Further History of a Quartz Thread Gravity Balance

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III. *Further History of a Quartz Thread Gravity Balance.*

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A former paper* by one of the present authors and JAMES ARTHUR POLLOCK contains an account of the construction of a quartz thread gravity balance which was made at the University of Sydney during the time R. THRELFALL was Professor of Physics there. This work extended from 1889 up to the time of publication, and included an account of a good many gravimetric observations at Sydney, Melbourne, Hobart, and at various places in New South Wales. Final tests were made by taking the balance to and fro between Sydney and Hornsby, which is near Sydney but is 592 feet above sea-level, the University of Sydney, which was the Sydney observation station, being only slightly above sea-level (120 feet). As the result of several such journeys we finally felt entitled to say that "We have therefore determined the value of g at Hornsby relatively to that at Sydney in three journeys with a maximum difference of 0·4 sextant minutes, or to less than 1 part in 500,000 in the value of g." It had been intended to embark on a series of observations on the Australian coast, but, unfortunately, R. THRELFALL returned to England in 1898 and arrangements for carrying on the work had to be considered. J. A. POLLOCK succeeded R. THRELFALL as Professor of Physics at the Sydney University, and it was arranged that the balance, which, by the way, had been exhibited at the British Association Meeting at Dover, should be in J. A. POLLOCK's charge and that he should continue the work in so far as his new duties as Professor of Physics enabled him to do so. Unfortunately, an opportunity never occurred and the balance was stored in one of the cellars of the Physical Laboratory of the University till 1923. Meanwhile Professor POLLOCK died.

In 1923 Sir FRANK SMITH, at that time Director of Research at the Admiralty, suggested that it would be interesting to get the balance to England with a view to seeing what condition it was in, and, if possible, to make use of it. This was done, and in September 1923, the balance was unpacked and mounted in the Magnetic Annexe of the National Physical Laboratory, through the kindness of the Director. In what follows it is assumed that the reader has ready access to the original paper (*loc. cit.*). Great difficulties were encountered, for of set purpose no oil had been used in the arrestor of the balance for fear that an oil film might creep on to the lever whose equilibrium position indicated the intensity of gravity. It was thought at first that it would be impossible to free the arrestor and allow the lever to swing, but by opening the balance

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* 'Phil. Trans.,' A, vol. 193, p. 215 (1899).

it was ultimately found to be possible to get the arrestor to work and to restore the balance as an observational instrument. It was also found that the reading position of the sextant arm had altered by something like 30 sextant degrees, and some re-adjustment was necessary. It was then found that the coils of the resistance box used in conjunction with the platinum thermometer had altered, and the thermometer itself had altered very considerably in resistance. The reason for this was that the platinum thermometer had been originally constructed by winding the platinum wire on an exceedingly thin glass tube. During the 27 years that had elapsed the glass tube, which had been held from one end in a horizontal position, had sagged, and no doubt strained the wire in so doing. The fluid used to fill the very sensitive level employed in the instrument had escaped, and in an attempt to restore this the level was unfortunately broken and a new one had to be obtained—a matter of some difficulty, having in view the great sensitiveness required. Worst of all, however, the instrument was no longer air-tight, and an enormous amount of time was taken up in tracing and curing the small air leak which had appeared. Meanwhile the whole of the temperature measuring gear was reconstructed, and the workmanship of the instrument itself was greatly improved by Mr. C. H. BEASLEY, the authors' mechanical assistant. All this amounted practically to a reconstruction of the instrument, the only part remaining untouched being the thread and its connections. We desire to express our deep gratitude to Mr. C. H. BEASLEY for his great help in this matter, and also for his valuable assistance in the preparation of the drawings showing our proposals with regard to the construction of a new instrument.

The re-establishment of the platinum thermometer proved to be a formidable task. Fortunately, we had the advantage of the help and advice of the National Physical Laboratory, so that some improvement in detail was achieved. The thermometer wire was wound on a stiff brass tube. The wire was supported on mica, which was held by saw cuts made in the brass in the ordinary way, so as to be thoroughly in contact with the atmosphere in the balance. The resistances in the box were again of manganin, and it was the adjustment of these coils that took so long a time, as special wire bridges had to be made to enable proper comparisons by the Carey-Foster method to be carried out. The wires employed in these bridges were also of manganin, and it is not easy to get manganin wire in lengths of 1 or 2 metres of sufficient uniformity for our purpose. The fact that the thermometer was built on a tube enabled us, in filling the balance case, to circulate plenty of air; this proved to be an advantage. The final data of the box are as follows:—

Large coil	35·3368 ohms.
Equal arm coils	9·98815 ohms.
5° coils	0·6585 ohms.
1° coils	0·1314 ohms. (This should be 0·1317 ohms, hence the error is 0·0003 ohms, or 1/400° C.)

For some years one of the authors had no assistance and was indeed too much occupied in other matters to work at the balance except at rare intervals, and it was not until he was joined by Mr. A. J. DAWSON in 1926 that anything like regular work became possible. After some preliminary experimenting as to the effect of travelling and so forth on the instrument, it was decided to make a preliminary study of its behaviour when kept in a definite position. A building, which had been used as a mazagine during the war, was therefore fitted up at the works of Albright & Wilson, Ltd., at Oldbury, and an attempt was made to ascertain what was the best method of observing as a routine matter. For instance, in the original work the lever had always been clamped in a definite position at the close of each observation, but it was soon found that slightly greater consistency was obtained by omitting the clamping—leaving the lever to swing freely—the jaws of the arrestor being opened sufficiently to allow the lever to swing through an arc of 30°, the sextant arm being, of course, always set to a definite reading. In practice it would not be possible to adopt such a procedure, for the balance has to be clamped before it can be transported, but we hoped that observations made without the complication of clamping might throw some light on the cause of the small variations in reading which we have always treated as experimental errors. The fact that the observations were only slightly more consistent when clamping was not resorted to seems to be connected with the opinion we entertained, namely, that the main deviations were due to temperature uncertainties, but that a small contribution was nevertheless made by the disturbance caused by the clamping. Observations were made, of the action of a strong magnet, to test the possibility of some magnetic effect, but not the slightest sign of any such action could be found. The possibility of the lever becoming electrified was also examined, by bringing up a considerable quantity of radium to the window which lets in the light by which the lever is observed, but in no case was any effect observed.

The net result of observations made at Kew and Teddington between February 1928, and December 1928, and at Oldbury in 1927 and again in 1930–31, did not indicate that the behaviour of the balance was materially different from its behaviour in Australia up to 1898, as detailed in the original paper. Mention may be made, however, of two observational experiences.

(1) When it is desired to observe the balance without clamping the lever between successive observations, it is necessary that the sextant arm should be moved slightly, so as to reduce the twist of the fibre. This is necessitated by the fact that the lever, being habitually observed as close to the position of instability as possible, would upset, so far as the arrestor jaws permitted, if the temperature rose more than a few degrees. This upsetting of the lever would alter the strain in the fibre much more than ever happens during a set of ordinary observations. On several occasions during the work the lever did upset, and remained upset for periods up to several days. The zero reading and daily rate were proportionately altered. This involved considerable loss of time, as after the daily rate has been suddenly changed a considerable period—several

weeks—has to elapse before the rate again becomes sufficiently uniform for useful observations.

(2) After the observations without clamping had been discontinued in November 1930, and the normal procedure of keeping the lever clamped between observations had been resumed, it was found that the balanced position of the lever was subject to a daily rate very much in excess of anything we had previously experienced. This rate was now of the order of 10 minutes per diem, and in the direction of requiring that the fibre should be more twisted to bring the lever to the sighted position. It was not until February 1931, that the rate again became normal and approximately steady, the sextant reading now being about 6° lower than its value in November 1930. We fear that this phenomenon may be due to slight slipping at the soldered joints between the quartz fibre and the lever, or between the quartz fibre and the end points to which it is attached. In support of this we have the following facts. In July and August 1927, observations were made for a period of about 3 weeks during which time the lever was unclamped. On resuming the clamping at the end of the period and continuing daily observation, no change in the daily rate took place. Between 1927 and 1930 the balance had, however, been dismantled for the purpose of tracing faulty joints which were causing air leakage into the instrument, and it occurred to us that the observed fall in sextant reading noted above might possibly be due to strains in the metal work suddenly becoming relieved. The internal framework carrying the thread is made of brass and is enclosed in a copper tube to which it is rigidly connected at one end, the other end being fastened by securely driven brass wedges. As the metals involved have different rates of thermal expansion, there seems a possibility that, firstly, the whole structure might become distorted with change of temperature causing minor irregularities in the observations, and secondly, that actual slipping at the wedges might occur, such slipping being induced by the strains imposed on the framework when reassembling the instrument and driving in the wedges. The cover of the instrument at the end opposite the sextant was therefore removed and the brass wedges were replaced by wedges of soft rubber. On reassembling the instrument and continuing observations, it was found that no change had been introduced.

Summarising therefore, we have, with reference to the observed fall in sextant reading, the following information :—

A. The drop in reading between November 1930, and February 1931, was greater than ever before observed and cannot be attributed to daily rate, the rate of fall being over 100 times the daily rate.

B. The effect of overbalancing the lever and leaving it overbalanced is to increase the sextant reading. We have experienced a decrease in sextant reading.

