ista veneziano del sec. XVIII."; Ant. Favaro, "Matteo Carosio (Amici e corrispondenti di Galileo. XLI.)"; Gino Loria, "Per una storia della matematica nel secolo XIX."; Andrea Corsini, "L''influenza' oggi e nel passato"; Studi e Note Vinciane Proemio, D. T. Per l'edizione nazionale delle opere di Leonardo, Notizie varie; Bibliografia metodica dei lavori di storia della scienza publicati in Italia; Analisi critiche: R. Almagià, Cristoforo Colombo (G. Stefanini); U. Viviana, Andrea Cesalpino; R. Marcolongo, Il problema dei tre corpi; W. Libby, An Introduction to the History of Science (A. Mieli); Gli Scienziati Italiani, Aggiunte, note e discussiono; Notizie e Commenti: Organizzazioni italiane per promuovere lo studio della storia della scienza (A. Mieli). La storia della scienza nelle Università—Notizie varie.

Due credit must be given, even to-day, to the Germans for their activity in the publication of journals of an international character. However, Americans should now realize the desirability of stimulating and encouraging Italian, English and other European scientific publications of an international character. The revived Belgian journal *Isis,* now published by Dr. George Sarton and Dr. Charles Singer, of Oxford, should be remembered in this connection.

The best way to stimulate these publications is by personal subscription and by personal interest on the part of scientists in urging upon librarians the subscription to these enterprises.

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SPECIAL ARTICLES

THE MOTION OF A GRAVITATING NEEDLE[1]

1. *Static Elongations.*—The apparatus[2] with which I am working is of the simplest character, but judiciously designed. Two shots ($m = .6$ gram), one at each end of a straw shaft 22 cm. long (diagram 1*a*), are supported by a long quartz fiber, fixed with cement above and below. The attracting weight ($M = 1$ kilog., or more) can easily be moved from one side to the other and definitely placed by a smooth-working crank mechanism, between stops. Observations are made in a dark room (except for distant lamp light), in a damp, semi-subterranean basement, in midsummer, with very fair constancy of temperature and no electric charges. The motion of the needle is essentially creeping with a period (if I may so call it) of 20 or 30 minutes. The scale distance is over 4 meters from the little mirror at the center of the shaft. The observer keeps out of the way.

Under these circumstances reasonably constant scale deflections, for periods of alternation exceeding 30 minutes would be expected; but the reverse of the case. Here is an example of the successive mean excursions or double amplitudes of the needle during the day:

July	16	17	18	19	20
Scale displacement in cm	2.79	3.02	3.27	2.79	3.65
July	21	22	23	25	25
Scale displacement in cm	4.03	3.64	3.07	4.50	5.39

The values of the morning and afternoon readings were equally different. Individual excursions may run as high as 6 cm. on certain days, though the behavior is throughout, of course, quite systematic.

2. *Triplets for three-minute Periods.*—The results for short period alternations of the pull of M (3 minutes in the examples given, Figs. 1, 2, 3) are equally bizarre; though, here they become interesting. In Fig. 1, the turning points of M are indicated by little circles, R and L are pulls to right and to left, respectively, and the mean double amplitude of the successive triplets are marked on the curves. There is drift throughout the figure; otherwise the behavior is about what would be expected. Inertia apparently carries the ball a little time after the gravitational pull has changed sign. But for this, there would be a phase difference of 90° as there should be. Moreover, the motion of the needle, after turning, is uniform.

[1] Advance note from a Report to the Carnegie Institution of Washington, D. C.

[2] *Proc. Nat. Ac. Sc.,* IV., 338, 1918.

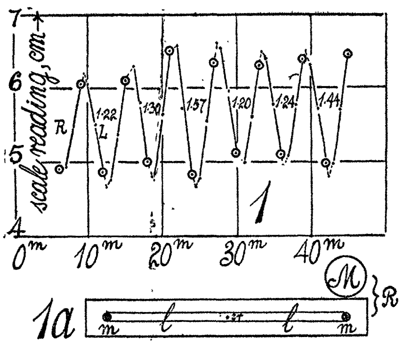

FIG. 1.

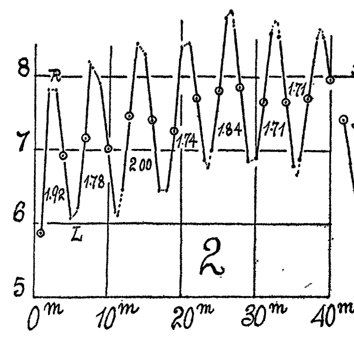

FIG. 2.

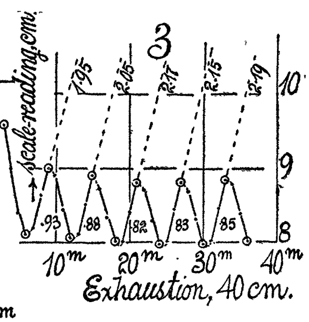

FIG. 3.

In Fig. 2, made under the same circumstances on a different day, the phenomenon is totally changed. The needle turns in the middle of the interval between the turning times of the pulling weight. There is no phase difference, while the drift has been accentuated. The triplets are larger, though the motion within the branches is still uniform. Similar observations were obtained with a downward drift. So I might adduce examples with all kinds of phase-differences, in some of which what was called "inertia" in relation to Fig. 1, comes just *before* the reversal of the pull! For the same reason alternations in periods of one minute each rarely succeed.

