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~~MAGNETICAL~~ AND METEOROLOGICAL OBSERVATIONS

MADE AT THE

GOVERNMENT OBSERVATORY,

BOMBAY.

1871—1878.

MAGNETICAL AND METEOROLOGICAL OBSERVATIONS

MADE AT THE

GOVERNMENT OBSERVATORY, BOMBAY,

IN THE YEARS 1871 TO 1878.

UNDER THE SUPERINTENDENCE OF

CHARLES CHAMBERS, Esq., F.R.S.,

AND

F. CHAMBERS, Esq.

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ERRATA.

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„ xlv., line 12	<i>After</i> then, <i>insert</i> that.
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Page 23, December 24, 1871...	<i>For</i> 3·6 N <i>read</i> 7·7 N
„ „ „ 29, „	„ 3·6 N „ 7·8 N
„ „ „ 30, „	„ 2·3 N „ 6·5 N
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„ 114 ... ‘	<i>Insert</i> asterisks in columns 5 and 7 for March 1876 and enter a foot-note “No observations for the 11th March.”
„ (35), line 3	<i>For</i> No. 49, <i>read</i> Nos. 49 and 29.
„ „ „ 4	<i>For</i> January 3 to September 19, <i>read</i> January 3 to 24, and from June 13 to September 19.
„ „ „ 8	<i>Omit</i> and November 1.

APPENDIX I.

Notes on a comparison of two Unifilar Magnetometers made at the Colaba Observatory, Bombay, in the years 1873 and 1874. By Charles Chambers, F.R.S.

The two instruments are by Elliott Brothers, of London, and were supplied, after examination at the Kew Observatory, the one, numbered 17, to the great Trigonometrical Survey of India, and the other, numbered 23, to the Colaba Observatory. No. 17 was used by the late Captain J. P. Basevi, R.E., in a Magnetic Survey of India between the years 1866 and 1870; and No. 23 has been used for regular weekly determinations of horizontal Magnetic force at the Colaba Observatory, from June 1867 up to the present time.

2. A considerable body of observations having been taken with both these instruments, it seemed to the writer desirable that some careful observations should be made with the two instruments, nearly simultaneously and under similar circumstances, with a view to bringing the two series of observations into a state of exact comparability. And on mentioning this to Col. J. T. Walker, R.E., the Superintendent of the great Trigonometrical Survey, he courteously placed the instrument No. 17 in the writer's hands, to allow of the proposed observations being made.

3. The constants required in the reduction of the observations were, in general, determined for both instruments at the Kew Observatory:—they are given below in the nomenclature adopted at Kew:*

	No. 17.	No. 23.
Correction for error of graduation of deflection bar at 62° Fahr.		
at distance 1·0 foot.....	0·00000 foot	·00000 foot.
at distance 1·5 „	—·00003 foot	00000 foot.
Induction coefficient (μ).....	·0003433	·000228
Log π^3 K at 60° Fahr.	1·638886	

Temperature correction of deflecting magnet of No. 17 = $0\cdot0001216 (t_0 - 38^\circ) + 0\cdot000,000,157 (t_0 - 38^\circ)^2$.

Temperature correction of deflecting magnet of No. 23 = $0\cdot000188 (t_0 - 35^\circ) + 0\cdot000,000,112 (t_0 - 35^\circ)^2$.

Besides the above the values of constants adopted for the reduction of the comparison observations were as follows:—

K' (the moment of inertia of the deflecting magnet of No. 23 at 35° Fahr.) = $4\cdot2004$, being the mean of thirteen determinations made at Colaba.

P (for the magnets of Unifilar No. 23) = $-0\cdot00634$, derived from 125 pairs of deflection observations at Colaba.

And P (for the magnets of Unifilar No. 17) = $-0\cdot01852$ derived from eight pairs of deflection observations at Colaba—*viz.* the comparison observations.

4. The comparison observations were taken in the usual manner, and on the dates shown below; and at the beginning and end of each vibration observation and of each deflection observation, the readings were taken of the horizontal force magnetometer of the Colaba Observatory and of its thermometer, by means of which the variation of the horizontal force are recorded. The means of these readings are shown, together with the values of the horizontal force calculated from the corresponding observed data, in the subjoined table, and the data of each value are furnished by one vibration experiment, and one deflection experiment for each of the deflection distances 0·8 foot and 1·0 foot.

* See Introduction to the "Bombay Magnetical and Meteorological Observations, 1865 to 1870," pages xli and xlii.

TABLE I.