C. A slip of the thread connections would reveal itself as a decrease in sextant reading.

D. The observed drop in reading is presumably not due to the effect of clamping after a period of reading without clamping, since on a previous occasion the same procedure was carried out without influencing the balance reading.

E. It has been proved that it is probably not due to inequalities in frame expansion.

Since we cannot think of any other factor which can account for the phenomenal fall of the sextant reading, the above statements lead us to the opinion that actual slipping at the thread connections has probably taken place.

Having satisfied ourselves by many journeys that the reading of the balance was not affected by travelling, we felt justified in taking advantage of a most helpful offer, received from Sir JOSEPH PETAVEL, to take the instrument to the National Physical Laboratory, and erect it in a basement where the temperature only varies over 2° or 3° throughout the year. This was most attractive, for we had never either in Australia or at Oldbury had the advantage of seeing how the instrument would behave if temperature changes were almost negligible. Moreover, we should learn how a competent, but not specially trained, observer would succeed single-handed in observing, as must often occur in a survey. Accordingly the balance was taken to Teddington on February 1, 1928, and erected in the constant temperature basement. In order to imitate a survey it was considered desirable to take the balance to Kew, and permission was kindly given by the Director of the Meteorological Office, and Mr. WHIPPLE, of Kew Observatory, for us to mount the instrument in one of the cellars. Neither at Kew nor Teddington was it possible for us to change the temperature artificially, as other instruments requiring as nearly uniform temperatures as possible were in position in the basements allotted. If we had been engaged in a really formal attempt to settle the Kew–National Physical Laboratory difference instead of a preliminary trial, the resulting lack of an overlap of temperature at the two stations would have been a source of uncertainty, for it means that one of the series at Kew or National Physical Laboratory would have to be extrapolated by the use of the temperature coefficient. If these are different, then an arbitrary choice would have to be made, and on this choice the result would depend.

The following is an account of observations made at Kew Observatory and the National Physical Laboratory, February–August 1928 (taken from a report of August 17, 1928, by Mr. F. A. GOULD, M.A., Senior Scientific Assistant in the Metrology Department, National Physical Laboratory, the report being based on observations made by Mr. C. H. BONE, Senior Observer, Metrology Department, National Physical Laboratory).

We desire to express our deep gratitude to Mr. GOULD, who reduced many of the observations which form Appendix I, and whose suggestions and comments were most valuable to us. We have to thank Mr. BONE for the great care he took in making the observations single-handed.

The observations may conveniently be divided into six series as follows :—

Series No.	Date, 1928.	Number of individual observations in series.	Place of observation.	Mean temperature as indicated by the resistance thermometer belonging to the balance.
				° C.
1	February 10 to March 15	48	National Physical Laboratory	14·15
2	April 28 to May 1	7	National Physical Laboratory	13·84
3	May 2 to June 8	18	Kew Observatory	11·91
4	June 9 to June 15	7	National Physical Laboratory	14·50
5	July 3 to July 5	3	National Physical Laboratory	14·93
6	August 8	2	National Physical Laboratory	16·86

The relation between the temperature and the reading of the balance was found to be very closely linear (to within the limits of precision of the balance) over the range of temperature corresponding to a given series of observations (*cf. loc. cit.*, p. 236).

In each of the first three series, the temperature coefficient of the balance was determined graphically from the observations. In the remaining series, which were relatively short, the range of variation of temperature from day to day was insufficient to enable the temperature coefficient to be redetermined by this method.

The values of the temperature coefficient determined from Series (1) and (2) at Teddington were as follows :—

Series (1)	—28′ 25″ (sextant scale) per 1° C. at 14·15° C.
Series (2)	—28′ 22″ (sextant scale) per 1° C. at 13·84° C.

(and at Sydney in 1898, —31′ 5″).

As these values were in satisfactory agreement, a mean value of 28′ 24″ (sextant reading) per 1° C. was taken in reducing all the observations made at the National Physical Laboratory to a common temperature of 13° C. for purposes of comparison.

The value of the temperature coefficient determined from the observations at Kew was 27′ 10″ (sextant scale) per 1° C. at 11·91° C. This value was used in reducing the Kew observations to 13° C.

In the absence of facilities for temporarily heating the basement room at Kew, the observations at Kew were specially prolonged in the hope of obtaining temperatures more closely approximating to those at the National Physical Laboratory.

Table II is a summary of the results obtained after reducing all the readings to refer to a common temperature of 13° C.

It can be seen from this table that there was a progressive drift of the balance reading. Examination of the detailed tables in Appendix I shows that the degree of consistency obtained from the balance during short intervals of a week or two is about 30″ (sextant scale), corresponding to a precision of 1 part in about 400,000 in the determination of the

TABLE II.—Summary of Results.

Series No.	Date, 1928.	Mean reading of gravity balance reduced to 13° C.		Difference (Kew less National Physical Laboratory).
		At the National Physical Laboratory.	At Kew.	
		° ′ ″	° ′ ″	° ′ ″
1	February 10 to March 15	60 31 32	—	—
2	April 28 to May 1	60 26 23	—	—
3	May 2 to June 8	—	60 26 4	—
4	June 9 to June 15	60 24 40	—	—
	Mean of (2) and (4)	60 25 31	—	+ 0 0 33
5	July 3 to July 5	60 21 35	—	—
6	August 8	60 13 36	—	—

value of g (*loc. cit.*, p. 241). The existence of the drift, however, seriously complicates matters and possibly explains why a different temperature coefficient was obtained for the Kew and National Physical Laboratory observations. The figures given in Table II for the Kew–Teddington difference (namely 33″) is derived by taking only Series 2, 3 and 4 into consideration, the Teddington value being taken as the mean of the observations obtained immediately before and after the Kew readings. In view of the drift and uncertainty of the temperature coefficient the probable error associated with this figure must be set as wide as $\pm 2' = 1$ in 100,000 of g.

Assuming the same value for the sensitiveness of the balance as deduced from the Melbourne–Sydney difference over 30 years ago (the change in g for 1′ sextant reading $= 4 \cdot 53 \times 10^{-3}$), then the value of g at the National Physical Laboratory as determined by the balance is found to be

$$981 \cdot 201 \pm 0 \cdot 009$$

relative to an accepted value of $g = 981 \cdot 199$ at Kew Observatory (which in turn is based on g at Potsdam $= 981 \cdot 274$) as found from pendulum observations.

It must not be supposed that we put this result forward as the actual value at the National Physical Laboratory as determinable by the balance from the Kew value. In the first place, a calibration of the balance has not been carried out since it was taken from Sydney to Melbourne for the purpose in 1898. In the second place, the temperatures at Kew and National Physical Laboratory did not overlap, so that an extrapolation had to be made in reducing the Kew observations to 13° C., the temperature selected for a comparison. It is merely a figure obtained in the course of work on the behaviour of the balance when readings were made by an observer single-handed. Most important of all, one set of observations at Kew sandwiched between two sets at National Physical Laboratory is inadequate—several interlockings are desirable.

In order to get the maximum of information from the Kew–Teddington observations, a further analysis of the results was made by the authors, in which the correction due to the daily rate or drift was separated from the temperature correction. In the above analysis the drift has been ignored in plotting the observations from which the temperature coefficient was derived, a procedure which was adopted after it was observed that the readings fell fairly well on a straight line whatever the date. The sextant readings (corrected to 13° C. using the temperature coefficient of 28′ 24″, see Appendix I) were plotted against time giving graph 1, on which aneroid readings are also plotted. It will be seen that there is a very decided drift before any change is shown by the aneroid, *i.e.*, up to about June 8, about 4 months. Regarding the drift as very nearly a constant rate, which is consistent with the graph and probably on other grounds, it can be roughly estimated and is apparently —3·534″ per diem., *i.e.*, sextant readings diminish as time increases.

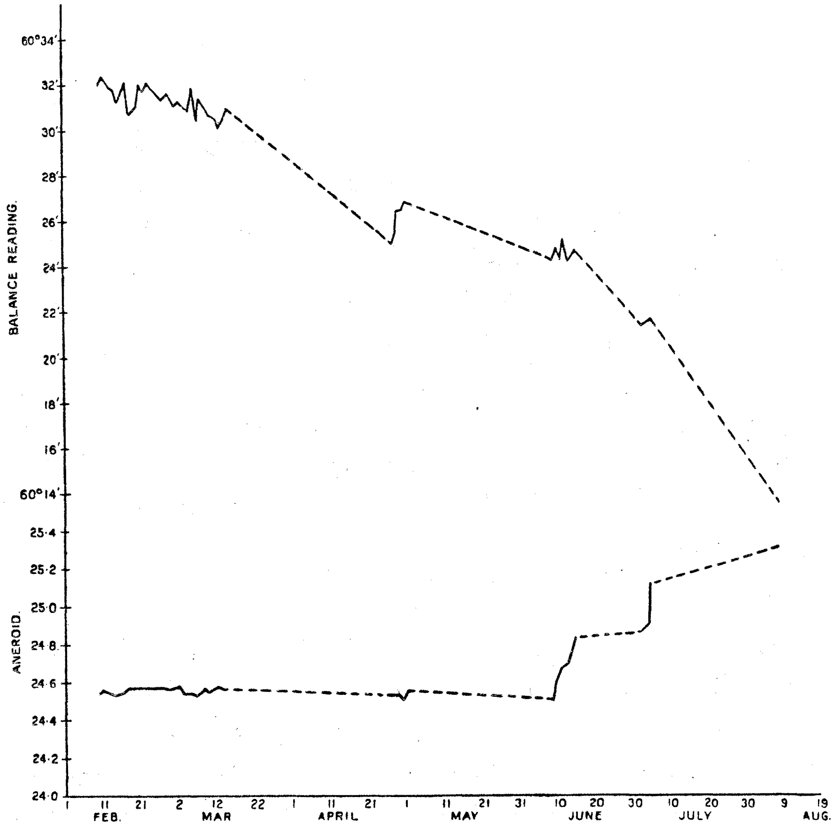


Fig. 1.

