

leaf, experiments should be performed to show photosynthesis and transpiration. While studying the flower, the relations of insects and plants and the remarkable adaptations for cross-pollination should receive attention.

That most remarkable of all the plant's powers, its irritability, as shown in hydrotropism, geotropism and heliotropism, should be carefully studied; and more especially should be emphasized the light relations of the plant and in particular of the leaves. The mechanism of animals for response to light is extremely crude compared with the wonderful sensitiveness of the plant which brings about those most marvelous and delicate adjustments that best adapt it to its environment. Field excursions should be taken to study these adjustments in the common trees. Before the leaves appear, the branches should be closely examined and the record of their struggle for sunlight deciphered. A little later, the leaves should also be besieged to reveal their story. For these studies, I have found the maple most excellent.

(Concluded in May.)

A MOUNTING FOR AN OSCILLATING MIRROR.

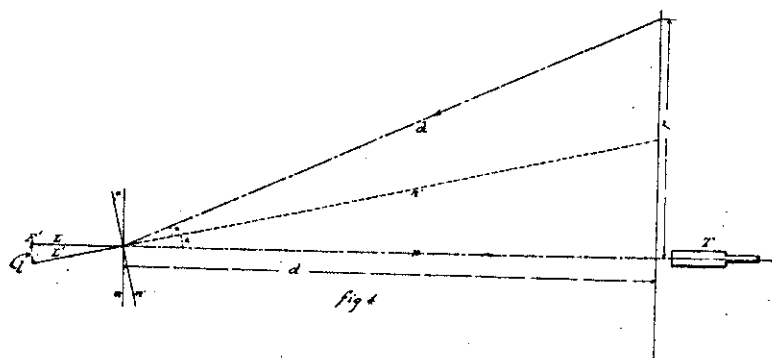
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Many experiments in elementary physics as described in the laboratory manuals involve errors inherent in the methods given greater than the observational errors of the veriest tyro. Obviously such methods are not desirable. The most sensitive and accurate apparatus compatible with simplicity and ease in working is just as desirable for those experiments which are intended mainly to vivify laws, as for those whose results have in themselves an intrinsic value. While the high-school laboratory should not become merely a place for training in manipulation, still it seems highly desirable that most experiments not otherwise too complex should include a certain amount of training in method and

mechanism just a little above the previous experience of the pupil.

There is a certain method of observation rather neglected in high-school work in spite of its simplicity and general applicability. The mirror and scale method, with or without a telescope, is the method to which attention is called. Perhaps a general description of the theory and practice of the method will not be out of place before taking up the special reason for the writing of this article. In general, then, when one wishes to measure a small rotational motion, or its equivalent, one attaches a mirror to the rotating body, sets up at a convenient distance from the mirror a scale perpendicular to the axis of rotation, and then observes through a suitably placed telescope the motion of the image of the scale in the mirror. In Fig. 4, T is the telescope, r the scale,



and m and m' the mirror in two positions corresponding to the positions of the body, L and L' . Let d be the distance from mirror to scale, and n and n' the normals to the mirror in its two positions. Suppose that initially, in the position m the normal n passes through the zero line of the scale and also along the optical axis of the telescope. Then the observer will see the zero line coincide with the cross-hair of the telescope. Now if the body, mirror and normal rotate through the angle α to the positions L , M' and N' the mirror will be in the position to reflect light from the scale division on the line P along the axis of the telescope. Let r be this scale-reading. Then the large apparent motion r is what

is directly observed instead of the relatively small displacement l of the point F' in the rotating body, and the motion of F' is magnified in the ratio $\frac{r}{d}$ which ratio may be of any convenient value controlled by varying d . Now the observer is in a position to do any one of three things:

(1) A small motion of the body may be easily detected. This is the use of the method in the "zero methods" in galvanometer work.

(2) One may compare successive motions of the body by calculating from $\frac{r}{d} = \tan 2a$ the ratios of the various a 's, or if the angles a are all small the ratios of the successive r 's will give the relative motions with but little error.

(3) One may calculate the actual displacement l from a knowledge of L , d , and r . This may be done in two ways:

(a) $\frac{r}{d} = \tan 2a$;—(i), and $\frac{l}{L} = \tan a$ (nearly);—(ii).

Solve (i) for a and then solve (ii) for l .