1873 Date.	Observed X.	L. H. F. Magneto-meter. Scale Reading.	Thermo-meter		L. H. F. Magneto-meter. corrected to 82°.	Excess over 11·00.	Column 7 multiplied by —·0121.	X. Corrected to 11·00.	Means at 11·0 of L. H. F. Magneto-meter.	
1	2	3	4	5	6	7	8	9	10	
Elliot's Unifilar No. 17 (Basevi's).										
July 11	8·0694	10·83	82·7		10·94	—·06	+·0007	8·0701	} 8·0730	Difference =·0154 =·00190 of the whole force.
	8·0657	10·51	83·0		10·66	—·34	+·0041	8·0698		
„ 16	8·0684	10·28	82·5		10·36	—·64	+·0078	8·0762		
	8·0724	10·56	82·7		10·67	—·33	+·0040	8·0764		
„ 26	8·0768	11·47	82·9		11·61	+·61	—·0074	8·0694		
	8·0725	10·97	83·2		11·15	+·15	—·0018	8·0707		
August 10	8·0688	10·42	82·1		10·43	—·57	+·0069	8·0757		
	8·0731	10·76	82·2		10·79	—·21	+·0025	8·0756		
Mean.....	8·0709									
Elliot's Unifilar No. 23 (Colaba Instrument).										
July 9	8·0869	11·09	82·9		11·23	+·23	—·0028	8·0841	} 8·0884	Difference =·0154 =·00190 of the whole force.
	8·0848	11·07	82·9		11·21	+·21	—·0025	8·0823		
„ 16	8·0903	10·59	84·0		10·89	—·11	+·0013	8·0916		
	8·0886	10·20	84·1		10·51	—·49	+·0059	8·0945		
„ 23	8·0924	10·51	83·0		10·66	—·34	+·0041	8·0965		
	8·0846	10·37	83·0		10·52	—·48	+·0058	8·0904		
„ 30	8·0934	11·54	83·3		11·74	+·74	—·0090	8·0844		
	8·0845	10·99	83·4		11·20	+·20	—·0024	8·0821		
August 6	8·0880	10·67	83·0		10·82	—·18	+·0022	8·0902		
	8·0824	10·48	83·6		10·72	—·28	+·0034	8·0858		
„ 13	8·0917	10·87	83·5		11·10	+·10	—·0012	8·0905		
	8·0869	10·70	83·4		10·91	—·09	+·0011	8·0880		
Mean.....	8·0879									

Increasing readings of the horizontal force magnetometer denote increasing force, and the coefficient for converting differences of scale reading into decimal fractions of the horizontal force is ·0015 : the decrease of scale reading caused by an increase of 1° Fahr. of temperature is 0·15 division.

The mean scale readings in the table are first corrected to the constant temperature 82°, then their excesses above 11·00 are taken, and multiplied by (—·0121) to reduce them to the British unit of force, and finally the numbers last found are added to the values of the horizontal force deduced from the observations. Then, if there were no defect in the instruments and no error of observation, these last numbers ought all to be alike.

5. It is at once noticed that the observed values (as we may call them) of the horizontal force, shown in column 2 of the table, are all less when observed with the Unifilar No. 17 than when observed with the Unifilar No. 23,—also that the greatest value given by the former instrument is less than the least given by the latter; on the average the difference amounts to ·0170 British unit or ·00223 of the whole force. This result is subject to correction on account of the variations of the intensity of the force that are perpetually occurring, and to which are owing the considerable differences in the values found on different days.

To eliminate these variations the observations of the horizontal force magnetometer have been applied in the manner above described, and it is seen that the numbers in column 8 are in much greater accord with each other than those in column 2. The difference in the values given by the two instruments remains, however, almost as great as before, being now, on the average, ·0154 or ·00190 of the whole force.

6. In seeking an explanation of a discrepancy of this kind, one naturally first inquires what is the probable error of an observation : and that this is comparatively small in the present case we may see by noting the degree of accordance that subsists between the several determinations made all with instrument No. 17 or all with No. 23 ; and besides the probable error of regular observations made in the same manner and with Unifilar No. 23 has been calculated from 356 determinations to be only \pm ·0032 British unit for an average of eight determinations. Hence we must look for an explanation not to indelicacy of the instruments, nor to inaccuracy of the observer in noting the several phenomena which make up an observation, but either to

specific differences in the construction of the two instruments or to possible errors in the constants used in the reductions.

7. Generally speaking, the two instruments are of the same pattern and dimensions, the only notable differences being that the brass deflection box of No. 17 is removed bodily during the vibration experiment, and the bottom of the vibration box has no metal plate under it, whilst in No. 23 these conditions are reversed. To determine whether this difference of construction caused any discrepancy in the results yielded by the two instruments, the magnet of No. 23, being in every case suspended by the same silk thread, was vibrated alternately in the two Unifilers and the times of one oscillation shown below were observed.

TABLE II.

Date.	Unifilar No.	Time of one Vibration.	L. H. F. Magnetometer.	Thermometer.	L. H. F. corrected to temperature 82°	L. H. F. Magnetometer, excess over 12 15	Temperature of Magnet.	Semi-arc.		Effect of 90° Torsion.	Time corrected.
								At commencement.	At end.		
On July 10, 1874, completed within four hours.		s.		°			°	Scale divisions.		Scale divisions.	s.
	23	2.76930	11.94	83.6	12.18	+0.3	84.0	15.00	5.05	1.04	2.76944
	17	2.76833	12.16	83.4	12.37	+0.22	83.3	15.05	6.50	0.86	2.76905
	23	2.76917	12.11	83.3	12.30	+0.15	84.3	15.00	5.00	1.04	2.76948
	17	2.76866	11.91	83.2	12.09	-0.06	84.0	15.00	6.80	0.87	2.76861
	23	2.76934	11.77	83.4	11.94	-0.17	84.7	15.00	5.05	1.02	2.76889
Means..	23	2.76927	11.94	83.4	12.15	.00	84.3	15.00	5.03	1.03	2.76927
Means..	17	2.76849	12.03	83.3	12.22	+0.08	83.6	15.02	6.65	0.86	2.76883

The last column shows the times of vibration corrected to the uniform force corresponding to reading 12.15 of L. H. F. Magnetometer at temperature 82°, and to constant temperature of the vibrating magnet 84°.3.