Having an approximate value for the drift and noting that it is very small, it is possible to correct the original sextant readings (*i.e.*, the actual observational readings) for " rate." If these corrected readings are plotted against temperature, a new value for the temperature coefficient is obtained. This is found to be 27·866′ per ° C.—a figure fairly close to 28′ 24″ used in the previous analysis. Making use of this new figure for the temperature coefficient, it is now possible to reduce the sextant readings (already corrected for rate) to a uniform temperature of 13° C. (See Appendix II for detailed results). This is done in graph 2, the deviation from a straight line (up to June 7) being a sort of indication of the imperfection of the straight line used to indicate the rate in graph 1.

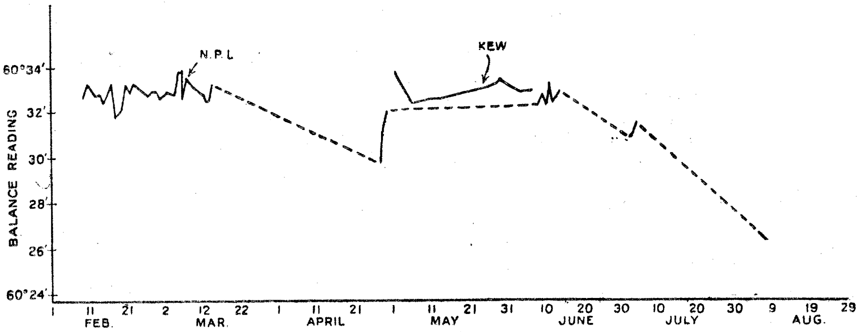


FIG. 2.

Both National Physical Laboratory and Kew observations have been treated in the same manner, the separate application of a correction for drift justifying the use of the same temperature coefficient for both sets of observations.

It will be seen that the observations at Kew in graph 2 lie very distinctly above the observations at National Physical Laboratory, the difference as shown on the graph between Kew and the interpolated National Physical Laboratory readings being about 1′ of sextant arc. This gives for the value of g at National Physical Laboratory (taking as before g at Kew $= 981\cdot199$)

$$981\cdot199 + 0\cdot0045 = 981\cdot2035.$$

Since corrections have been made for both drift and temperature it is also admissible to average all Kew and National Physical Laboratory readings over the period February-June. This gives the following :—

	°	′	″
Average National Physical Laboratory readings (neglecting April 28)	60	32	44
Average Kew readings	60	33	7
So Kew–National Physical Laboratory difference	0	0	23

whence g at National Physical Laboratory $981\cdot199 + 0\cdot0017$ or $981\cdot2007$.

Thus by the first method of reduction adopted by Mr. GOULD, of the National Physical Laboratory, the value of g at National Physical Laboratory is

$$g = 981\cdot201 \pm 0\cdot009$$

and by the second more laborious method

$$g = 981\cdot2035 \pm 0\cdot009 \text{ at National Physical Laboratory.}$$

Having in view the uncertainties involved in the corrections used in applying the second method, Mr. GOULD, of the National Physical Laboratory, who kindly carried out the reduction by the first method, does not consider that anything is gained by employing the second and more laborious method in actual practice. The second method is, however, the one used (graphically) in the Australian observations, and is the one which we should propose to use in a survey.

The comparison of the value of g at Kew and National Physical Laboratory respectively was undertaken before we had entirely overcome the possibility of air leakage, and the observations are regarded as of the nature of a preliminary trial. This trial seems to show that the degree of consistency obtained is of the order of $\pm 0 \cdot 009\, g$. Since 1928, however, a great deal of work has been done in improving the method of observation as well as in overcoming the leakage difficulty. It was indicated in the original paper that when the gravity difference between two places A and B is to be determined it is desirable to have observations interlocking in time at both places— preferably three or more sets of observations at each place. In such a procedure it is now probable that the possible $\pm 0 \cdot 009\, g$ might be halved. On the other hand, a slip in the connections of the quartz to metal, or even discontinuity from some other yet undiscovered source might occur during the time occupied by an extended comparison and lead to a loss of time and labour. It is clear that arrangements should include means—natural or artificial—of regulating the temperature at each station, as was done originally, so as to bring the temperatures closer together than was possible with the arrangements at our disposal at either station.

We have, of course, proceeded on the assumption that gravity is constant over even quite short periods at each station, but it must not be forgotten that there is the possibility of small changes due to movements in the earth in the neighbourhood of the place of observation. For instance, at Oldbury the whole substratum is honeycombed with old coal mines—one of them, indeed, lying almost below the place of observation—but the location of these mines is not exactly known. It is possible that motions of water in and out of the old workings, according to the seasonal rainfall, might not be without influence on the value of g, to the order of accuracy we desire to attain.

Discussion of Errors.

A. *Errors of Observation.*—It is shown on p. 241 of the original paper that the observations required for a determination of a difference in gravity are subject to the following errors :—

1. Accuracy of setting the lever in the sighted position and reading the sextant	$\pm 10''$, sextant seconds = 1 part in 1,300,000 in the value of g.
2. Errors of levelling—possible but unlikely . .	$18''$, or 1 part in 700,000 in the value of g.
3. Temperature error taken at $0 \cdot 01°$ C. The thermometer itself can be read to about $0 \cdot 005°$ C.	$\pm 18''$, or 1 part in 700,000 in the value of g.

Errors according to the Observations since 1926.

1. Lever setting	$\pm 10'' = 1$ part in 1,300,000.
2. Levelling—not more than $\pm 10''$	The least that can be observed on sextant.
3. Estimation of temperature $\pm 0 \cdot 01°$ C. . . .	$\pm 16 \cdot 8''$.

Thus the possible errors accounted for above when observing in a place of nearly constant temperature is ± 36·8″, which equals 1 part in 350,000 of *g*.

Now it is shown in Appendix I that the average error of observation over short periods is 33″ in Series 1, 28″ in Series 2, 32″ in Series 3, and 22″ in Series 4. This may be considered as a satisfactory confirmation.

B. *Errors introduced by the Application of a Temperature Coefficient so as to reduce Readings which are to be compared to a Standard Temperature.*—The error to be expected in correcting the observed readings obviously depends on the magnitude of the correction to be applied and on the accuracy of the coefficient employed.

Now, contrary to the experience in Australia, we have found it difficult to obtain a satisfactory temperature coefficient, *e.g.*, at Teddington Mr. GOULD found a value of 28′ 24″ per degree C., whereas at Kew the best value seemed to be 27′ 10″ per degree C. In both these cases the appendices will show that the temperature changed by about 2° C. only, so the range was narrow. It must also be remembered that the observations from which the temperature coefficient was deduced were plotted without any correction for daily rate.

Whatever the cause of the discrepancy may be in temperature coefficient given above, we see that the use of those coefficients would lead to an uncertainty of 1′ 14″ for each degree of temperature corrected for. In reducing the Kew and Teddington observations to a standard temperature of 13° C., the correction required was in each case about 1° C. The total errors to be expected in the final result are therefore :—

(1) Observational	± 0′ 36·8″
(2) Reduction to standard temperature	± 1′ 14″
	± 1′ 50·8″

Hence the statement made previously that in the Kew–Teddington results the error may be as great as ± 2′ or 0·009 in the value of *g*.

C. *Errors resulting from the Use of the Instrument in a Room in which the Temperature may vary several Degrees each Day.*—Under these circumstances, in addition to the errors already mentioned, a further error is introduced, due to a possible lack of uniformity of temperature over different parts of the instrument. In the observations at Oldbury the daily readings of the sextant arm, after correction for temperature, have varied up to 2′ from the mean value. Of this 36·8″ may, as before, be accounted observational error, but the remainder we feel is most probably due to "temperature inequalities" in the instrument itself. If all these errors conspired we have 0·02 in the value of *g* as a possible error of one observation, as an extreme case ; this is obviously of limited usefulness.

On the Design of a New Instrument.

Obviously any modification made in a design for a new instrument must be with the object of reducing the above sources of error. As far as observational errors are concerned, we feel that very little improvement can be effected. By the use of a larger sextant the accuracy of reading might be increased so that the error was ± 5″ instead of ± 10″. Attempts to reduce the temperature error to less than ± 0·01° C. would be useless unless steps were first taken to increase the heat insulation of the instrument as a whole. It is felt that improvements could be made in this connection, the object being, of course, to reduce the error of ± 2′, noted under C above, to the order of ± 36″ at least, as obtained in a constant temperature room with the existing instrument.

