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"Nec aranearum sane textus ideo melior quia ex se fila gignunt, nec noster vilior quia ex alienis libamus ut apes." JUST. LIPS. *Polit.* lib. i. cap. 1. Not.

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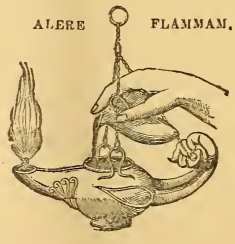
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"Meditationis est perscrutari occulta; contemplationis est admirari perspicua .... Admiratio generat quæstionem, quæstio investigationem, investigatio inventionem."—*Hugo de S. Victore.*

——"Cur spirent venti, cur terra dehiscat,
Cur mare turgescat, pelago cur tantus amaror,
Cur caput obscura Phœbus ferrugine condat,
Quid toties diros cogat flagrare cometas,
Quid pariat nubes, veniant cur fulmina cœlo,
Quo micet igne Iris, superos quis conciat orbes
Tam vario motu."

J. B. Pinelli ad Mazonium.



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fairly indicated because of the presence of electrical circuits in the neighbouring rooms of the laboratory and a changing distribution of iron about the building.

VI. *Summary.*

1. A magnetometer has been designed and built, depending on the property of the cathode rays being deflected by a magnetic field, the deflexion being compared with that produced by a known standard field.

2. A Wehnelt cathode is used to impart a low velocity to the electrons, resulting in measurable deflexions for the weak magnetic fields. The deflexions are recorded on a photographic plate.

3. The elimination of the earth's magnetic field for a zero reading of the deflexion is avoided by mounting the tube so as to turn about a vertical axis, and deflexions observed for different orientations.

4. The magnetometer is also a declinometer of sufficient precision for setting the coil in a plane perpendicular to the magnetic meridian.

5. Account is taken of the fact that the field of the standard coil is not uniform along the path of the rays, and an analytical solution of the problem is found.

6. Seven determinations of H have been made with a relative probable error in the fourth significant place.

The general design and construction of the apparatus is that of the senior author, who also did a part of the preliminary work. The junior author supplied some of the details of construction, deduced the formula, and made the final observations and the necessary calculations.

Laboratory of Physics,
University of Illinois,
June 9, 1916.

XLIII. *On the "Wolf-note" in Bowed Stringed Instruments.* *By* C. V. Raman, *M.A.**

[Plate IX.]

IT has long been known that on all musical instruments belonging to the violin family there is a particular note which it is difficult to elicit in a satisfactory manner by bowing. This is called the "wolf-note," and when it is sounded the body of the instrument is set in vibration in an

* Communicated by the Author.

unusual degree; and it appears to have been realized that the difficulty of maintaining the note steadily is due in some way to the sympathetic resonance of the instrument*. In a recent paper †, G. W. White has published some interesting experimental work on the subject, confirming this view. The most striking effect noticed is the *cyclical* variation in the intensity of the note when the instrument is forced to speak at this point. White suggests as an explanation of these fluctuations of intensity that they are due to beats which accompany the forced vibration impressed on the resonator when the impressed pitch approaches the natural pitch of the system. The correctness of this suggestion seems open to serious criticism. For, the beats which are produced when a periodic force acts on a resonator are of brief duration, being merely due to the superposition of its forced and free oscillations, and when, as in the present case, the resonator freely communicates its energy to the atmosphere and the force itself is applied in a progressive manner and not suddenly, such beats should be wholly negligible in importance, and should, moreover, vanish entirely when the impressed pitch coincides with the natural pitch.. In the present case the essential feature is the *persistency* of the fluctuations of intensity and their markedness over a not inconsiderable range; and it is evident that an explanation of the effect has to be sought for on lines different from those indicated by White. I had occasion to examine this point when preparing my monograph on the "Mechanical Theory of the Vibrations of Bowed Strings," which will shortly be published, and the conclusions I arrived at have since been confirmed by me experimentally.

From the mechanical theory, it appears that when the pressure with which the bow is applied is less than a certain critical value, proportionate to the rate of dissipation of energy from the vibrating string, the bow is incapable of maintaining the ordinary mode of vibration in which the fundamental is dominant, and the mode of vibration should progressively alter into one in which the octave is the predominant harmonic ‡. In the particular case in which the frequency of free oscillation of the string coincides very nearly with that of the bridge of the violin and associated masses, the mode of vibration of the string is *initially* of the well-known type in which the fundamental is dominant.

* Guillemin, "The Application of Physical Forces," 1877.

† G. W. White, Proc. Camb. Phil. Soc. June 1915.

‡ Compare with the observations of Helmholtz, 'Sensations of Tone,' English Translation by Ellis, p. 85.

But the vibrations of the string excite those of the instrument, and, as the vibrations of the latter increase in amplitude, the rate of dissipation of energy increases continually till it outstrips the critical limit, beyond which the bow fails to maintain the usual type of vibration. As a result of this, the mode of vibration of the string progressively alters to a type in which the fundamental is subordinate to the octave in importance. The vibration of the belly then begins to decrease in amplitude, but, as may be expected, this follows the change in the vibrational form of the string by a considerable interval. The decrease in the amplitude of the vibrations of the belly results in a falling off of the rate of dissipation of energy, and, when this is again below the critical limit, the string regains its original form of vibration, passing successively through similar stages, but in the reverse order. This is then followed by an increase in the vibrations of the belly, and the cycle repeats itself indefinitely. The period of each cycle is approximately twice the time in which the vibrations of the belly would decrease from the maximum to the minimum, if the bow were suddenly removed.