The mean times corrected differ by .00045 of a second, which corresponds to a difference of .00016 of the whole in the deduced value of the force, or .0013 of a British unit, No. 17 giving the larger value. The individual times observed in Unifilar No. 17 are in both cases less than the preceding and following times observed in Unifilar No. 23, and they are so both before and after the application of the small corrections for change of force and change of temperature of the magnet. It is probable therefore that the instruments, or one or other of them, re-act in some way* on the vibrating magnet, but the difference of effect is less than a fourteenth of that which we are seeking an explanation of, and it need not, for this purpose, be further regarded. No corrections were applied for torsion of the suspension thread, because the same thread was used in every experiment, and the agreement of the three values (1.04; 1.04; and 1.02 scale divisions) of the effect of 90° of torsion when measured in Unifilar No. 23, shows that the torsion did really not change. It is remarkable, nevertheless, that the measure of the torsion force made in Unifilar No. 17 is a sixth less, in both cases, than the preceding and following measures of it in Unifilar No. 23: and this was the case also when a brass inertia cylinder was vibrated with the magnet.† An allowance for the difference of the two measures would however, only affect the value of the force by .000035 of itself, and need not therefore be made. A vibration experiment was also made in each instrument with an inertia cylinder vibrating with the magnet. Here again the resulting times of vibration were very nearly identical, but the small difference found (.00009 of the whole force) was in the contrary direction to that found when the magnet alone was suspended.

8. The magnetic moments of the two vibration magnets, as also their times of vibration, are widely different, and—the commencing arc of vibration being always made nearly the same (a little less than 2°)—the relative velocities, at corresponding phases of the arc, are also widely different, and the resistance of the air on the one magnet is therefore greater than on the other. The reduction of energy of the magnet in the course of an experiment, indicated in Table I. by the reduction of the arc of vibration at the end of the observation as compared with that at the

* A possible manner would be by the re-action on the magnet of currents of electricity generated by it in the metal base-plate of the box of No. 23.

† The writer is unable to offer even a surmise as to the cause of these differences.

beginning, is very considerable. It must be attributed either to resistance of the air, friction of the suspension thread, or the re-action of currents in the metal surroundings. Its value in terms of the whole energy at commencement is $\left\{ 1 - \left(\frac{\alpha'}{\alpha}\right)^2 \right\}$, α, α' being the arcs (or semi-arcs) at commencement and end of the observation. The average values of α and α' for the comparison observations made with Unifilar No. 17 were 30.6 and 18.6 scale divisions respectively, whilst for the observations with No. 23, they were 31.3 and 13.6. These numbers give for the respective reductions of the whole energy 0.63 and 0.81.

It was conceivable that the time of oscillation might be affected by resistance of the air, and the actual losses of energy being very unequal, an endeavour was made to find an expression for the time of vibration allowing for the resistance of the air, but without success. Not caring to use an unexplained rule given in the books of reference at hand, the writer determined to arrange an apparatus for vibrating the magnets in air of various pressures, so as to afford means of determining the effect of the air's resistance experimentally. The air-tight receiver consisted of a cylindrical glass shade, with globular top, resting on a slate base: through the slate a tube projected having a valve at the outer end for attachment of the air-pump.

The vibration box of each instrument was successively fixed to the slate base, and the observations were made by viewing the scale on the magnet through the side of the glass shade, the small observing telescope being placed outside the receiver.

9. The times of oscillation were observed under three different pressures with each magnet, and with and without an inertia cylinder. The results are shown in the following table:—

TABLE III.

Inertia cylinder.	Unifilar No.	Time of vibration.	L. H. F. Magnetometer.	Thermometer.	Temperature of magnet.	Semi-arc.		Pressure of air in inches of mercury.	90° of Torsion.	Time corrected*	$\frac{\Delta T}{T}$
						At commencement α .	At end α' .				
		s.		°	°	Scale divisions.			Scale divisions	s.	
Without ..	23	2.77236	9.68	83.2	85.9	15.50	7.80	29.85		2.77280	
" ..	"	2.77244	9.80	83.5	85.9	15.00	8.50	14.30		2.77322	+0.00042
" ..	"	2.77268	10.03	84.0	86.8	15.50	10.00	3.50	1.51	2.77382	
With	23	4.87808	9.47	84.8	89.4	16.00	10.50	29.83	4.95	4.87725	
"	"	4.87825	9.31	84.8	88.4	15.00	10.50	9.82		4.87732	+0.00039
"	"	4.87783	9.81	84.8	87.8	15.50	11.00	2.70		4.87900	
Without ...	17	3.78950	10.26	84.1	86.1	15.50	9.50	29.91		3.79151	
" ..	"	3.78908	10.36	84.3	86.0	15.00	10.00	12.90		3.79154	+0.00005
" ..	"	3.78875	10.47	84.7	86.1	15.00	10.50	4.03	1.29	3.79167	
With	17	6.77166	10.68	85.0	87.7	15.50	10.50	29.86	6.21	6.77701	
"	"	6.77108	10.41	85.2	87.5	15.50	11.00	13.10		6.77535	-0.00040
"	"	6.77050	10.16	85.3	86.3	15.00	11.00	1.67		6.77443	