Reduction of the error caused by the application of a temperature coefficient necessitates steps being taken to ensure that this coefficient as observed is always constant. With the existing instrument the coefficient is most difficult to determine over short temperature ranges, being dependent on the consistency of the balance readings, which itself depends on the previous history of the quartz thread. For example, the determination of the temperature coefficient, say, a day after the lever had been left in its overbalanced position, would give a different figure from that obtained previous to this event. In short, it would be advisable to use the thread under such conditions that better advantage was taken of the elastic properties of the quartz. This may probably be best accomplished by less twisting of the thread when assembling the instrument, and it is suggested that two whole turns instead of three be tried. The loss in sensitiveness of the instrument due to the procedure would most probably not be observable, since the existing accuracy of setting the lever is much greater than that of reading the sextant. In any case the effective accuracy of setting could be increased if necessary by observing closer to the overbalancing position.

Referring to p. 234 of the original paper, it is there shown that with the three whole turns of twist in the thread, the upsetting position of the lever is approximately given by $\cot \psi = -\frac{1}{6}\pi$, where ψ is the angle which the lever makes at any moment with the vertical plane drawn downwards through the thread. Hence it follows that the lever is about 3° above the horizontal when upsetting takes place.

If now the twist be reduced to two turns, then approximately $\cot \psi = -\frac{1}{4}\pi$, and the upsetting position will be about 4·5° above the horizontal, which is not materially different from the previous case.

The sensitiveness of the instrument to gravitational changes, according to the approximate theory, is greater the nearer the position of the lever chosen for observation is to the horizontal plane, and this can be attained equally well for a thread in which the twist is two turns as for one in which it is three turns.

Assuming that the elastic properties of a fused quartz thread are more perfect than those of any other material available, sufficiently so to outweigh the disadvantage of the very rapid increase of stiffness with rise of temperature, the present instrument might be modified as follows :—

(1) Referring to the drawing in the previous paper, it is obvious that the instrument might be shortened. The relation of the length to the thickness of the fibre, being based on trials extending over some years, should be maintained. It is possible also that the diameter of the instrument might be reduced. The smaller the instrument the better is the chance of obtaining a uniform temperature throughout.

(2) Nothing much is to be gained by altering the means of observing the lever or of twisting the thread, but great care should be exercised in attaching the thread to the twisting axle so that the point of attachment is strictly the centre of the rotation of the axle.

(3) It is possible that some advantage might be gained by arranging the thermometer so that the platinum wire winding is entirely opposite to the thread, and the winding itself supported on a silica rather than a brass tube.

(4) Among modern alloys it might be possible to find a better material than phosphor bronze of which to make the lever, so that a lighter lever might be constructed, having the same moment about the thread as the present one. This would undoubtedly facilitate the construction of the instrument, for it is the weight of the lever, as well as the amount of twist in the thread, which causes the thread to break during mounting and preliminary adjustment.

(5) The degree of heat insulation of the instrument needs to be enormously improved, and also the conductivity of the tube—or preferably two concentric tubes, separated by insulating material, which form the walls. Thick copper or possibly aluminium should be used, and all devices such as silvering and applying insulating material should be employed.

(6) Much more elaborate precautions should be taken for insulating the ends of the instrument and the reading microscope.

(7) There are a good many minor improvements in the existing instrument, mainly due to Mr. C. H. Beasley, the chief of which is in the stuffing box, through which the arrestor lever works.

(8) More ample provision should be made by slow motion screws for levelling the instrument.

(9) The twisting of the thread could be reduced with advantage to two turns at least, and possibly to one and a half.

It is not expected that an improvement could be effected by using a thread either of greater length or of greater diameter, but of course the greatest improvement of all would be to find a material more perfectly elastic and with a smaller temperature coefficient than a quartz thread. In this connection we have examined the possibility of using a thread drawn from a single crystal of tungsten, but, as far as we have been able to ascertain, the change of rigidity with temperature is of the same order of magnitude for tungsten as it is for quartz, and there seems therefore no particular merit in its adoption.

APPENDIX I.

Summary of Observations.

Series 1 (at the National Physical Laboratory).

Date, 1928.	Time.	Temperature (by resistance thermometer belonging to balance).	Reading of gravity balance (sextant scale).			Reading of balance reduced to 13° C.			Average for day.			Departure from mean of series (seconds of sextant scale).
		° C.	°	′	″	°	′	″	°	′	″	
February 10	11.3 a.m.	14·17	61	5	10	60	31	56	60	32	3	+24
,, ...	12.49 p.m.	14·50	61	15	0	60	32	24				+52
,, ...	2.33 p.m.	14·60	61	17	20	60	31	54				+22
,, ...	4.2 p.m.	14·70	61	20	15	60	31	58				+26
February 11	10.30 a.m.	14·09	61	2	45	60	31	48	60	32	25	+16
,, ...	12.39 p.m.	14·38	61	12	15	60	33	3				+91
February 13	10.29 a.m.	13·84	60	55	10	60	31	19	60	31	58	−13
,, ...	12.48 p.m.	14·11	61	3	20	60	31	49				+17
,, ...	2.36 p.m.	14·22	61	6	40	60	32	1				+29
,, ...	4.2 p.m.	14·36	61	11	20	60	32	43				+71
February 14	9.47 a.m.	13·97	60	59	20	60	31	47	60	31	49	+15
,, ...	11.19 a.m.	14·31	61	8	0	60	30	48				−44
,, ...	12.53 p.m.	14·55	61	16	40	60	32	39				+67
,, ...	2.26 p.m.	14·55	61	16	10	60	32	9				+37
,, ...	2.51 p.m.	14·61	61	17	10	60	31	27				− 5
,, ...	5.13 p.m.	14·71	61	20	40	60	32	6				+34
February 15	10.1 a.m.	14·15	61	3	50	60	31	10	60	31	11	−22
,, ...	12.7 p.m.	14·59	61	16	0	60	30	51				−41
,, ...	2.32 p.m.	14·88	61	23	55	60	30	31				−61
,, ...	4.13 p.m.	14·91	61	25	40	60	31	25				− 7
,, ...	5.21 p.m.	14·99	61	28	30	60	31	59				+27
February 16	10.9 a.m.	14·32	61	10	10	60	32	41	60	31	40	+69
,, ...	12.48 p.m.	14·63	61	18	20	60	32	2				+30
,, ...	2.42 p.m.	14·70	61	19	0	60	30	43				−49
,, ...	4.4 p.m.	14·83	61	23	40	60	31	42				+10
,, ...	5.23 p.m.	14·90	61	25	40	60	31	12				−20
February 17	10.26 a.m.	14·35	61	10	30	60	32	10		—		+38
February 18	10.27 a.m.	14·28	61	7	0	60	30	39		—		−53
,, ...	12.37 p.m.	(14·44)	(61	9	30)	(not used)				—		—
February 20	10.20 a.m.	14·04	61	0	40	60	31	8		—		−24
February 21	10.25 a.m.	13·94	60	58	50	60	32	8		—		+36
February 22	10.27 a.m.	13·87	60	56	30	60	31	48		—		+16
February 23	10.32 a.m.	13·71	60	52	20	60	32	10		—		+38
February 27	10.30 a.m.	13·40	60	42	50	60	31	28		—		− 4
February 28	10.48 a.m.	13·46	60	44	40	60	31	36		—		+ 4
February 29	10.27 a.m.	13·45	60	44	20	60	31	33		—		+ 1
March 1........................	10.16 a.m.	13·48	60	44	50	60	31	12		—		−20
March 2........................	11.46 a.m.	13·56	60	47	10	60	31	16		—		−16
March 3........................	11.39 a.m.	13·68	60	50	30	60	31	11		—		−21
March 5........................	10.29 a.m.	13·66	60	49	40	60	30	55		—		−37
March 6........................	10.34 a.m.	13·79	60	54	20	60	31	54		—		+22
March 7........................	10.22 a.m.	13·88	60	55	30	60	30	30		—		−62
March 8........................	10.32 a.m.	13·97	60	59	0	60	31	27		—		− 5
March 9........................	10.16 a.m.	13·94	60	57	50	60	31	8		—		−24
March 10........................	10.31 a.m.	14·01	60	59	30	60	30	49		—		−43
March 12........................	10.21 a.m.	13·69	60	50	10	60	30	34		—		−58
March 13........................	10.17 a.m.	13·56	60	46	10	60	30	16		—		−76
March 14........................	10.25 a.m.	13·46	60	43	30	60	30	26		—		−66
March 15........................	10.36 a.m.	13·37	60	41	30	60	31	0		—		−32
Mean..		14·15	61	4	10	60	31	32		—		±33

NOTE.—In reducing the readings to refer to a common temperature of 13° C. a mean value of 28′ 24″ (sextant scale divisions per 1° C.) has been used for the temperature coefficient (assumed linear).

Series 2 (at the National Physical Laboratory).

Date, 1928.	Time.	Temperature (by resistance thermometer belonging to balance).	Reading of gravity balance (sextant scale).			Reading of balance reduced to 13° C.			Average for day.			Departure from mean of series (seconds of sextant scale).
		° C.	°	′	″	°	′	″	°	′	″	
April 28	12.33 p.m.	13·58	60	41	20	60	24	52	—			—91
April 29	9.52 a.m.	13·61	60	43	50	60	26	31	—			+ 8
April 30	10.45 a.m.	13·60	60	43	30	60	26	28	60	26	36	+ 5
,,	12.16 p.m.	13·82	60	50	10	60	26	53				+30
,,	2.28 p.m.	14·15	60	59	30	60	26	50				+27
,,	4.28 p.m.	14·36	61	4	50	60	26	13				—10
May 1	12.26 p.m.	13·78	60	49	0	60	26	51	—			+28
Mean		13·84	60	50	19	60	26	23	—			±28

Note.—The linear temperature coefficient, 28′ 24″ per 1° C. was used in the above reductions.