The foregoing indications of theory are amply confirmed by the photographs reproduced in Plate IX., which show the simultaneous vibration-curves of the belly and string of a 'cello at the wolf-note pitch. It will be seen that the form of vibration of the string alters cyclically in the manner predicted by theory, and that the corresponding changes in the vibration-curve of the belly *follow* those of the string by an interval of about quarter of a cycle. That the two sets of changes are dynamically interconnected in the manner described is further confirmed by the prominence of the octave in both curves at the epochs of minimum amplitude. The explanation of the cyclical changes given above is also in accordance with the observed fact that they disappear and are replaced by a steady vibration when the ratio of the pressure to the velocity of bowing is either sufficiently increased or sufficiently reduced. In the former case the string vibrates in its normal mode, and in the latter case the fundamental disappears altogether and the string divides up into two segments.

Effect of Muting on the "Wolf-note."

Since the pitch of the wolf-note coincides with that of a point of maximum resonance of the belly, we should expect to find that by loading the bridge or other mobile part of the body of the instrument important effects are produced.

This is readily shown by putting a mute on the bridge. The pitch of the wolf-note then falls immediately by a considerable interval. On the particular 'cello I use, a load of 17 grammes fixed at the highest point of the bridge lowers the wolf-note pitch from 176 to 160 vibrations per second. A larger load of 40·4 grammes depresses it further to 137 vibrations per second, and also causes two new but comparatively feeble resonance-points to appear at 100 and 184 respectively, without any attendant cyclical phenomena. An ordinary brass mute has a very similar effect.

The Formation of Violin-tone and its Alteration by a Mute.

The positions of the frequencies of maximum resonance of the bridge and associated parts of the belly for notes over the whole range of the scale are undoubtedly of the highest importance in determining the character of violin-tone, and the explanation of the effect of a mute on the tone of the instrument is chiefly to be sought for in the effect of the loads applied on the frequencies of the principal free modes of vibration of the bridge and associated parts of the belly. The observations of Dr. P. H. Edwards on the effect of the mute * are evidently capable of explanation on the basis of the lowering of the frequencies of maximum resonance by the loading of the bridge. But a more detailed understanding of the dynamics of the problem requires further theoretical and experimental investigation. Recently, I have secured an extensive series of photographs showing the effect on the motion of the bridge in its own plane produced by fixing a load on it at one or other of a variety of positions. The close parallelism between the effect of loading, as shown by these photographic curves and as observed by the ear, seems to show that the motion of the bridge in its own plane determines the quality of violin-tone to a far greater extent than might be supposed from the work of Giltay and De Haas †. A detailed discussion of this and other problems relating to the physics of bowed instruments is reserved for a separate communication.

This investigation was carried out in the Laboratory of the Indian Association for the Cultivation of Science, Calcutta.

20th May, 1916.

* P. H. Edwards, Physical Review, January 1911.

† Giltay and De Haas, Proc. Roy. Soc. Amsterdam, January 1910. See also E. H. Barton and T. F. Ebblewhite, Phil. Mag. September 1910, and C. V. Raman, Phil. Mag. May 1911.

Note dated the 8th of August added in proof.

Since the paper was first written, several other interesting effects have been noticed, of which the following is a summary:—

(*a*) Cyclical forms of vibration of the G-string and belly of a 'cello may also be obtained when the vibrating length is double that required for production of the wolf-note, that is, when the frequency is half that of the wolf-note. In this case, when the pressure of the bow is sufficient to maintain a steady vibration, the second harmonic in the motion of the belly is strongly re-inforced. When the pressure is less than that required for a steady vibration, cyclical changes occur, the principal fluctuations in the motion, both of the string and the belly, being in the amplitude of the second harmonic. In this, as in all other cases, the cyclical changes disappear and give place to a steady vibration, when the bow is applied at a point sufficiently removed from the end of the string. In this particular case, a large, *almost soundless* vibration may be obtained by applying the bow rather lightly and rapidly at a point distant one-fifth or more of the length from the end; the octave is then very weak in the vibration of the string, but may be restored, along with the tone of the instrument, by increasing the pressure of the bow.

(*b*) The 'cello has another marked point of resonance at 360 vibrations per second. The pitch of this is also lowered by loading the bridge.

(*c*) When the vibrating length of the G-string or A-string of the 'cello is about a fourth of the maximum or less, cyclical forms of vibration may be obtained at almost any pitch desired, by applying the bow with a moderate pressure rather close to the bridge.

(*d*) As the frequency of vibration is gradually increased from a value below to one above the wolf-note frequency, the phase of the principal component in the "small" motion at the end of the string, that is also of the transverse horizontal motion of the bridge, undergoes a change of approximately 180°. This is in accordance with theory.