10. There are four distinct series of determinations, each consisting of one observation, at the normal pressure of the air, one at an intermediate pressure, and one at a very low pressure. In all the four series the air is found to affect the time of vibration in the same sense between the upper and middle pressures as between the middle and lower pressures; and the three first series are in accordance in indicating a slight decrease of the time of vibration as due to the air pressure, but they differ as to the amount of it; on the other hand, the fourth series indicates an increase of the time of vibration as the effect of the air pressure. In the last column of Table III. is shown, for each series, the proportional correcting factor to the time of vibration due to the whole atmospheric pressure, on the assumption that the rate of effect found between the highest and lowest pressures holds good for the total pressure; these effects are all too small to be regarded in our present search—the greatest being 0.00042: if X represent the horizontal force and if allowance were made for such effect $\left(\frac{dX}{X}\right)$ of pressure as we have found, $\frac{dT}{T}$ would be equal to $-\frac{dT}{T}$.

It may be mentioned too that the error of the moment of inertia of the magnet, that would be caused by the air affecting the time of vibration of the magnet alone differently from the time of vibration of the magnet and inertia cylinder together, would amount to almost

* Corrected to uniform force corresponding to reading 10.00 of L. H. F. Magnetometer at temperature 82°, and the first six to temperature of magnet 88.5 and last six to 87.2.

† For 87.8 the temperature coefficient = 0.00200 = 0.00188 + 2(87.8 - 35.0) 0.00000112.

nothing with the magnet of No. 23 and only to $\cdot 0012$ of the whole with the magnet of No. 17 : and the $\frac{\Delta X}{X}$ that would correspond to the latter error would be only $\cdot 0006$. Too much uncertainty attaches to a result derived from so few observations to allow of our making any use of this quantity.

11. We have yet to examine whether possible errors in the constants adopted in the reduction of the observations can be the source of the discrepancies under consideration.

To take first the temperature co-efficients of the magnets ; these happen to differ for the two magnets more than is usual, that of the magnet of No. 17 being only about $\cdot 00013$, whilst that of the magnet of No. 23 is $\cdot 00020$; but as the correction does not affect the deduced values of the force unless there is a difference between the temperature at which the deflection experiment is made and that at which the vibration experiment is made ; and as the average of these differences for the comparison observations amounts in neither set of observations to so much as 2° , so the effect of the whole temperature correction is less than $\cdot 0001$ of the whole force, and any error in it must be inappreciable.

12. Errors in the deflection distances (r_0) used in the reductions, would affect the result both directly and by altering the value of the constant P,—the total effect being represented by

$$\frac{\Delta X}{X} = -\frac{3}{4} \left(\frac{\Delta r_0}{r_0} + \frac{\Delta r'_0}{r'_0} \right) + \frac{3r_0^2 r'^2}{r_0'^2 - r_0^2} \left(\frac{\Delta r_0}{r_0} - \frac{\Delta r'_0}{r'_0} \right)$$

No means exist at the Colaba Observatory for determining the absolute errors of the deflection distances ; but by placing the two deflection bars horizontal, one inverted above the other, so that the divided edges were in contact and the faces of the scales directed towards a telescope provided with a micrometer, it was possible to compare one scale with the other at corresponding divisions. In this way, taking the bar of Unifilar No. 23 as a standard, it was found that the corrections required to that of No. 17 were at $0\cdot 8$ foot $\cdot 00000$ and at $1\cdot 0$ foot $-\cdot 00010$ with an estimated probable error, in each case, of less than $\pm \cdot 00001$ foot. In the reductions of the comparison observations, the distances, on both bars, of the $0\cdot 8$ and $1\cdot 0$ lines were regarded as correct ; hence the full amount of the relative corrections just found must be applied. Inserting in the above expression

$\cdot 00000$ for $\frac{\Delta r_0}{r_0}$ and $-\cdot 00010$ for $\frac{\Delta r'_0}{r'_0}$ we get

$$\frac{\Delta X}{X} = + \cdot 00040, \text{ which, again, is negligible.}$$

13. The moment of inertia (K') adopted for the magnet of Unifilar No. 23 was the mean of thirteen independent determinations made in 1868. Its value at temperature 35° Fahr. was $4\cdot 2004$, and the probable error of an individual determination $\pm \cdot 0025$; that is to say, it is an even chance that a single determination will be within or without the limits $4\cdot 1979$ and $4\cdot 2029$. The mean of all the determinations made up to the end of 1873—ninety-one in number—is $4\cdot 2014$. The excess ($\cdot 0010$) of this over the adopted value would, if allowed for, increase the horizontal force by only $\cdot 00012$ of itself. The observations were all made with the same inertia cylinder—the one which belongs to the instrument No. 23 ; they would all therefore be affected alike, if the inertia cylinder happened not to be of uniform density throughout its mass. A determination was therefore made with the inertia cylinder of the Unifilar No. 17, giving a value $4\cdot 1991$ or $\cdot 0013$ less than the adopted value ; as this lies within the limits of probable departure from the true value of a single determination, the result may be taken as evidence of similarity of condition of the two inertia cylinders ; and as the similarity aimed at in the manufacture of the cylinders is that of uniform density, it is more likely similarity of that kind than a similar unequal distribution of the matter in each of the two cylinders.

