frac{c}{4\pi^2 I}$$

so that a plot of $\frac{1}{T^2}$ against $\cos\phi$ gives a straight line the slope of which is $\frac{MH_0}{4\pi^2 I}$

i.e. $$M = \frac{4\pi^2 I}{H_0}\cdot\frac{BC}{AC}.$$

Graph 2.

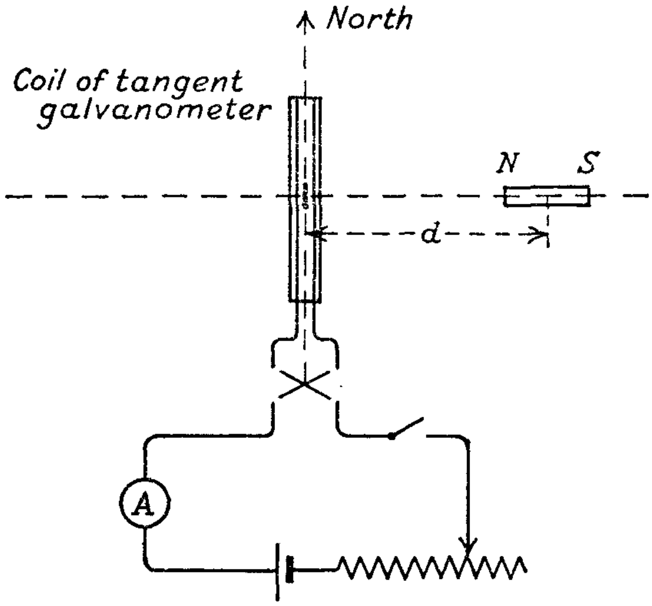


Hence knowing H_0 and evaluating I from the formula $W\left(\frac{L^2 + B^2}{12}\right)$—where W is the weight of the magnet in gm. and L and B are respectively its length and breadth in cm.—a value of M can be obtained.

TO DETERMINE THE MAGNETIC MOMENT OF A BAR MAGNET USING A TANGENT GALVANOMETER

Apparatus

Tangent galvanometer, ammeter, rheostat, reversing key, accumulator, circuit switch, bar magnet supported on wooden block at height of galvanometer needle.



Method

Connect up the electrical circuit as indicated in the diagram and arrange the tangent galvanometer with the plane of its coil in the meridian. Place the bar magnet on its stand so that the axis of the magnet lies on the E–W line passing through the centre of the coil of the galvanometer. Adjust the magnet so that its mid-point is a measured distance d from the needle of the galvanometer. Now insert the switch in the galvanometer circuit and adjust the current to such a value that the deflection of the galvanometer needle is annulled. Note this current. Now reverse the magnet end-for-end in its present position and, after switching over the reversing key, find again the current value for no deflection. Repeat the experiment for different values of d. Finally measure the mean diameter (for radius) of the galvanometer coil and measure the length of the magnet.

Results

Mean diameter of coil = cm., ∴ radius (r) = cm.
Number (n) of turns used on galvanometer = length of magnet = cm.,
∴ l($\frac{5}{12}$ths of physical length) = cm.

d cm.	Current values for no deflection		Mean Current I amp.	M
			Average =	

e.g.s. units

Theory

Intensity of field at galvanometer needle due to bar magnet in " end on " position

$$= \frac{2Md}{(d^2 - l^2)^2},$$ where M is the magnetic moment of the magnet.

Intensity at centre of coil due to current (I amp.) through it

$$= \frac{2\pi nI}{10r}.$$

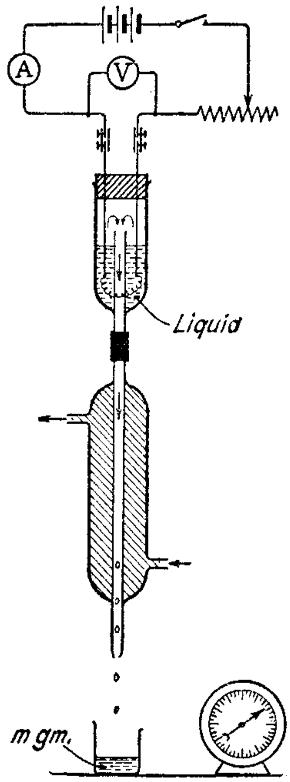
Hence for no deflection of galvanometer needle