Series 3 (at Kew Observatory).

Date, 1928.	Time.	Temperature (by resistance thermometer belonging to balance).	Reading of gravity balance (sextant scale).			Reading of balance reduced to 13° C.			Average for day.			Departure from mean of series (seconds of sextant scale).
		° C.	°	′	″	°	′	″	°	′	″	
May 2	2.44 p.m.	10·60	59	22	0	60	27	12	60	27	21	+68
,,	4.30 p.m.	10·81	59	28	0	60	27	30				+86
May 7	2.30 p.m.	11·56	59	47	10	60	26	17	—			+13
May 14	2.52 p.m.	10·71	59	23	10	60	25	23	60	25	36	—41
,,	3.38 p.m.	10·82	59	25	0	60	24	13				—111
,,	4.23 p.m.	10·97	59	30	40	60	25	49				—15
May 29	4.10 p.m.	11·83	59	54	20	60	26	7	60	26	4	+ 3
,,	4.48 p.m.	11·95	59	57	30	60	26	2				— 2
May 30	2.54 p.m.	12·29	60	7	0	60	26	17	60	26	33	+13
,,	3.36 p.m.	12·39	60	10	10	60	26	44				+40
,,	4.14 p.m.	12·53	60	14	0	60	26	46				+42
,,	4.53 p.m.	12·66	60	17	10	60	26	24				+20
June 4	2.46 p.m.	12·21	60	3	50	60	25	18	60	25	45	—46
,,	3.29 p.m.	12·31	60	6	50	60	25	35				—29
,,	4.7 p.m.	12·48	60	11	40	60	25	48				—16
,,	4.42 p.m.	12·61	60	15	30	60	26	6				+ 2
,,	5.21 p.m.	12·75	60	19	10	60	25	58				— 6
June 8	2.24 p.m.	12·83	60	21	10	60	25	47	—			—17
Mean		11·91	59	56	21	60	26	4	—			±32

Note.—A different linear temperature coefficient, 27′ 10″ per degree C. was used in reducing the Kew readings to refer to a common temperature 13° C.

Series 4 (at the National Physical Laboratory).

Date, 1928.	Time.	Temperature (by resistance thermometer belonging to balance).	Reading of gravity balance (sextant scale).	Reading of balance reduced to 13° C.	Average for day.	Departure from mean of series (seconds of sextant scale).
		° C.	° ′ ″	° ′ ″	° ′ ″	
June 9	12.5 p.m.	14·56	61 8 40	60 24 22	—	−18
June 10	9.53 a.m.	14·48	61 6 20	60 24 18	60 24 4	−22
,,	11.19 a.m.	14·64	61 11 50	60 25 15		+35
June 11	9.58 a.m.	14·47	61 6 10	60 24 25	—	−15
June 12	10.6 a.m.	14·43	61 5 50	60 25 13	—	+33
June 13	10.5 a.m.	14·45	61 5 30	60 24 19	—	−21
June 15	10.45 a.m.	14·48	61 6 50	60 24 48	—	+ 8
Mean		14·50	61 7 19	60 24 40	—	±22

Series 5 (at the National Physical Laboratory).

Date, 1928.	Time.	Temperature (by resistance thermometer belonging to balance).	Reading of gravity balance (sextant scale).	Reading of balance reduced to 13° C.	Average for day.	Departure from mean of series (seconds of sextant scale).
		° C.	° ′ ″	° ′ ″	° ′ ″	
July 3	5.14 p.m.	14·78	61 12 0	60 21 27	—	− 8
July 4	5.14 p.m.	14·80	61 12 40	60 21 33	—	− 2
July 5	5.15 p.m.	15·21	61 24 30	60 21 44	—	+ 9
Mean		14·93	61 16 23	60 21 35	—	± 6

Series 6 (at the National Physical Laboratory).

Date, 1928.	Time.	Temperature (by resistance thermometer belonging to balance).	Reading of gravity balance (sextant scale).	Reading of balance reduced to 13° C.	Average for day.	Departure from mean of series (seconds of sextant scale).
		° C.	° ′ ″	° ′ ″	° ′ ″	
August 8	11.14 a.m.	16·75	62 0 10	60 13 43	60 13 36	+ 7
,,	12.38 p.m.	16·98	62 6 30	60 13 30		− 6
Mean		16·86	62 3 20	60 13 36	—	± 6

NOTE.—The linear temperature coefficient, 28′ 24″ per 1° C., was used in the reduction of Series 4, 5 and 6.

APPENDIX II.

National Physical Laboratory Observations.

Date, 1928.	Time.	Balance temperature.	Reading of sextant scale.			Sextant scale reading corrected for daily rate $-3\cdot534''$ per diem.			Column 5 results reduced to 13° C. $d\theta/dt=27\cdot866'$ per °C.			Average for day.			Aneroid reading reduced to 0° C.
(1)	(2)	(3)	(4)			(5)			(6)			(7)			(8)
			°	′	″	°	′	″	°	′	″	°	′	″	
February 10	11.0 a.m.	14·17	61	5	10	61	5	10	60	32	34	60	32	44	24·54
,,	12.49 a.m.	14·50	61	15	0	61	15	0	60	33	13				
,,	2.33 p.m.	14·60	61	17	20	61	17	20	60	32	35				
,,	4.2 p.m.	14·70	61	20	15	61	20	16	60	32	54				
February 11	10.30 a.m.	14·09	61	2	45	61	2	49	60	32	47	60	33	19	24·55
,,	12.39 p.m.	14·38	61	12	15	61	12	19	60	33	51				
February 13	10.29 a.m.	13·84	60	55	10	60	55	21	60	31	56	60	32	45	24·54
,,	12.48 p.m.	14·11	61	3	20	61	3	31	60	32	35				
,,	2.36 p.m.	14·22	61	6	40	61	6	51	60	32	52				
,,	4.2 p.m.	14·36	61	11	20	61	11	31	60	33	38				
February 14	9.47 a.m.	13·97	60	59	20	60	59	34	60	32	32	60	32	50	24·53
,,	11.19 a.m.	14·31	61	8	0	61	8	14	60	31	44				
,,	12.53 p.m.	14·55	61	16	40	61	16	54	60	33	43				
,,	2.26 p.m.	14·55	61	16	10	61	16	25	60	33	14				
,,	2.51 p.m.	14·61	61	17	10	61	17	25	60	32	33				
,,	5.13 p.m.	14·71	61	20	40	61	20	55	60	33	17				
February 15	10.1 a.m.	14·15	61	3	50	61	4	8	60	32	6	60	32	24	24·54
,,	12.7 p.m.	14·59	61	16	0	61	16	18	60	32	0				
,,	2.32 p.m.	14·88	61	23	55	61	24	13	60	31	50				
,,	4.13 p.m.	14·91	61	25	40	61	25	58	60	32	45				
,,	5.21 p.m.	14·99	61	28	30	61	28	49	60	33	22				
February 16	10.9 a.m.	14·32	61	10	10	61	10	31	60	33	44	60	32	50	24·54
,,	12.48 p.m.	14·63	61	18	20	61	18	41	60	32	16				
,,	2.42 p.m.	14·70	61	19	0	61	19	22	60	32	0				
,,	4.4 p.m.	14·83	61	23	40	61	24	2	60	33	3				
,,	5.23 p.m.	14·90	61	25	40	61	26	2	60	33	6				
February 17	10.26 a.m.	14·35	61	10	30	61	10	55	60	33	18		—		24·56
February 18	10.27 a.m.	14·28	61	7	0	61	7	28	60	31	48		—		24·57
February 20	10.20 a.m.	14·04	61	0	40	61	1	15	60	32	16		—		24·57
February 21	10.25 a.m.	13·94	60	58	50	60	59	29	60	33	18		—		24·57
February 22	10.27 a.m.	13·87	60	56	30	60	57	12	60	32	58		—		24·57
February 23	10.32 a.m.	13·71	60	52	20	60	53	6	60	33	19		—		24·57
February 27	10.30 a.m.	13·40	60	42	50	60	43	50	60	32	41		—		24·57
February 28	10.48 a.m.	13·46	60	44	40	60	45	44	60	32	55		—		24·56
March 1	10.16 a.m.	13·48	60	44	50	60	46	1	60	32	39		—		24·57
March 2	11.46 a.m.	13·56	60	47	10	60	48	24	60	32	48		—		24·57
March 3	11.39 a.m.	13·68	60	50	30	60	51	48	60	32	51		—		24·54
March 5	10.29 a.m.	13·66	60	49	40	60	51	6	60	32	43		—		24·54
March 6	10.34 a.m.	13·79	60	54	20	60	55	50	60	33	49		—		24·53
March 7	10.22 a.m.	13·88	60	55	30	60	57	2	60	32	31		—		24·53
March 8	10.32 a.m.	13·97	60	59	0	60	0	35	60	33	33		—		24·55
March 9	10.16 a.m.	13·94	60	57	50	60	59	29	60	33	18		—		24·56
March 10	10.31 a.m.	14·04	60	59	30	61	1	12	60	33	4		—		24·54
March 12	10.21 a.m.	13·69	60	50	10	60	52	0	60	32	46		—		24·57
March 13	10.17 a.m.	13·56	60	46	10	60	48	3	60	32	27		—		24·57
March 14	10.25 a.m.	13·46	60	43	30	60	45	27	60	32	38		—		24·56
March 15	10.36 a.m.	13·37	60	41	30	60	43	30	60	33	11		—		24·57
April 28	12.33 p.m.	13·58	60	41	20	60	45	56	60	29	46		—		24·53
April 29	9.52 a.m.	13·61	60	43	50	60	48	29	60	31	29		—		24·53
April 30	10.45 a.m.	13·60	60	43	30	60	48	13	60	32	30	60	32	5	24·51
,,	12.16 p.m.	13·82	60	50	10	60	54	53	60	32	2				
,,	2.28 p.m.	14·15	60	59	30	61	4	13	60	32	11				
,,	4.28 p.m.	14·36	61	4	50	61	9	33	60	31	39				
May 1	12.26 p.m.	13·78	60	49	0	60	53	46	60	32	2		—		24·55

