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A GALVANOMETER FOR MEASURING RESISTANCE BY THE METHOD OF SUBSTITUTION.

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A galvanometer to be suitable for measuring resistance by the method of substitution must be sensitive to small *changes* in current strength. Its own resistance must be small in comparison with that which is to be measured; its coils close to the needle, so as to give a strong enough deflecting field; the controlling field weak; and the suspension of the needle delicate. Tangent galvanometers, and also the fairly sensitive galvanometers usually found in high school laboratories, are not suitable for this purpose. With the best of more than half a dozen such instruments which the writer found in a high school when he came to teach there, about five years ago, the resistance in series with it and a Daniell element had to be changed about 10 per cent in order to produce a barely perceptible change in the deflection; and when he recently questioned a number of physics teachers in the eastern states of the Union concerning their experience he failed to find a single one who felt sure that he could measure a few ohms by the substitution method closer than 20 or 30 per cent. And yet with such apparatus pupils are often expected to *discover* or to *prove* such things as the laws describing the variation of the resistance of a wire with its dimensions!

To improve matters the galvanometer illustrated in the accompanying figure was designed*. The controlling magnetic field of this is adjustable, enabling the sensitiveness to be adapted to the needs of the case in hand. It was found very easy to secure such sensitiveness that, when any resistance from 1 to 10 ohms was in

* In the plan the tumbler carrying the control magnets is removed to show the coils and the suspension.

series with the galvanometer and a Daniell cell, the deflection of a pointer 14 cm. long would change 0.1 mm. for a change in the resistance of from 0.1 per cent. to 1/40 per cent.; in fact, the falling off of the current furnished by the cell was perceptible in a few seconds. By using a longer pointer or a mirror, even smaller changes could readily be measured. This instrument is also easy to construct and cheap.

The coil, which is of rectangular cross section, is formed of six turns of ordinary insulated copper wire about 1 mm. in diameter, and is fastened with sealing-wax in a rectangular hole cut in the middle of the small board A, the ends terminating in the mercury cups B. To make room for the magnet suspension, half of the turns are slightly separated from the remainder. A is screwed as indicated across the top of a shallow rectangular box of wood, whose ends are covered by pieces of window glass C.

The magnet is a small bar of hard steel. Around this is wrapped and soldered a single turn of fine brass wire, which extends upward to form a hook for the attachment of the suspending fibers (3 or 4 of unspun silk), and downward to carry a small damper immersed in kerosene. The long, thin glass capillary D that forms the pointer is fastened with wax in a loop similar to that holding the magnet. One end of this is drawn out to a very fine point and dipped in India ink until this ascends two or three millimeters. The strong contrast between this sharp, black point and the white background of the scale E beneath (which may be a piece of measuring rod, or of co-ordinate paper divided into millimeters) enables tenths of divisions to be estimated with ease. Parallax is avoided by the use of the mirror F. Two brass pins G limit the motion of the pointer.

The brass wire frame H, bent out of one piece, is fastened with four copper tacks to the upper surface of A. Sliding with slight friction along the horizontal part of H is a cork, through a second hole of which slides the wire I, whose lower end terminates in a small hook for the attachment of the fibers supporting the magnet. This form of suspension permits motions in three directions at right angles to one another, as well as rotation about a vertical axis, so that the magnet can be centered and any desired torsion given to the fibers; and if the friction of the wires in the cork is

eased with a little tallow, the adjustment can be made with great delicacy.

The whole suspended system is covered with an ordinary drinking tumbler, secured by the three wire springs J, so that it may be readily removed, and, when in position, may be rotated with slight friction about a vertical axis. On top is cemented a wooden block K to carry the control magnets L. These are made of old clock springs about 1 cm. wide, softened in the middle to permit punching or drilling the holes through which the screw M passes for securing them to K. Brass or copper washers prevent their touching each other, and facilitate turning about M as an axis.

In assembling the parts of the galvanometer, the vessel for the kerosene must be filled and the glass pointer laid across its top before the board A is screwed in place. In order to balance the pointer so that it will be horizontal when freely swinging, the arm that does not come over the scale is made too long, and then gradually shortened by breaking off the end until it remains just a trifle heavier than the pointed arm. The final adjustment is made after it is mounted in the galvanometer by fusing the heavier end with a minute gas flame until the desired balance is obtained by the shortening due to the surface tension of the melted glass. If a mirror is substituted for the pointer, the horizontal dimensions may be reduced to those of A, and a window covered by a microscope slide must be placed in one side of the box.

When necessary to move the galvanometer, the suspended system is lowered until the pointer rests on the vessel containing the kerosene.

METHOD OF USE.

Connect the galvanometer in series with the unknown resistance and with a Daniell or other cell of constant E. M. F. and low resistance. The deflection will probably bring the pointer against one of the stops. Turn the control magnets until their like poles are somewhat near each other, so as to produce a strong field; and rotate the tumbler until the direction of the field is such that the pointer is brought to about the middle of the scale. Then gradually separate the like poles of the magnets until the field is just barely strong enough to hold the pointer in this position.

When the needle comes to rest, read the position to a tenth of a division. Then, *without* disturbing the galvanometer adjustment, replace the unknown resistance by a resistance box* divided to tenths of ohms, and find the deflections produced by each of two resistances differing by one tenth of an ohm, between which the unknown resistance lies. The hundredths of ohms can now be found by interpolation. If great sensitiveness is not desired, time may be saved by not weakening the control field so much.

ANOTHER ALGEBRAIC BALANCE.

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In the June number of *SCHOOL SCIENCE AND MATHEMATICS*, F. C. Donecker describes an interesting balance designed to illustrate some of the fundamental operations on algebra.¹ The balance in question is quite fertile in possibilities. The use of the negative number, addition, subtraction, multiplication and division of positive and negative numbers as well as transformations of linear equations are exhibited to the eye.

The writer has used similar devices in his classes in algebra. The apparatus described in this note is of the same general character as that described by Mr. Donecker. There are points of difference, however, which the writer thinks are of sufficient importance to warrant a description in this journal of the whole apparatus. The material required for its construction can readily be obtained from the physical or chemical laboratories of any well-equipped high school.

A hole large enough to admit a small bolt is bored through the center of an ordinary meter-stick, which is then made to swing freely about a fixed point, O, producing an ordinary balance. About twelve inches above the meter-stick is a fixed horizontal rod parallel to the meter-stick and slightly longer. This rod as well as the meter-stick may be clamped to ordinary iron standards, as shown in the figure. One end, A, of the meter-stick is connected with the fixed rod and also with the table by means of

* A very convenient and easily constructed resistance box, which cannot be injured by such use, has been described by the writer in *SCHOOL SCIENCE AND MATHEMATICS*, 32, p. 188, 1905.

¹ "An Algebraic Balance," by F. C. Donecker, *SCHOOL SCIENCE AND MATHEMATICS*, Vol. V, (1905), p. 411.