The value of K' adopted for the magnet of Unifilar No. 17 is $4\cdot 4105$ at temperature 43° Fahr. : this was determined at the Kew Observatory. It is known that before the instrument was put into use the magnet had become rusted and had to be cleaned ; in removing the rust the mass would be slightly diminished, and with it the moment of inertia. In June 1874 a determination at Colaba gave the value $4\cdot 4053$ at temperature 43° Fahr. The accuracy of single determinations of moment of inertia the writer has much reason to be suspicious of, and accordingly he rather advances this value as confirmatory of the expected reduction than as a determination that is fit to be used as a standard value for the reduction of a series of observations. Accepting it, however, in default of any other, the values of the force calculated with the original K' require to be reduced by $\cdot 00059$ of the whole force. Adding this to the defect $\cdot 00190$ found from the comparison observations, we have a total defect of $\cdot 00249$ of the whole force shown by Unifilar No. 17 as compared with Unifilar No. 23.

14. The adopted constant, P, for the magnets of Unifilar No. 23 is $-\cdot 00634$: from the observations of the year 1873 alone the value found is $-\cdot 00665$: if the difference were allowed for the force would be diminished by $\cdot 0002$ of itself—again a negligible quantity.

The comparison observations which gave the value of P for the magnets of Unifilar No. 17, were accordant amongst themselves; and it may thence be inferred that the adopted value is substantially correct.

15. The corrections that have been applied for the earth's magnetic induction upon the magnets—using the co-efficients given in para. 3—are for the two instruments respectively :—

	For No. 23.	For No. 17.
$\div \frac{m_0}{X_0}$	·00275	·00733
$\frac{2\mu}{r_0^3}(\text{mean})$	·00067	·00101
Sum	<u>·00342</u>	<u>·00834</u>
$\frac{dX}{X} =$	<u>—·00171</u>	<u>—·00417</u>

The consideration of induction has reduced the force that would otherwise have been shown by the observations with Unifilar No. 23, by ·00171 of itself, and that which would have resulted from the observations with Unifilar No. 17 by ·00417 of itself: the difference of these two numbers ·00246 is almost exactly the amount by which No. 17 gives the force less than No. 23. Can it be that induction really produces an inappreciable effect on hard steel, such as the hollow cylindrical magnets are made of? To suggest such an explanation, as otherwise than very doubtful, would at the present moment be to leave unexplained the invariable indications of a real effect which are shown by the experiments for determination of the induction co-efficient.

16. The results of the preceding experiments are the more perplexing because a previous comparison of the same two instruments, omitting much of the elaboration attending the later comparisons, gave results that were almost identical. This comparison was made in November 1867, the observations with the Unifilar No. 17 being taken by Captain Basevi, on the 22nd and 23rd; three separate determinations of the force gave the value 8·0678 with the approximately corresponding readings of the Colaba horizontal force magnetometer and its thermometer 24·10 scale divisions, and 84°·8 respectively. The mean value of the force deduced from the regular observations at Colaba for November 1867, is 8·0523, with corresponding readings of magnetometer &c. 23·97 and 82°·7. The readings of the Colaba horizontal force magnetometer show the mean value of the force during Captain Basevi's experiments to have been ·00066 of itself greater than the mean value during the regular Colaba observations. Also the reductions of the observations with Unifilar No. 17 were made with the Kew value of K', and Captain Basevi (as the mean of two determinations at Colaba and Madras) found this to require a correction of —·002607 × K'. The correction to X (the force), to render the determinations with No. 17 comparable with those with No. 23, will therefore be

$$\frac{\Delta X}{X} = -\cdot00066 + \frac{1}{2} \frac{dK'}{K'} = -\cdot00066 - \cdot00130 = -\cdot00196,$$

and the corrected value of the force equal to 8·0678 (1 —·00196) = 8·0520. Thus No. 17 gives the value 8·0520, and No. 23 the practically identical value 8·0523.

17. It is not improbable that the attainment of a more rigid comparability between individual instruments than is indicated in what precedes, will be deemed by observers to be of some importance; the writer has accordingly described his own unsuccessful endeavours to detect the cause of the discrepancies, in the hope that they may, at any rate, be useful to a more fortunate inquirer, in directing his steps elsewhere than over the already trodden ground. He has not, to his knowledge, left unquestioned any of the more important conditions that affect the result of an observation. He anticipates also that the vibration experiments in air of different pressures will be of interest to others besides himself.

January 1875.

On Magnetic Induction as affecting Observations of the Intensity of the Horizontal Component of the Earth's Magnetic Force. By Charles Chambers, F.R.S., Superintendent of the Colaba Observatory, Bombay.

[Communicated to the British Association at its Plymouth Meeting in 1877].

The magnets used in observations of deflection and vibration, which observations are necessarily made in the field of the earth's magnetic force, are subject to the inducing action of that force; and it is the universal practice of magnetic observatories, sanctioned by the most

eminent writers on terrestrial magnetism, to apply corrections on account of induction both to the deflection and vibration observations.