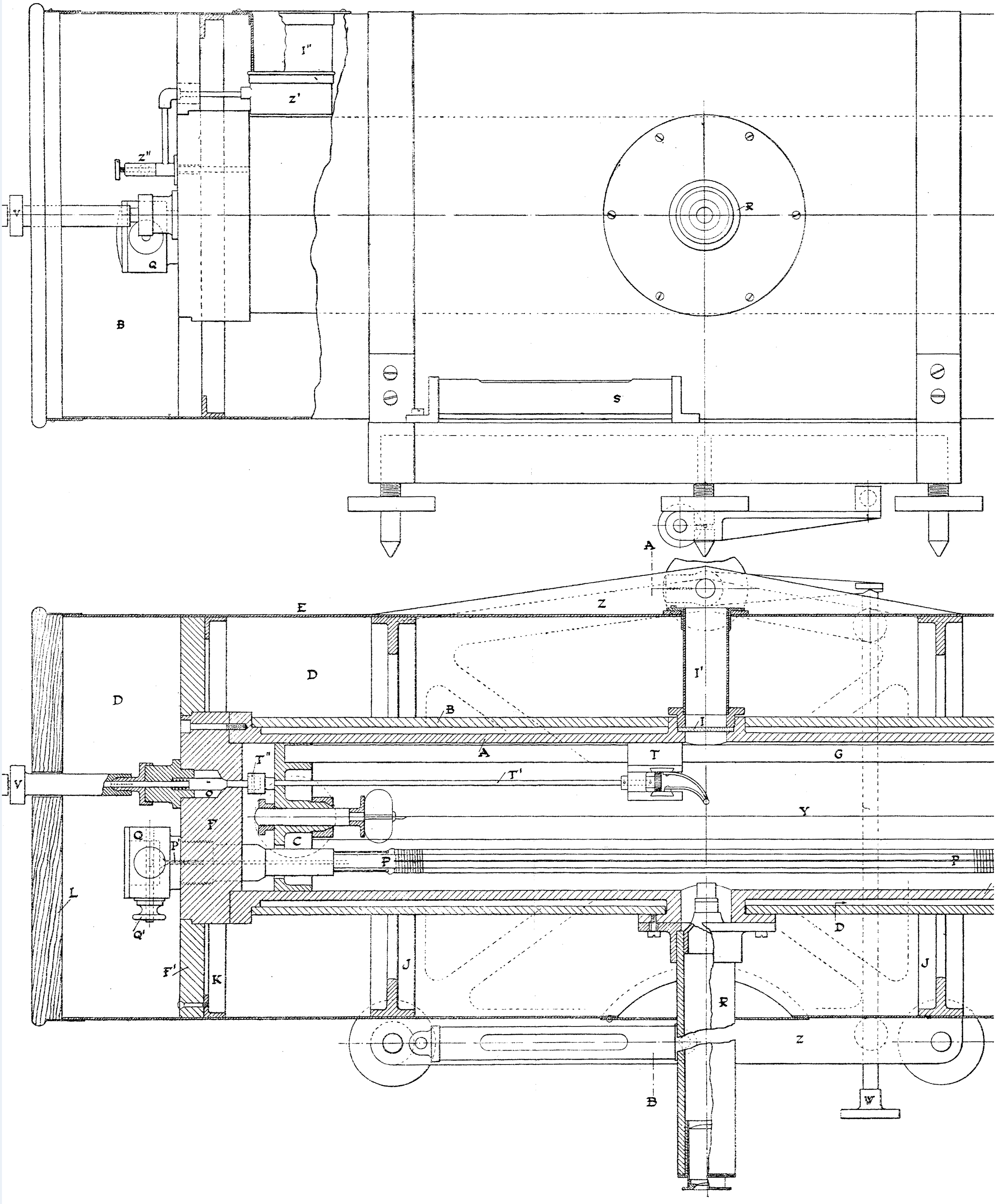
Kew Observations.

Date, 1928.	Time.	Balance Temperature.	Reading of sextant scale.			Sextant scale reading corrected for daily rate $-3{\cdot}534''$ per diem.			Column 5 results reduced to 13° C. $d\theta/dt = 27{\cdot}866'$ per °C.			Average for day.			Aneroid reading reduced to 0° C.
(1)	(2)	(3)	(4)			(5)			(6)			(7)			(8)
			°	′	″	°	′	″	°	′	″	°	′	″	
May 2	2.44 p.m.	10.60	59	22	0	59	26	50	60	33	43	60	33	47	24·58
,, ...	4.30 p.m.	10·81	59	28	0	59	32	50	60	33	51				
May 7	2.30 p.m.	11·56	59	47	10	59	52	18	60	32	25		—		24·51
May 14	2.52 p.m.	10·71	59	23	10	59	28	42	60	32	31	60	32	38	24·50
,, ...	3.38 p.m.	10·82	(59	25	0)	not used				—					
,, ...	4.23 p.m.	10·97	59	30	40	59	36	12	60	32	46				
May 29	4.10 p.m.	11·83	59	54	20	60	0	45	60	33	21	60	33	16	24·48
,, ...	4.48 p.m.	11·95	59	57	30	60	3	55	60	33	11				
May 30	2.54 p.m.	12·29	60	7	0	60	13	29	60	33	16	60	33	24	24·47
,, ...	3.36 p.m.	12·39	60	10	10	60	16	39	60	33	39				
,, ...	4.14 p.m.	12·53	60	14	0	60	20	29	60	33	35				
,, ...	4.53 p.m.	12·66	60	17	10	60	23	39	60	33	7				
June 4........	2.46 p.m.	12·21	60	3	50	60	10	37	60	32	37	60	32	53	24·49
,, ...	3.29 p.m.	12·31	60	6	50	60	13	37	60	32	51				
,, ...	4.7 p.m.	12·48	60	11	40	60	18	27	60	32	57				
,, ...	4.42 p.m.	12·61	60	15	30	60	22	17	60	33	9				
,, ...	5.21 p.m.	12·75	60	19	10	60	26	11	60	33	9				
June 8	2.24 p.m.	12·83	60	21	10	60	28	11	60	32	55		—		24·48

National Physical Laboratory Observations.

Date, 1928.	Time.	Balance temperature.	Reading of sextant scale.			Sextant scale reading corrected for daily rate $-3{\cdot}534''$ per diem.			Column 5 results reduced to 13° C. $d\theta/dt = 27{\cdot}866'$ per °C.			Average for day.			Aneroid reading reduced to 0° C.
(1)	(2)	(3)	(4)			(5)			(6)			(7)			(8)
			°	′	″	°	′	″	°	′	″	°	′	″	
June 9........	12.5 p.m.	14·56	61	8	40	61	15	44	60	32	24		—		24·51
June 10	9.53 a.m.	14·48	61	6	20	61	13	28	60	32	13	60	32	45	24·62
,, ...	11.19 a.m.	14·64	61	11	50	61	18	58	60	33	16				
June 11	9.58 a.m.	14·47	61	6	10	61	13	21	60	32	23		—		24·67
June 12	10.6 a.m.	14·43	61	5	50	61	13	5	60	33	15		—		24·68
June 13	10.5 a.m.	14·45	61	5	30	61	12	48	60	32	24		—		24·70
June 15	10.45 a.m.	14·48	61	6	50	61	14	15	60	33	1		—		24·84
July 3	5.14 p.m.	14·78	61	12	0	61	20	29	60	30	53		—		24·87
July 4........	5.14 p.m.	14·80	61	12	40	61	21	13	60	31	3		—		24·89
July 5	5.15 p.m.	15·21	61	24	30	61	33	6	60	31	31		—		25·22
August 8........	11.14 a.m.	16·75	62	0	10	62	10	46	60	26	16	60	26	14	25·32
,, ...	12.38 p.m.	16·98	62	6	30	62	17	6	60	26	12				

	°	′	″
Average National Physical Laboratory readings, February 10 to June 15 (neglecting April 28)	60	32	44
Average Kew readings	60	33	7
Kew–National Physical Laboratory difference	0	0	23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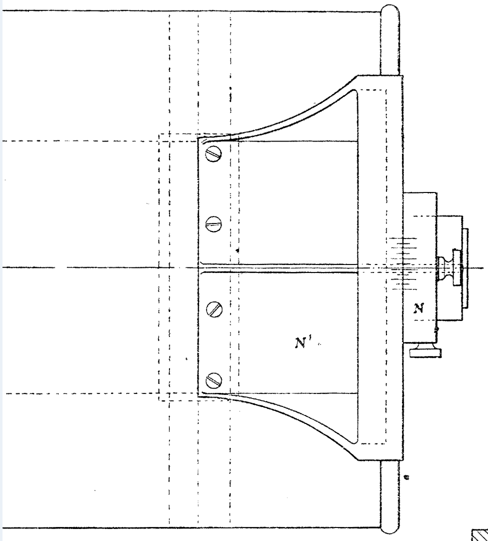