$$\frac{2Md}{(d^2 - l^2)^2} = \frac{2\pi nI}{10r}$$

or

$$M = \frac{(d^2 - l^2)^2}{2d} \cdot \frac{2\pi nI}{10r}.$$

TO DETERMINE THE LATENT HEAT OF VAPORISATION OF A LIQUID BY AN ELECTRICAL METHOD



Apparatus

Source of D.C. volts—e.g. 12-volt accumulator battery, ammeter reading to 3 amps., voltmeter reading to 12 volts, switch, beaker, stop-clock, supply of liquid—e.g. ethyl alcohol, special distilling apparatus. This consists of a boiling tube through the bottom of which is fused a length of glass tube, and this in turn is connected to a Liebig condenser. A quantity of the liquid whose latent heat is required is placed in the boiling tube along with a heating coil (e.g. 30 to 40 cm. of 28 S.W.G. Eureka wire closely coiled) which connects to the electric circuit by means of two stout copper leads passing through a tightly-fitting rubber bung closing the top of the tube.

Method

The apparatus is set up as shown in the diagram. The switch is inserted and the rheostat adjusted until a suitable current (at least 2 amp.) is recorded by the ammeter. The voltmeter reading is then taken. The heat developed in the heating coil raises the temperature of the liquid until finally it boils, the vapour rising from the liquid passing down the exit tube to the condenser from which condensed droplets emerge. After a short time the steady state will be reached—the condensed liquid issuing regularly from the condenser. At this stage the liquid emerging in a given time is collected in the weighed beaker and the mass of the liquid found by weighing. The experiment is then repeated, using different current (and voltage) values, the mass of the liquid emerging in the same time as the previous experiment being determined as before.

Theory

The heat supplied by the heating coil in t sec. is $\frac{IV}{J}$ cal. where J is the mechanical equivalent of heat in joules per cal. When the steady state has been reached, this heat is used to evaporate m gm. (reclaimed from the condenser unit) of the liquid (of latent heat L cal. per gm.), the remainder (h cal.) of the heat being lost by radiation, etc., from the sides of the distilling unit.

Hence we have—

for the first expt. $\frac{I_1 V_1 t}{J} = m_1 L + h$

and for the second expt. $\frac{I_2 V_2 t}{J} = m_2 L + h$

h being the same in each case since the temperature of the apparatus is the same in each experiment and the radiation loss occurs for the same time in each case. Hence, by subtraction, we have—

$$\frac{(I_1 V_1 - I_2 V_2)t}{J} = (m_1 - m_2)L,$$

from which L can be calculated.

Results

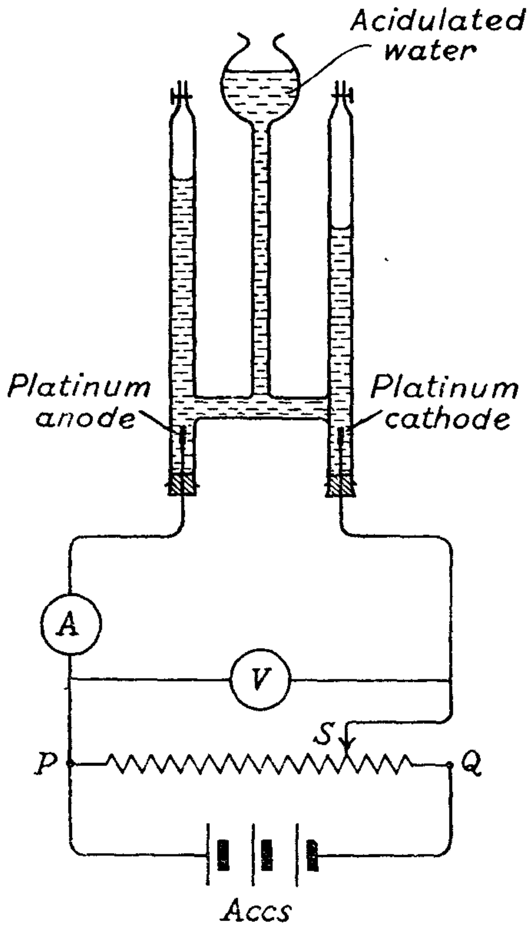
	Ammeter reading (I amp.)	Voltmeter reading (V volts)	Mass of liquid condensed (m gm.)
1st expt.			
2nd expt.			

time (t) – same for each expt. = sec.