The object of this communication is to advance theoretical reasons—supported by experimental evidence—against the propriety of the particular correction applied to the vibration observation. This correction is based on the assumption that the vibration-magnet is susceptible of induction longitudinally but not transversely, or not so sensibly; and the assumption probably rests on what the writer regards as a false analogy between a permanent magnet and an induced magnet. The former, when removed from the influence of a strong magnetizing action, remains a magnet by virtue of its own internal forces, whilst the latter is a magnet by virtue of external forces alone; it does not therefore follow that because the power of a permanent magnet—measured by its magnetic moment—cannot be made by the same means nearly as great transversely as longitudinally, therefore the same may be said of an induced magnet. Indeed, in his treatment of the subject of the deviations of the compass, Sir George Airy gives to each elemental portion of a ship's iron as great a susceptibility to induction in one direction as in another; and in the more elaborate treatment of the same subject, in which Poisson's equations are taken as expressing the fundamental conceptions of the theory, terms representing transverse induction are still retained, as of comparable magnitude, in presence of others representing longitudinal induction.

Applying the Astronomer Royal's theory to the particular case of the vibration magnet, its induced magnetism becomes an assemblage of elementary magnets whose magnetic axes are all parallel to the magnetic meridian, and which, since they sensibly retain their parallelism to the meridian during the oscillation of the magnet, give rise to no moment of restitution; hence, according to this view, no correction would be required. According to Poisson's theory the amount of the correction is matter for experimental inquiry, and cannot be safely determined on *à priori* ground. It may be objected, however, that the swinging of a ship being a slow motion compared with the oscillation of a magnet, the theory of the deviations of the compass must be modified in its application to the case in question; and this is no doubt a correct view; for the theory regards the inductive action as being, at every moment considered, sensibly carried to its limit of effectiveness; whilst it is not only conceivable, but doubtless the fact, that where, as with the oscillating magnet, the motion is reversed every few seconds, the transverse inductive action does not reach, but only approaches, its limit. On this account we should be prepared to expect, then, that even if the transverse induction were as great as the longitudinal, when time for full development of the induction was allowed, it would be in some degree in defect in the case of the vibrating magnet.

In the years 1873 and 1874, long before these views on the subject of induction first occurred to the writer, he had had made in Bombay a careful comparison of two Kew Unifilar magnetometers, by means of practically contemporaneous observations. The result was to show a persistent difference in the values of the horizontal force yielded by the two instruments, far exceeding any probable errors of observation; and after a careful examination of each single observational quantity, and of each constant entering into the computations, the writer came to the conclusion that no error of the magnitude of that in question could have its source anywhere but in connection with the induction corrections. The values obtained for the horizontal force were (in British units of force) :—

With magnetometer No. 17.	With magnetometer No. 23.
8·0701 } 8·0698 } 8·0762 } 8·0764 } 8·0694 } 8·0707 } 8·0757 } 8·0756 }	8·0841 } 8·0823 } 8·0916 } 8·0945 } 8·0965 } 8·0904 } 8·0844 } 8·0821 } 8·0902 } 8·0858 } 8·0905 } 8·0880 }
Mean = 8·0730	Mean = 8·0884

No. 23, showing an excess over No. 17 of ·0154 British units of force, or of ·0019 of the whole horizontal force.

We observe that the greatest value given by No. 17 is less than the least value given by No. 23, and infer that the difference between the two means cannot be attributed to probable

error of observation, the value of which for a single determination (about .001 of the whole force) is, moreover, much smaller.

If we now remove the corrections applied for induction to the vibration observations, the mean value yielded by No. 17 becomes .0004 of the whole force greater than the mean yielded by No. 23. It thus appears that a small correction, such as we have already seen reason to expect, is required for the vibration observation, but (on an average for the two instruments employed) only of about one-sixth of the value of that which it is the custom of magneticians to apply; and as this small quantity scarcely exceeds the probable error of the mean determination of the horizontal force, it is yet premature to attribute it to any definite cause. Whilst, however, the experiments afford no sufficient reason for applying this small correction, they speak very distinctly in favour of no induction correction at all for the vibration observation as against the common practice.

To show that the error that we have been discussing is not of that minute order that is usually disregarded, we may mention that it would amount, in the case of the Unifilar magnetometer used at the Kew Observatory, to about eight times the probable error of an observation.

TABLE 165.—Showing the diurnal variation of the readings of the Thermometer of Grubb's Horizontal Force Magnetometer for each month of the year 1872 and for the groups of months March to October and November to January.