FIG. 2

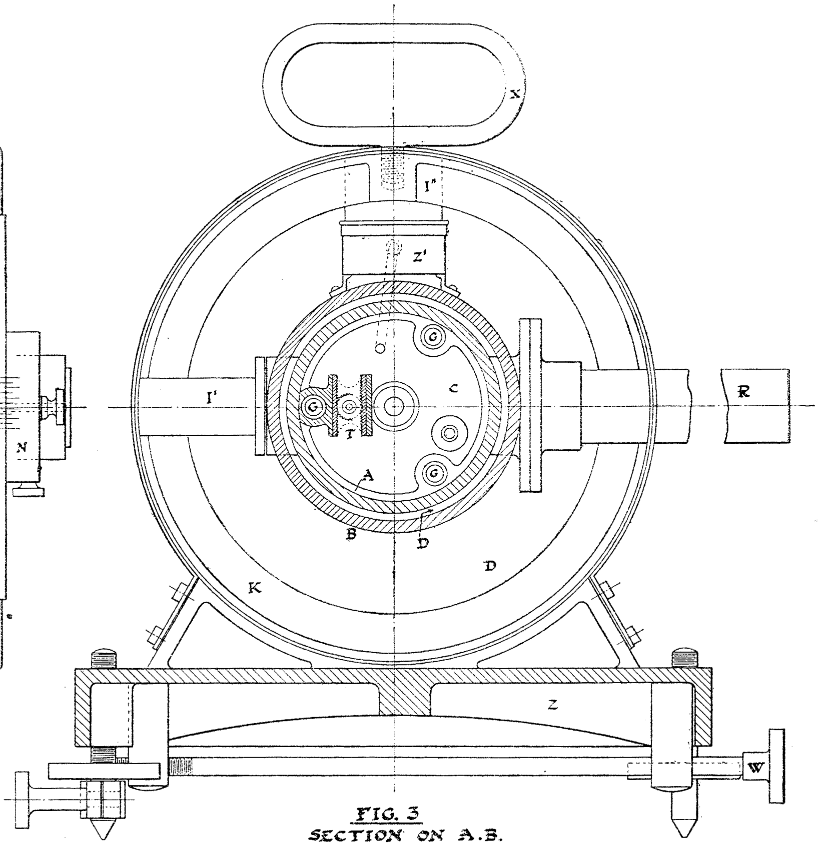

FIG. 3
SECTION ON A.B.

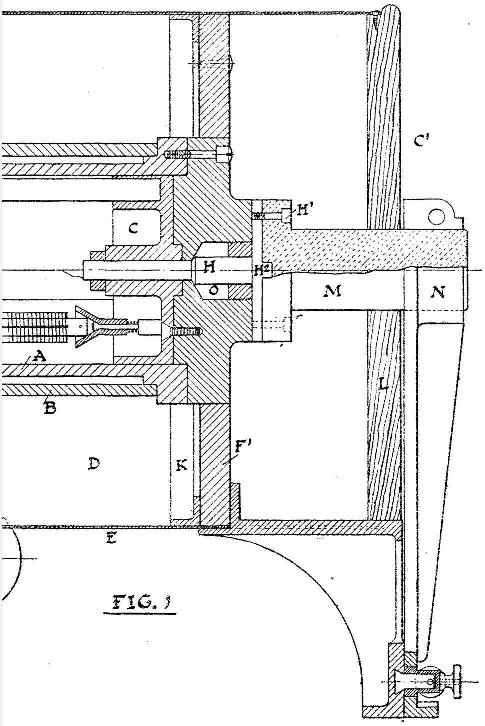

FIG. 1

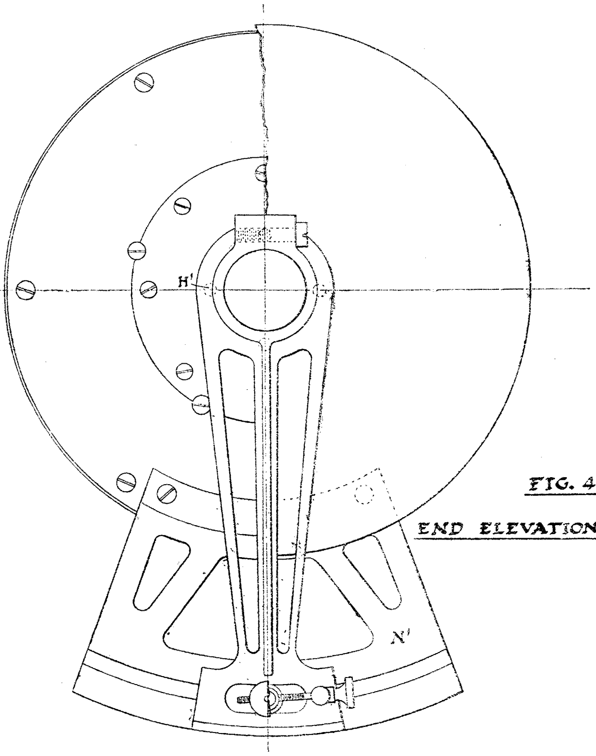

FIG. 4
END ELEVATION OF C'.

The accompanying Drawing, to a Scale of $\frac{1}{3}$ full size, illustrates our Proposals for the Design of a New Instrument.

Index to the Lettering on the Drawing.

A.	Inner copper tube accurately bored to accommodate turned copper discs C.
B.	Outer copper tube insulated from A by cork wool packing and acting as a temperature equaliser.
D.	Cork wool packing.
E.	Outer case of polished copper.
F.	End pieces of Tufnol or similar material rigidly fixed to copper tube A.
F^1.	Outer rings of Tufnol or similar material which hold and centralise the instrument in its outer case.
G.	Three copper tubes sweated at both ends into copper discs C. (Shown in section in fig. 3.)
H.	Stainless steel spindle secured to porcelain shaft M. The screws H^1 and the key H^{11} prevent a possibility of shaking taking place.
I.	Glass window.
I^1 I^{11}.	Fibre tubes to outer case.
J.	Stiffening rings for outer case.
K.	Inner flanges for securing end pieces.
L.	Discs of hard wood.
N.	Sextant arm firmly clamped on to shaft M.
N^1.	Sextant frame, screwed to end rings F^1.
O.	Mercury-filled stuffing boxes.
P.	Platinum thermometer wound on mica wings carried on a brass tube.
P^1.	Air-vent screw. This is to facilitate the filling of the instrument with dry air.
Q.	Head-piece for thermometer, made of Tufnol or similar material.
Q^1.	Thermometer terminals. (One only shown on drawing.)
R.	Quartz microscope barrel accurately ground to accommodate striding level.
S.	Level for horizontal adjustment of thread.
T.	Arrestor mechanism.
T^1.	Arrestor shaft.
T^{11}.	Coupling, made of Tufnol or similar material.
U.	Handle for operation of arrestor fitted with clamping device V.
W.	Fine-adjustment screw for levelling.
X.	Lifting handles.
Y.	Quartz thread. (Method of attachment as in existing instrument.)
Z.	Gun-metal frame.
Z^1.	Aneroid.
Z^{11}.	Tap for adjustment of air pressure.

Total weight of instrument—about 70 lbs.