Hence $L = \frac{(I_1 V_1 - I_2 V_2)t}{J(m_1 - m_2)} =$ __________ cal. per gm.

Note. In this experiment only modest quantities of the liquid are required and the issuing pure distilled liquid can be replaced in the apparatus to be used again.

TO DETERMINE THE POLARISING E.M.F. OF ACIDULATED WATER



Apparatus

Hoffman voltameter fitted with platinum (or carbon) electrodes and containing water to which has been added a little sulphuric acid to increase its conductivity, accumulator battery of three cell units, voltmeter reading up to 6 volts, milliameter reading up to 50 milliamps., high resistance rheostat to serve as potential divider.

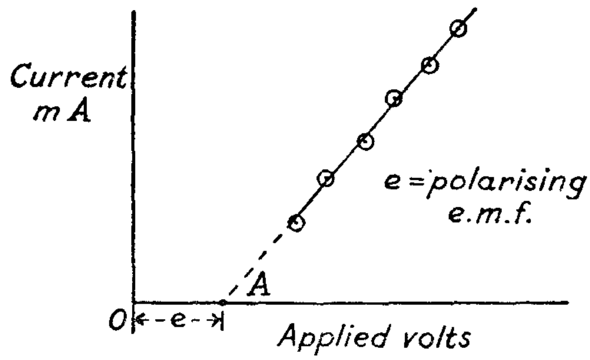
Method

Connect the circuit up as shown in the diagram in which *PQ* represents the high-resistance rheostat. Starting with the sliding contact near the end *P* of the rheostat, adjust the position of *S* until a suitable voltage is recorded on the voltmeter and note the reading of the ammeter. *S* is now continuously readjusted and a series of readings of the ammeter is taken as the voltage applied across the voltameter is increased in steps of $\frac{1}{4}$-volt up to a maximum of 3 or 4 volts. Plot a graph of the ammeter reading against the applied volts to obtain the polarising e.m.f. of water as shown.

Results and Theory

Voltmeter reading volts	Ammeter reading milliamps.

For an electrolyte of given concentration at constant temperature Ohm's law holds provided the passage of a current does not cause polarization at the electrodes. With acidulated water polarization occurs and the films of oxygen and hydrogen formed on the



respective electrodes develop a **back e.m.f.** (e) known as the polarizing e.m.f. Thus if V is the voltage applied across the voltameter (of resistance R), the current (I) passing is given by $I = \frac{V - e}{R}$. To obtain a value for e, therefore, all that is necessary is to extrapolate the straight line current-voltage graph obtained in the experiment until it cuts the voltage axis.

Thus $\qquad e = OA =$ ____________ volts.

Note. The back e.m.f. of polarization (e) can be obtained if we assume that the energy required to separate water into its constituents is equal to the energy liberated when hydrogen and oxygen combine to form water. Now the heat of formation of 1 gm. of hydrogen with 8 gm. of oxygen = 34,156 cal. = 34,156 × 4·185 joules.

But to liberate 1 gm. of hydrogen or 8 gm. of oxygen by electrolytic decomposition of water 96,500 coulombs of electricity are needed. These, passing between the voltage of e volts set up by the gases, liberate 96,500 × e joules of energy. Hence we get—

$$96{,}500 \times e = 34{,}156 \times 4 \cdot 185$$

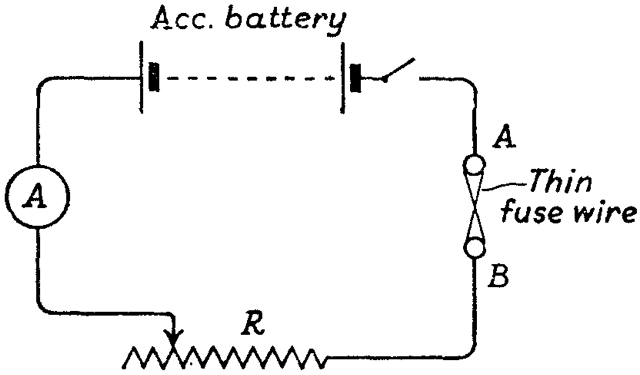
giving
$$e = \frac{34{,}156 \times 4 \cdot 185}{96{,}500} = 1 \cdot 48 \text{ volts}$$

as the least voltage needed for the electrolytic decomposition of water.