1872.	MONTH.												Mar. to Oct.	Nov. to Jan.	
	Bombay Civil time.	Jan.	Feb.	March	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.			Dec.
h.															
10	-1'23	-1'14	- '37	- '25	- '06	- '13	+ '08	+ '03	+ '01	- '33	- '93	- '63	- '13	- '93	
11	- '53	- '36	+ '11	+ '17	+ '28	+ '16	+ '34	+ '32	+ '34	+ '09	- '27	- '15	+ '23	- '32	
12	+ '11	+ '36	+ '53	+ '55	+ '52	+ '34	+ '51	+ '68	+ '63	+ '48	+ '27	+ '27	+ '33	+ '22	
13	+ '75	+1'07	+ '88	+ '86	+ '82	+ '58	+ '64	+ '85	+ '90	+ '86	+ '97	+ '65	+ '80	+ '79	
14	+1'33	+1'58	+1'16	+1'12	+1'07	+ '73	+ '66	+ '97	+1'02	+1'11	+1'64	+1'10	+ '98	+1'36	
15	+1'72	+1'96	+1'26	+1'16	+1'23	+ '83	+ '69	+ '97	+1'12	+1'33	+2'09	+1'45	+1'07	+1'75	
16	+1'91	+2'02	+1'19	+1'11	+1'20	+ '82	+ '65	+ '83	+1'02	+1'36	+2'17	+1'56	+1'02	+1'88	
17	+1'83	+1'85	+ '93	+ '95	+1'07	+ '64	+ '59	+ '69	+1'19	+1'94	+1'47	+ '84	+ '84	+1'75	
18	+1'46	+1'41	+ '53	+ '61	+ '73	+ '45	+ '33	+ '38	+ '37	+ '88	+1'49	+1'17	+ '53	+1'37	
19	+1'23	+1'12	+ '33	+ '34	+ '42	+ '20	+ '14	+ '11	+ '14	+ '72	+1'24	+1'01	+ '30	+1'16	
20	+ '96	+ '90	+ '19	+ '20	+ '27	+ '07	- '01	- '02	+ '06	+ '61	+ '97	+ '81	+ '17	+ '91	
21	+ '79	+ '70	+ '14	+ '12	+ '18	- '00	- '09	- '09	- '03	+ '47	+ '59	+ '54	+ '09	+ '64	
22	+ '58	+ '52	+ '06	+ '05	+ '07	- '03	- '17	- '18	- '10	+ '26	+ '21	+ '21	- '00	+ '33	
23	+ '36	+ '27	+ '10	- '03	- '07	- '11	- '22	- '25	- '20	+ '04	- '13	- '20	- '09	+ '01	
0	+ '01	- '37	- '20	- '24	- '29	- '04	- '26	- '29	- '41	- '18	- '24	- '21	- '24	- '15	
1	- '23	- '54	- '29	- '31	- '47	- '22	- '28	- '38	- '49	- '40	- '48	- '41	- '35	- '37	
2	- '46	- '67	- '36	- '41	- '58	- '30	- '35	- '45	- '57	- '60	- '75	- '53	- '45	- '58	
3	- '69	- '89	- '46	- '53	- '71	- '40	- '40	- '51	- '64	- '83	- '97	- '65	- '56	- '77	
4	-1'00	-1'02	- '59	- '70	- '84	- '54	- '42	- '62	- '69	- '97	-1'21	- '85	- '67	-1'02	
5	-1'31	-1'27	- '73	- '82	- '98	- '60	- '50	- '69	- '75	-1'22	-1'47	-1'01	- '79	-1'26	
6	-1'61	-1'61	- '97	- '98	-1'15	- '70	- '57	- '68	- '75	-1'38	-1'77	-1'33	- '90	-1'57	
7	-2'01	-1'98	-1'25	-1'11	-1'14	- '71	- '61	- '68	- '79	-1'44	-1'98	-1'53	- '97	-1'84	
8	-2'11	-2'11	-1'30	-1'08	- '93	- '61	- '46	- '56	- '63	-1'24	-1'92	-1'53	- '85	-1'85	
9	-1'84	-1'78	- '97	- '72	- '53	- '44	- '24	- '37	- '30	- '78	-1'49	-1'12	- '54	-1'48	

275. In concluding these appendices the writer desires to place on record his sense of obligation to those who have assisted him in the preparation for and production of them :—to Mr. F. Chambers and Mr. Vinayak Narayen Nene and, in a less degree, to Mr. Jehangirshah Erachshah Kohiyar for the immediate supervision of observational, experimental, and routine-computing operations, for the making or oversight of the higher class calculations that were of an extra-routine nature, and for the revision and verification of his own special work : to Mr. Purshram Luxuman Datar and Mr. Vishnoo Damodhar Benderker for carefully conducted experiments and their methodical reduction, and for intelligent and vigilant attention to secure accuracy in the copying of matter for the press and in the drawing of diagrams respectively : and to Mr. Govind Dhondey Deshpandey and Mr. Crishnaji Gunesh Thakur, who have acted successively as photographer, for unremitting attention to the responsible duties of working the photographic self-recording instruments.

273. Fig. 664 tells us that the range of the declination magnetometer is greater by about one-fourteenth of itself than the range of the declination magnetograph, and the excess variation is of the same character as the mean diurnal variation of the year: the numbers of Table 162 for separate months also show, generally, that the excess variation is of the same character throughout the year.

