being that the virtual image of the object shall lie at the axis of rotation.

The arrangements shown in Figs. 1a and 1b have been used with good success in simple air-driven microscope centrifuges.[2]

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A PIEZOELECTRIC ULTRAMICROMETER

THE ultramicrometer is an instrument for the measurement of linear displacements smaller than those accessible by the methods of optical interferometry, which are limited by the wave-length of light. Whiddington,[1] using two oscillating electrical circuits tuned so as to produce an audible beat-tone, was able to extend the sensitivity of measurement to a value somewhat smaller than 10^{-8} cm. This was accomplished by the measurement of the variation of beat-tone between the two circuits, this variation being a measure of the change of frequency produced in one of them by the change of capacity of its condenser caused by alteration of distance between condenser plates. Another method consists in exciting a resonant circuit by an oscillator at such a frequency that the response of the resonant circuit is most sensitive to a variation of exciting frequency; the amplitude of current in the resonant circuit will then register a change caused by a shift in frequency, as that produced by a change in distance apart of the plates of a condenser in the exciting circuit. This method, with especially designed circuits, has been developed at the Bell Telephone Laboratories for the measurement of displacement of microphone contacts,[2] the sensitivity being such that a displacement of a condenser plate by 10^{-8} cm could produce a galvanometer deflection of one inch.

A piezoelectric quartz plate provided with suitable electrodes is the equivalent of a resonant electrical circuit, and the properties of such plates have been studied extensively by W. G. Cady[3] and by D. W. Dye.[4] When the plate electrodes are connected to the terminals of the condenser in a simple resonant circuit which is being excited by an external source of variable frequency, the response curve (*e.g.*, effective current plotted against frequency) of the circuit is modified by a deep cleft or *crevasse* at the natural frequency of the quartz plate. This *crevasse* is extraordinarily narrow and its sides are so steep that if the operating frequency of the exciting circuit be set so as to correspond to a point of the steepest slope, a small change of the exciting frequency will cause a correspondingly large change in the oscillatory current in the resonant circuit connected with the quartz, and a thermogalvanometer in this circuit will register a corresponding change of reading. In general, changes of frequency much too small to be detected by usual methods will cause a measurable change in the galvanometer reading.

Using a quartz plate of 600 KC resonant frequency, a frequency change of one sixtieth of a cycle per second may be detected, corresponding to a frequency change of about three parts in one hundred million. Such a change in frequency may be caused by a minute change in the distance between the plates of a condenser in the exciting circuit. The practical limits to which measurements may be pushed depend upon the stability of frequency of the exciting circuit and upon the freedom from minute mechanical disturbances of the small condenser, the displacement of one plate of which is to be measured. To test the method a micrometer condenser has been constructed so that each plate is attached to a separate support clamped to a heavy steel rod. Adjustments are provided for making the plates parallel and for making relatively large variations of plate distance by means of a micrometer screw. Additional known micro-variations of plate distance are made by applying small known bending forces to the steel rod. A variable condenser in parallel is provided so as to operate the micrometer condenser at any desired plate distance and thus to secure a wide range of sensitivities. In the experiments which have so far been carried out displacements of 10^{-9} cm have been measured to a few per cent., though no special precautions have been taken against mechanical disturbances. By taking such precautions it is expected that displacements of 10^{-10} cm may be measured. The attainment of a sensitivity of this order should open a new avenue of approach to a number of important problems.

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