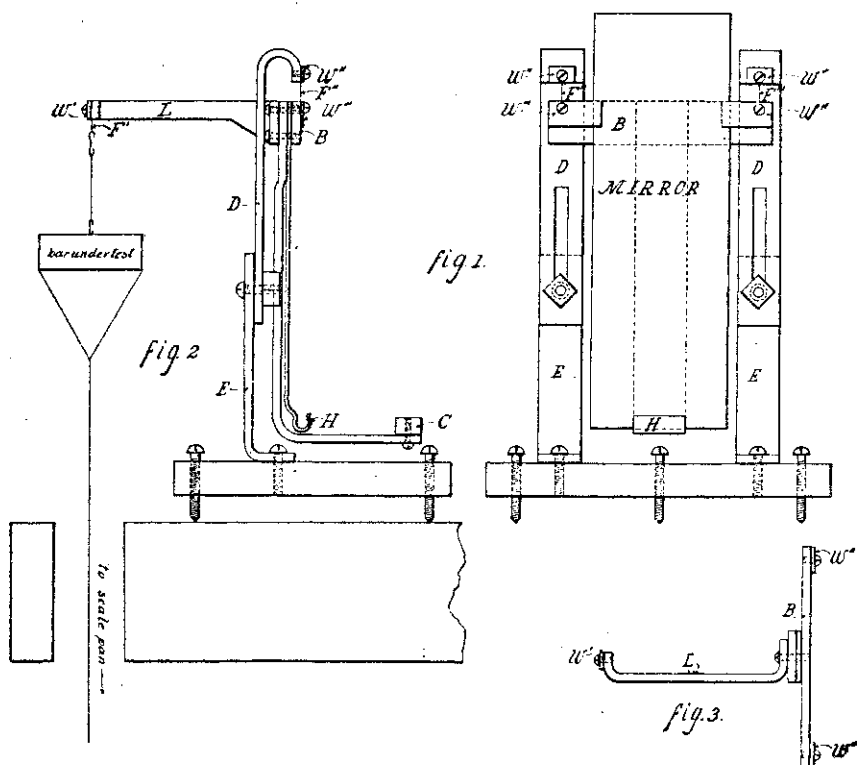
(b) If a is small,

$$\frac{l}{\frac{1}{2}r} = \frac{L}{d} \text{ or } l = r \frac{L}{2d} \text{ (very nearly).}$$

Method (b) is perhaps the best for student use since it is so easily grasped (as an approximation) from similarity of triangles. The error involved is very small, about $\frac{1}{4}$ per cent when a is in the neighborhood of 3° , as will be shown in detail later.

All three ways of using the method are used successfully by the writer's pupils, each in at least one experiment. There are certain standard experiments, notably those in elasticity of flexure, extension and torsion, which seem as described in recently published manuals to have the defects mentioned at the beginning of this article. The plan for a mounting for an oscillating mirror submitted in the accompanying drawing is designed to show how an oscillating mirror may be used in experiments of the above mentioned types, and especially in the measurement of elasticity of flexure. The special objects of the design were to secure ease in assembling apparatus, steadiness and uniformity in action, ease

in attaching the device to rods, tubes, and bars of widely differing cross sections, and the adaptability of the one design to many experiments. Likewise it was desired to have something that could be constructed from common stock, with simple tools, and yet that would admit of as exact and substantial a construction as one could wish. Fig. 1 shows a front elevation without the counter-



poise. Fig. 2 shows a side elevation with the mirror omitted, but with an indication of the method of attachment to a bar under test. Fig. 3 shows a top plan of the lever arm *L* and cross bar *B*. The dimensions of the various parts can be deduced from the size of the mirror, one by three inches. All the metal work is of brass. Most of the details of construction will be sufficiently evi-

dent from the drawing. The letters indicate the same parts in the four figures. C is a counterpoise of such a value as to offset the weight of the lever L , and to furnish a slight restoring force.

A special feature is the use of the three silk threads F' , F'' , and F''' , pinched under the thin washers w' , w'' , and w''' . The motion is as perfect as one could wish, and occurs where the threads are flexed just as they enter the cracks between B and w''' , and L and w' .

The actual strain of the bar can be readily calculated from the length of L and the measured distance from the mirror to the scale. The attaching of whatever object whose motion under stress is to be observed is accomplished simply by the use of small wire hooks and loops of thread.

The details of an actual experiment as performed by students are cited below; taken, with a few slight changes, direct from their note books:

January 22, 1902.

ELASTICITY OF FLEXURE OF A BRASS ROD.

Diameter of rod = 0.64 cm.

Mirror to scale.....178 cm. = d .

Lever arm of mirror....4.3 cm. = L .