The value obtained experimentally often differs from the above, the actual value depending on the nature and size of the electrodes used. The student should investigate this.

EXPERIMENT 114

TO INVESTIGATE THE RELATIONSHIP BETWEEN THE FUSING CURRENT AND DIAMETER FOR WIRE CONDUCTORS



Apparatus

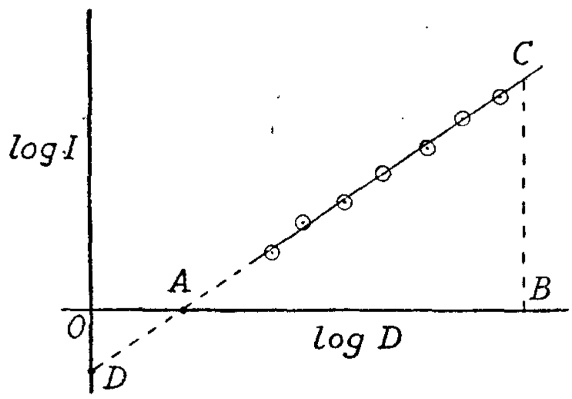
Source of D.C. volts—e.g. acc. battery, ammeter reading up to 15 amp., rheostat capable of handling 15 amp., terminal block for mounting the wire conductors which may be a set of thin copper wires of different gauges or commercial fuse wires of constant composition, circuit switch, screw-gauge.

Method

Connect the circuit up as shown in the diagram in which AB represents the terminal block across which is stretched the wire under test. Insert the circuit switch, and by gradually cutting out the resistance in R, increase the circuit current until the fuse blows. Repeat three or four times, recording the maximum ammeter reading each time. Take the average of these readings to obtain the fusing current. The whole procedure is then repeated for each of the wires, the diameters of which are found using the screw gauge provided.

Results

Wire no.	Max$^{m\cdot}$ ammeter readings	Fusing current (I amp.)	Screw gauge readings	Average diam. (D cm.)
1	, , ,		, , ,	
2				
.				
.				



If the general relationship between the fusing current I and the wire diameter D is of the type $I = kD^n$, a plot of log I against log D will produce a straight line graph since $\log I = n \log D + \log k$. The value of n is obtained from the slope of this graph; thus—

$$n = \frac{BC}{AB} = \_\_\_\_\_\_\_\_$$

The intercept OD on the log I axis is log k, and hence the value of k can be ascertained.

Theory

The heat produced per second by a current I flowing through a conductor of resistance $R = \frac{I^2R}{J}$ cal., where J is the mechanical equivalent of heat in joules per cal. The subsequent temperature rise of the conductor will depend on the emissivity (E) of the surface and the cooling law applicable to the temperature range concerned. If the equilibrium temperature of the conductor is $\theta°$ C., the rate of loss of heat from the wire (diam. D, length l) to the surroundings (temp. $\theta_R°$ C.) per sec. $= E \times$ surface area $\times (\theta - \theta_R)^p$

$$= E \times \pi D l \times (\theta - \theta_R)^p.$$

Accordingly, at thermal equilibrium,

$$\frac{I^2R}{J} = E\pi Dl(\theta - \theta_R)^p.$$

Now if the resistivity of the material of the wire is ρ ohm-cm. units, we have, $R = \frac{4\rho l}{\pi D^2}$, and the equation becomes

$$I^2\frac{4\rho l}{J\pi D^2} = E\pi Dl(\theta - \theta_R)^p$$

giving

$$\frac{I^2}{D^3} = \frac{\pi^2 JE}{4\rho}(\theta - \theta_R)^p.$$

(For reasonably small temperature differences, $p = 1$ (Newton's law); for higher temperatures, $p = \frac{5}{4}$ (convection cooling).)

For *fuse wires*, $\theta =$ the melting-point of the material when the fusing current is reached. Accordingly, for wire of the same materal

$$\frac{I^2}{D^3} = \text{const.} \qquad \text{or} \qquad \underline{I = kD^{3/2}}$$

being the relationship between the fusing current and the diameter of the wire.