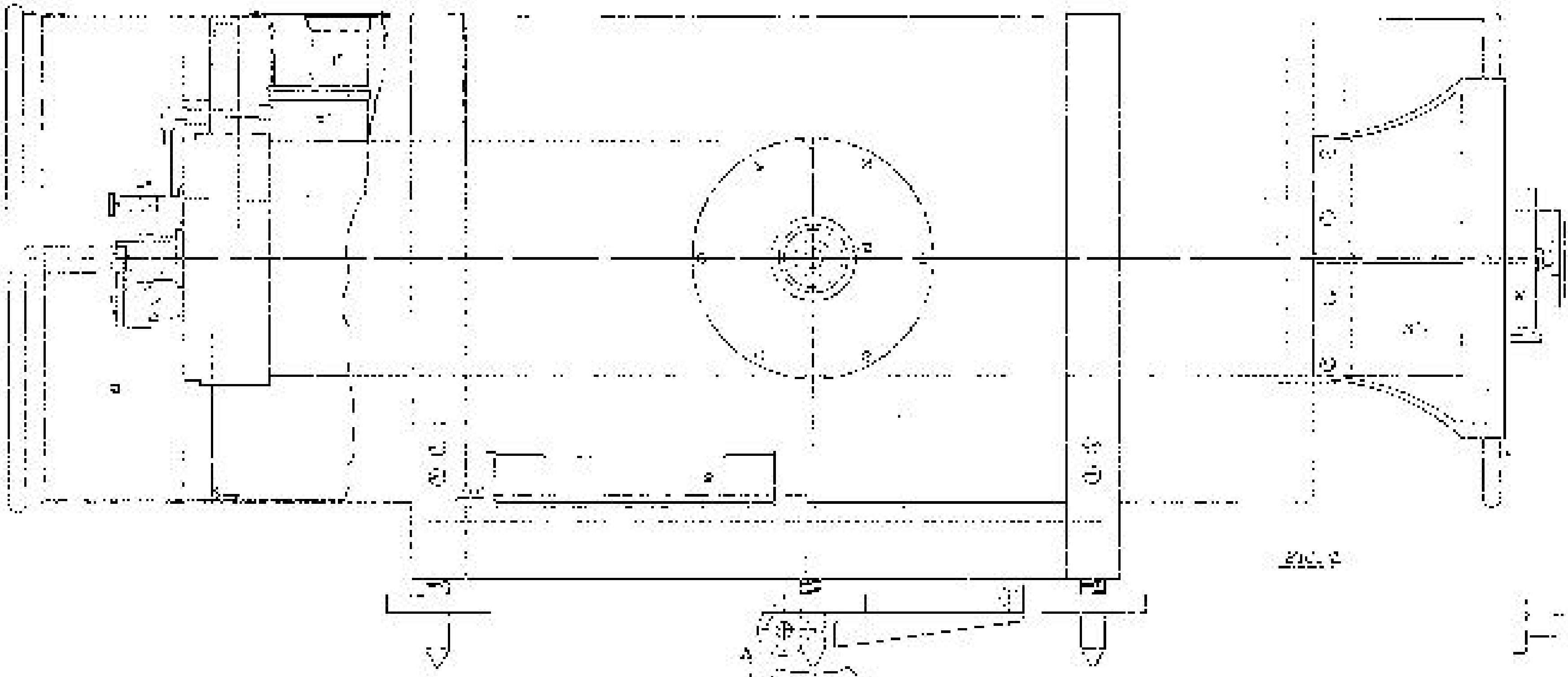
FIG. 2

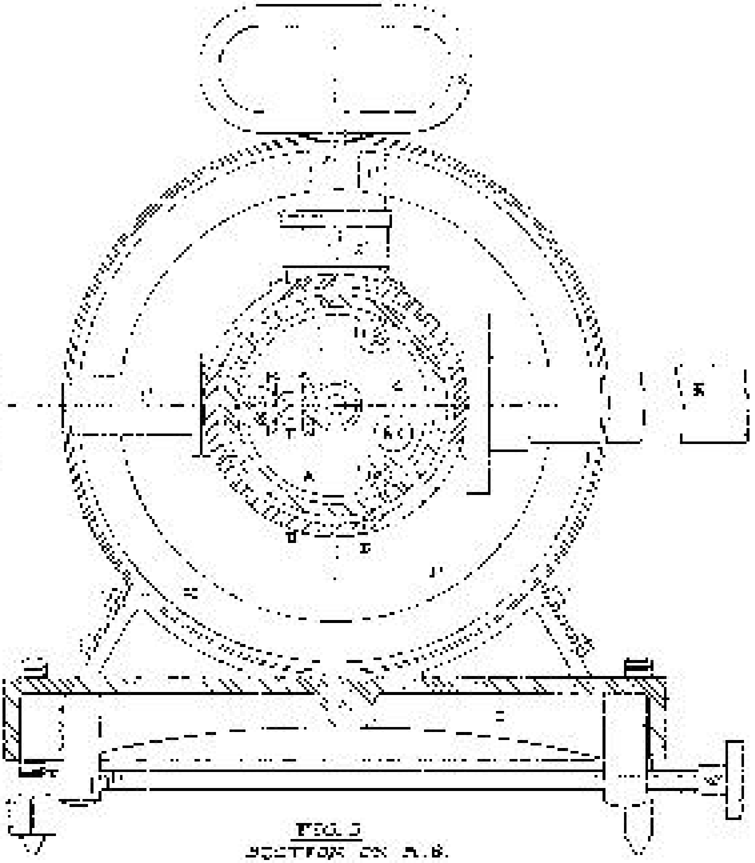
FIG. 3
SECTION ON A.B.

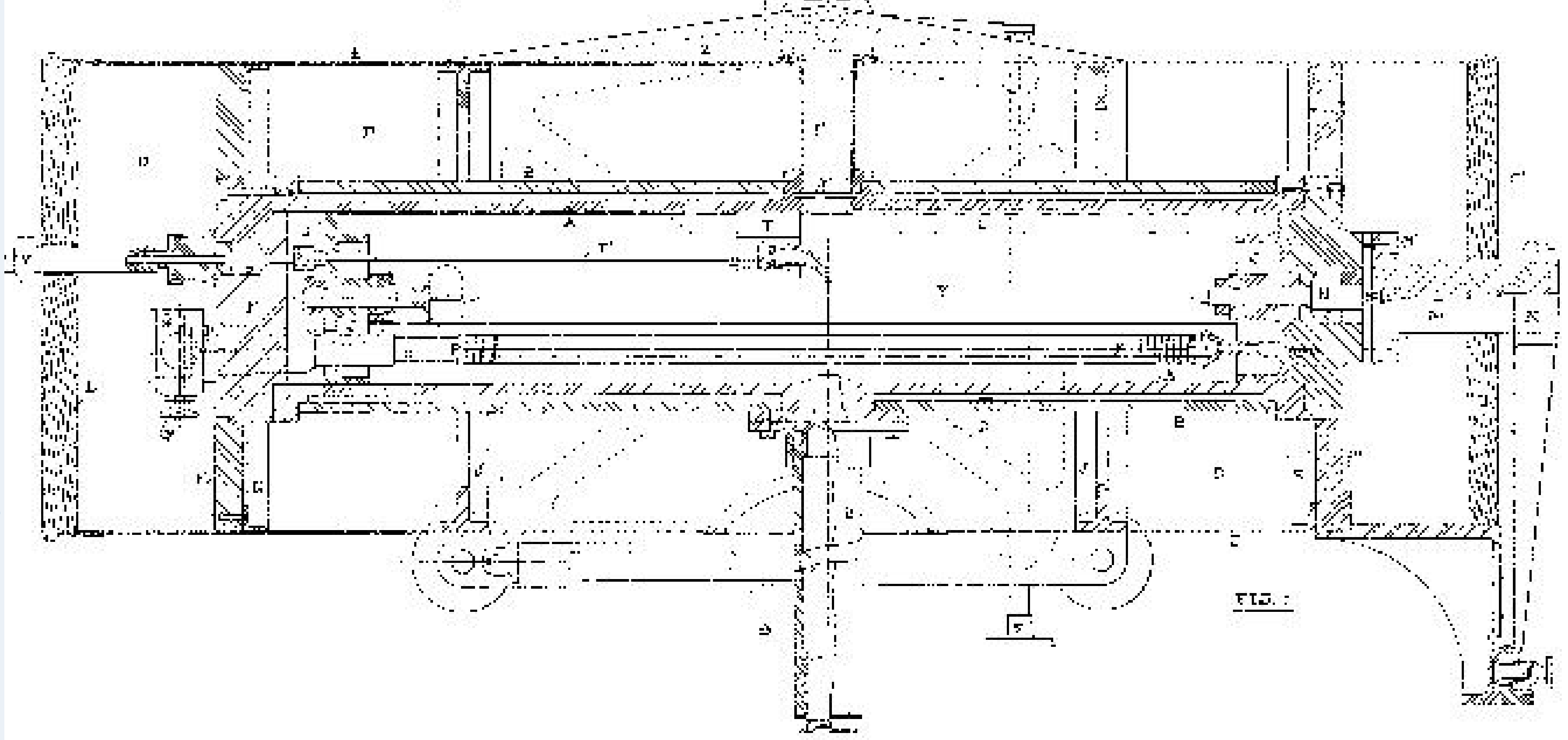
FIG. 1

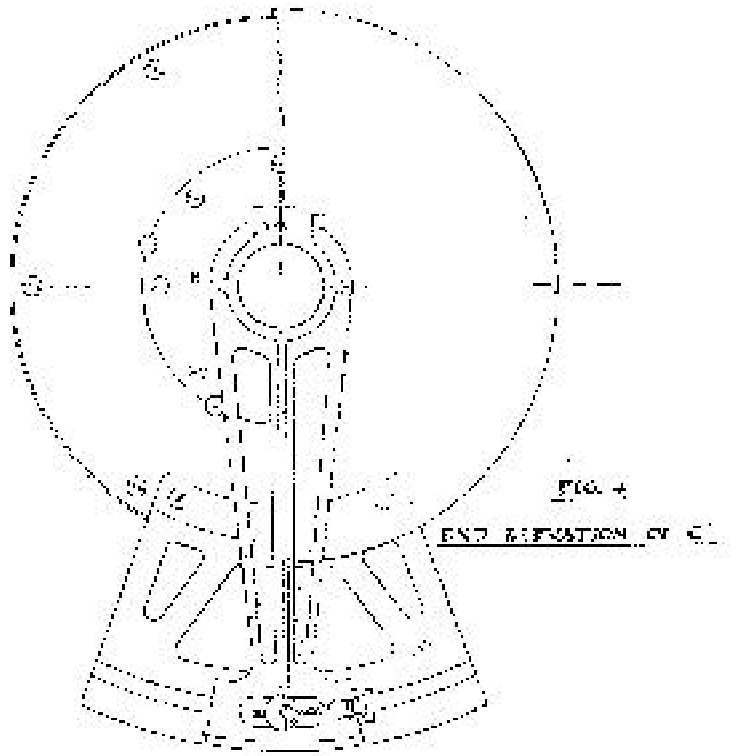
FIG. 4
END ELEVATION ON C.