It is obvious therefore, that in addition to the gravitational attraction there is in all these cases evidence of the development of an attractive (or in Fig. 2, of a repulsive) force more or less rapidly after the weight is turned.

3. *Radiation.*—The extraneous forces originating in *M* are clearly referable to radiation. We may argue plausibly that, if *M* be warmer than *m*, there is excess of convection on the *M* side and a corresponding part of the pressure is converted into kinetic energy. Attraction apparently results. In the opposite case (colder *M*), there is repulsion such as is evidenced, for instance, after the semi-periods in Fig. 2. The relative magnitude of the radiation forces is astonishing. One has merely to warm the ball *M* with the hands, in order to increase the "gravitational attraction" five or ten times. Again on cooling the ball in tap water only a few degrees below that of the room, repulsion may be obtained. Thus when the external temperatures are increasing even if very slowly, outside objects like *M* are hotter and the excursions of § 1 are large; and vice versa.

The warmer ball remains effectively though decreasingly so, for hours, even when it has become cold to the touch. Normal experiments are not again feasible until the day after.

4. *Radiation in Vacuo.*—At this point it was therefore necessary to build another apparatus, capable of being exhausted. This was done, and experiments similar to the last performed, by exhausting the interior in successive steps of 0–10 cm., 10–20 cm., etc. Thus again the interior was cooled relative to the exterior and there was an influx of radiation, the character of which was made evident by hanging the needle somewhat obliquely to the vertical walls of the case.[3] The ball *M* was discarded. It was found that the attractive forces obtained in each of these successive steps of exhaustion (allowing the needle to get back to equilibrium before the next step) gradually diminished with the decrease of pressure, until between 60 and 70 cm., there was no appreciable effect. For higher exhaustions (70–74 cm.) the attractive forces were reversed and became strong repulsive forces.[4] In other words at this point the radiometer forces supervene

[3] I give this explanation with some reservations. All that is in question is a reversible inequality of radiation on the two sides.

[4] Deflections of + 15 cm. and — 15 cm. were observed, respectively, at the first and last drop of pressure, whereas the gravitational deflection is but 3 or 4 cm.

and the pressures are larger on the warmer side of the needle. It follows therefore that one can eliminate the radiation discrepancies by work done in partial vacuum. In fact with the exhaustion somewhat below 70 cm., I heated the ball M (restored) as far as was safe, 60°–70°, without obtaining any appreciable effect on the needle. This suggests the method of obtaining trustworthy static data.

Exhaustions of even 40 cm. give very good results. In Fig. 3 for instance, obtained with the new apparatus (scale distance 265 cm., therefore less sensitive), there is no drift and the whole motion soon becomes steady, so that the triplets (data given on the curve) become repetitions of each other. Between the turning points the motion is uniform.

A further important result was substantiated. The size of the triplets, or better the speed of uniform motion between the turning points was the same, independent of pressure, from a plenum up to 70 cm. In Fig. 3 some of these speeds are given as displacements per 5 minutes inscribed on the lines prolonged. Improvement would not be difficult. Hence these resistances independent of the pressure or density of the air must be due purely to the viscosity of the medium and it must be possible to express the gravitational attraction in terms of the viscosity of air. This project is further elucidated tentatively, in the next paragraph.

5. *Tentative Estimate.*—The resistance experienced by a sphere of radius, r moving in a viscous fluid (η) with the velocity $v = l\omega$, is well known to be $6\pi\eta rv$. I do not happen to be familiar with the corresponding expression for a cylinder of radius r, semi-length l and with hemispherical ends, moving broadsides on. To get a mere order of values, however, I will postulate, that for equal frontal areas,

$$\pi r^2 = 2r \cdot \Delta l$$

the resistances are alike. Thus the element of resistance is

$$dF = 6\pi\eta rv = 6\sqrt{\pi}\eta l\omega\sqrt{\pi r^2} = 6\sqrt{\pi}l\omega\sqrt{2r \cdot \Delta l} = \omega\eta\sqrt{24\pi r\Delta(l^3)}$$

and this is to be integrated for the double length of the needle ($2l$). To carry out the integration put $l = n \times 2r$ where n is a serial number. The equation becomes

$$\Delta F = 8\omega\eta r^2\sqrt{3\pi\Delta(n^3)}$$

and the problem is reduced to the summation of a series of cubes

$$2\sqrt{\Sigma n^3} = n(n+1),$$

the length being $2l$. Hence finally for two masses M, m, at a distance R apart, disregardin corrections,

$$\gamma = 8\sqrt{3\pi}\eta\omega(R^2/Mm)n(n+1).$$

The constants of the second apparatus were:

$$M = 1602 \text{ grams}, \; m = .563 \text{ grams},$$

$$R = 5.1 \text{ cm.}, \; 2r = .4 \text{ cm.}, \; 2l = 22.8 \text{ cm.}, \; \eta = .00019, \; n = 28.5.$$

In Fig. 3, the last three scale rates have the mean value 2.17 per 5 minutes, or

$$\omega = 2.17/300 \times 530 = .00001364$$

radians per second, the scale being off 265 cm. Inserting these data into the equation, $\gamma = .10^{-8} \times 6.2$, which is much closer to the standard value than, from the improvised apparatus and inadequate theory, I had expected to get. It sufficiently substantiates, I think, the assumed purely viscous character of the resistance and moreover shows that the constant of gravitation may probably be found, with precision, in terms of the resistance, in air, to the uniform motion, broad-sides on, of a cylinder with hemispherical ends.

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