Note. For sudden heating of a conductor (e.g. by short circuit with heavy loads) a wire will reach its melting-point with negligible surface losses of heat. Thus if the temperature of the wire is raised by $\theta°$ C. in t sec., we have—

Heat supplied by current = Thermal capacity of wire × temp. change

= Volume × density × spec. heat × temp. change

or

$$I^2 . \frac{4\rho l}{J\pi D^2} . t = \frac{\pi D^2 l}{4} \times \Delta \times S \times \theta$$

i.e.

$$\frac{\theta}{t} \text{ (temp. rise per sec.)} = \left(\frac{16\rho}{J\pi^2 \Delta S}\right)\frac{I^2}{D^4}.$$

If θ' is the melting-point of the wire, the time (t') to reach this temp. is thus

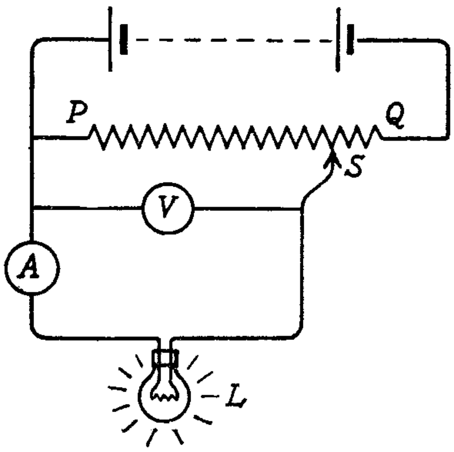
$$t' = \frac{J\pi^2\Delta S(\theta' - \theta_R)}{16\rho} . \frac{D^4}{I^2}.$$

Hence for a given current with wires of the same material,

$$t' \propto D^4$$

a relation which can be tested for copper wires (say) if an appropriate voltage source and suitable instruments are available.

TO INVESTIGATE THE RELATION BETWEEN THE CURRENT PASSING THROUGH A TUNGSTEN FILAMENT LAMP AND THE POTENTIAL APPLIED ACROSS IT



Apparatus

Source of low D.C. voltage—e.g. 12-volt accumulator battery, high resistance rheostat to serve as potential divider, voltmeter reading to 12 volts, ammeter reading to 3 amp., 12 volt 36 watt car bulb.

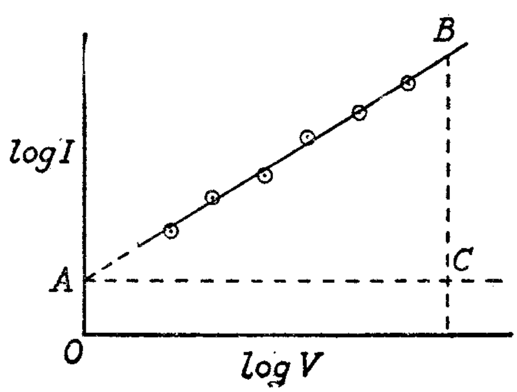
Method

Connect the circuit up as shown in the diagram in which *PQ* represents the high resistance rheostat. Starting with the sliding contact (*S*) near end *P* of the rheostat, adjust the position of *S* until a suitable voltage is applied across the lamp *L*, and obtain the current passing through the filament from the ammeter reading. Now move *S* towards *Q* and obtain a series of related voltage and current values until the full allowed voltage is applied to the lamp.

Results

Applied voltage *V* volts	Current through filament, *I* amp.	Log *V*	Log *I*

The relation between the current, *I*, through the heated filament and the applied voltage, *V*, is given by the general form $I = kV^n$
where *k* and *n* are constants for the particular lamp.



For the empirical relationship between *I* and *V*, the constants *k* and *n* can be obtained from the graph of log *I* against log *V*, thus

$$\log I = n \log V + \log k.$$

This is a straight line the gradient of which $\left(\frac{BC}{AC}\right)$ gives the value of *n*. Log *k* is the intercept *OA* on the log *I* axis, and thus *k* can also be determined.