Load grms.	Length = 100 cm.			Length = 50 cm.		
	Reading cm.	Difference	per 20 grms.	Reading cm.	Difference	per 20 grms.
0	13.05	....	....	11.75	....	....
20	16.65	3.60	3.60	12.25	0.50	0.50
0	13.15	....	....	11.75	....	....
40	20.35	7.30	3.65	12.7+	0.95	0.47+
0	13.0+	....	....	11.75	....	....
60	24.05	11.05	3.68	13.2+	1.45	0.48
0	13.05	....	....	11.75	....	....
80	28.05	15.00	3.75	13.65	1.90	0.47+
0	13.05	....	....	11.75	....	....
100	31.4±	18.35	3.67	14.1	2.35	0.47
0	13.05	....	....	11.75	....	....
120	35.15	22.10	3.68	14.55	2.80	0.46+
0	13.05	....	....	11.75	....	....
140	38.9—	25.85	3.69	15.05	3.30	0.47
0	13.05	....	....	11.75	....	....
160	43.05	30.00	3.75	15.55	3.80	0.47+
0	13.0—	....	....	11.75	....	....

180	48.85	33.85	3.76	16 0—	4.23	0.47
0	13.0±	....	....	11.75	....	....
200	50.5	37.5	3.75	16.45	4.70	0.47

NOTE: To stop vibration the table was supported on four rubber stoppers, and a second pan submerged in water was attached below the scale pan proper.

CALCULATIONS:

- (a) *With a stress of 200 grms.;*

Scale reading:

-For 100 cm. length = 37.5

" 50 " " = 4.7

But $\frac{37.5}{4.7} = 7.97$ +, and $\left(\frac{100}{10}\right)^3 = 8$

∴ The strain varies as the cube of the length.

- (b) *To calculate the actual deflection:*

For 100 cm. length and 200 grms. stress;

Actual deflection = $l = r \frac{L}{2d} = 37.5 \times \frac{4.3}{2 \times 178} = \underline{0.4529 \text{ cm.}}$

- (c) *To calculate Young's Modulus:*

For a rod supported at both ends,

Modulus = $\frac{4 \text{ Weight} \times (\text{length})^3}{3 \pi \times (\text{diameter})^4 \times \text{deflection}}$

$= \frac{4 \times 200 \times (100)^3 \times 178 \times 2}{2 \times \pi \times (0.64)^4 \times 4.3 \times 37.5}$

$= 1.117 \times 10^9 \text{ grams.}$

$= 1.094 \times 10^{12} \text{ dynes.}$

Curves, of course, were constructed showing the stresses as abscissas and the strains as ordinates, which curves demonstrated Hooke's law admirably.

It will be noticed that the student used the approximate formula for calculating the actual strain. If the strain is calculated by trigonometry, one gets 0.4492 cm. The error, then, is about 0.03 millimeter or less than 1 per cent. However, the angle was large, about 6°. Taking the strain for a stress of 100 grams and making the same calculation one obtains: By approximate formula $l = 0.2216 \text{ cm.}$; by trigonometric formula $l = 0.2211$, or an error of about 0.005 mm. or less than $\frac{1}{4}$ per cent. The angle was nearly 3°.

Ordinarily the pupil would not calculate Young's modulus, nor solve for l by trigonometry, though either step is simple enough for the stronger pupils. Even if one cannot deduce the formula

for the modulus by flexure, still it is of value to calculate the modulus, the formula being assumed, so as to compare with the modulus by extension. None need have difficulty with the derivation of the formula for extension.

A partial list of experiments to which this device is applicable would read as follows:

- (1) Elasticity of flexure.
- (2) Elasticity of extension.
- (3) Elasticity of torsion.
- (4) Coefficient of expansion by heat of solids, liquids and gases.
- (5) Instead of a cathetometer to measure small distances.
- (6) As a sensitive balance by hanging a scale pan from *L*. The observer can place the telescope alongside the mirror by using an auxiliary, stationary mirror placed near the scale. Either the method of constant deflection or Hooke's law can be used, just as with the Jolly balance.
- (7) Instead of using a pointer on any balance, *L* might be attached to the beam and deflections observed in the mirror.
- (8) As a magnetometer, especially for exploring a magnet from end to end.
- (9) As a suction ammeter.
- (10) As a suction voltmeter.
- (11) To demonstrate the laws of moving mirrors.
- (12) To measure the diameters of wires or the thicknesses of metal plates.
- (13) To measure the angles subtended by inaccessible objects, either terrestrial or celestial, the telescope remaining fixed.

In numbers 1, 2, 3, 4, 6, 7, 8, 9 and 10 the mirror would be fastened to the moving object. In numbers 4, 5, 12 and 13 a screw motion mechanism would be fastened to *L*, either with or without a micrometer head. To be sure, all of these possibilities are not adapted to high-school work. Numbers 1, 2, 6, 8, 9 and 11, however, are especially desirable. Pupils seem to have no difficulty in assembling or using the apparatus after it has been once set up, explained, and taken down. I wish to emphasize the teaching value of the "taking down."

If any teachers contemplate using such an apparatus for such work, I should be glad to hear from them with regard to any difficulties or any successes they may have.