Theory

If I, V are respectively the values of the filament current and applied voltage at a working temperature of T_0 (abs.), the resistance R_T of the filament at this temperature is given by

$$R_T = \frac{V}{I}.$$

Now assuming the resistance of the filament to increase directly as the absolute temperature, we have

$\frac{R_T}{T} = \frac{R_0}{T_0} = \text{const.}$—where $\frac{R_0}{T_0\,(\text{abs.})}$ is the cold resistance of the filament at the room temperature,

Hence $$\frac{V}{I} = \frac{R_0}{T_0}.T.$$

If we make the further assumption that the hot filament radiates as a " black body," we have, applying Stefan's law of radiation for the amount of energy (E) radiated by the filament when at a temperature T,

$$E = \sigma(T^4 - T_0^4) \text{ ergs per cm.}^2 \text{ per sec.} \simeq \sigma T^4 \text{ since } T \gg T_0,$$

σ being Stefan's constant.

If the filament has a length l and a diameter d, the emitting area is πdl, and hence the total quantity of energy emitted by the filament per sec. $= \pi dl\sigma T^4$ ergs. Now the rate at which energy is being supplied to the filament $= IV$ joules per sec. $= IV \times 10^7$ ergs per sec., and hence we have—

$$IV \times 10^7 = \pi dl\sigma T^4.$$

But, from above, $T = \frac{V}{I}.\frac{T_0}{R_0}$ and accordingly we have—

$$IV \times 10^7 = \pi dl\sigma\left(\frac{V}{I}\right)^4\left(\frac{T_0}{R_0}\right)^4$$

from which $$I = \left\{\frac{\pi dl\sigma}{10^7}\left(\frac{T_0}{R_0}\right)^4\right\}^{1/5}.V^{3/5}.$$

The value of k, obtained from the graph in the foregoing experiment, is thus

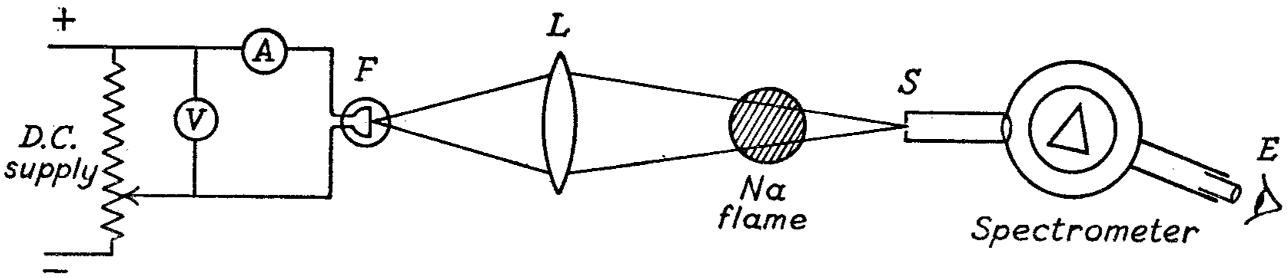
$$\left\{\frac{\pi dl\sigma}{10^7}\left(\frac{T_0}{R_0}\right)^4\right\}^{1/5}.$$

Accordingly, by measuring the resistance R_0 of the filament at the room temperature T_0, and using the values for d and l* given in the maker's specification, it is possible, within the limitations imposed by the assumptions made, to obtain a value for Stefan's constant σ.

* Alternatively l may be found, for a straight filament, by applying the method of the experiment on p. 221.

TO FIND THE TEMPERATURE OF A BUNSEN FLAME USING A HEATED FILAMENT

Using the electrical circuit of Expt. 115, the light from the heated filament *F* is focused by a lens *L* on to the slit *S* of a spectrometer and the spectrum produced is observed at *E*. A sodium flame is now interposed between *L* and *S* and the bright sodium *D* line is seen against the background of the continuous spectrum of the light from *F*. By gradually increasing the current through *F*, a stage is reached when the *D* line of the sodium flame is



just not discernible against this background. At this stage the temperatures of the emitting sources are the same. The resistance of the hot filament is then calculated from the voltmeter and ammeter readings, when, knowing the resistance of the filament at air temperature, and using the known value of the temperature coefficient of resistance of the filament wire, the temperature of the filament—and hence of the bunsen flame—can be found. Alternatively, if the physical dimensions of the filament are known, the temperature can be found by applying Stefan's law.