274. The first idea that is suggested by Figs. 801 and 802 is that, these being close counterparts of the temperature curves of the respective periods, and having proportional ranges, the temperature co-efficient that has been used in the reduction of the observations is much too large; but a closer examination of the respective variations compared leads to material modifications of this idea. First we remark, however, that the excess force ranges are for March to October and November to January respectively $\cdot 00121$ and $\cdot 00229$, whilst the corresponding temperature ranges are $2^{\circ} \cdot 04$ and $3^{\circ} \cdot 73$: and the respective ratios of these two pairs of numbers are $1 \cdot 9$ and $1 \cdot 8$, or nearly equal: consequently, disregarding the difference of phase of the two sets of variations, the temperature co-efficient used for the magnetometer must, on the supposition that the cause of the discrepancy lies therein, have been taken too great by $\frac{\cdot 00121 + \cdot 00229}{2 \cdot 04 + 3 \cdot 73} \div \cdot 00549 = \cdot 11$ scale division, $\cdot 00549$ being the scale coefficient for the year 1872: and the temperature coefficient used, having been $\cdot 15$, must have been $\frac{11}{15}$ ths of itself too great. But, as we have strong evidence (see paragraph 222) that the coefficient is not itself considerably in error, this means that the changes of temperature of the magnet have been only $\frac{4}{15}$ ths of the changes of temperature of the thermometer bulb, which lies well within the lid of the wooden box enclosure of the instrument. So great a difference in a small air-space, the circulation in which is unobstructed, is scarcely credible, and especially when it is borne in mind that the communication of external temperature influences is retarded and contracted by a padding of quilted cotton, 2 inches thick, which surrounds the wooden box on its sides and at top*. The retardation and contraction of range of the thermometer readings is clearly brought out on comparing the numbers of Table 165 with corresponding variations of the temperature of the external air: and if the temperature range of the magnet is subject to a further contraction down to $\frac{4}{15}$ ths of the ranges of Table 165, it is highly improbable that such contraction is not also accompanied by a further retardation of phase. Instead of a retardation of phase the excess force variations as compared with the temperature variations show, however, an acceleration of phase of no less amount than two hours; and, besides, the general similarity of variations that otherwise holds during the day hours is not closely maintained at night. Whilst, for the months March to October, the fall of the excess force between 22^{h} and 7^{h} is only $\cdot 00012$ or $0 \cdot 10$ of the whole range, the fall of temperature is $0^{\circ} \cdot 97$ or $0^{\circ} \cdot 48$ of the whole range: and, for November to January, the corresponding numbers are $\cdot 00034$ or $0 \cdot 15$ of the whole range, and $2^{\circ} \cdot 17$ or $0 \cdot 58$ of the whole range. So far the weight of evidence seems, then, to incline on the side of reality of the excess variations, as magnetic excesses that vary approximately with natural temperature and against their being regarded as uneliminated influences of temperature upon the instrument. The results point, at the same time, to the desirableness of placing the thermometer bulb in close proximity to the magnet.

* Quilted cotton covers were applied to the declination and horizontal force magnetometer boxes early in 1868 and have remained upon them ever since.

TABLE 164.—Excesses of the hourly inequalities of horizontal force as shown by Grubb's Horizontal Force Magnetometer over the same as shown by the Horizontal Force Magnetograph after correcting the latter for the average progress increase per day.

1872.		MONTH.												March to October.	November to January.
Bombay Civil Time.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.			
h.															
10	...	+ '00052	- '00017	+ '00005	+ '00024	+ '00042	+ '00026	+ '00009	+ '00037	+ '00046	+ '00029	+ '00021	+ '00029	+ '00027	+ '00034
11	...	+ '00081	+ '00005	+ '00045	+ '00054	+ '00068	+ '00044	+ '00038	+ '00045	+ '00072	+ '00057	+ '00096	+ '00062	+ '00053	+ '00079
12	...	+ '00101	+ '00062	+ '00057	+ '00069	+ '00085	+ '00063	+ '00053	+ '00066	+ '00082	+ '00083	+ '00132	+ '00080	+ '00070	+ '00105
13	...	+ '00122	+ '00098	+ '00100	+ '00103	+ '00083	+ '00067	+ '00060	+ '00057	+ '00090	+ '00067	+ '00144	+ '00075	+ '00078	+ '00113
14	...	+ '00136	+ '00099	+ '00096	+ '00098	+ '00074	+ '00065	+ '00047	+ '00066	+ '00078	+ '00070	+ '00154	+ '00107	+ '00074	+ '00132
15	...	+ '00127	+ '00091	+ '00076	+ '00062	+ '00055	+ '00063	+ '00070	+ '00057	+ '00060	+ '00054	+ '00145	+ '00092	+ '00062	+ '00121
16	...	+ '00139	+ '00069	+ '00065	+ '00040	+ '00037	+ '00051	+ '00056	+ '00050	+ '00051	+ '00047	+ '00106	+ '00082	+ '00050	+ '00109
17	...	+ '00117	+ '00025	+ '00037	+ '00018	+ '00023	+ '00020	+ '00050	+ '00046	+ '00026	- '00003	+ '00078	+ '00081	+ '00027	+ '00092
18	...	+ '00067	+ '00018	- '00012	+ '00006	+ '00003	+ '00010	+ '00034	+ '00017	+ '00004	+ '00023	+ '00038	+ '00040	+ '00010	+ '00048
19	...	+ '00061	- '00035	- '00016	- '00012	- '00016	+ '00004	- '00008	- '00015	- '00003	+ '00013	+ '00017	+ '00037	- '00007	+ '00038
20	...	'00000	- '00019	- '00029	- '00023	- '00021	- '00005	- '00009	- '00007	- '00009	- '00010	- '00016	+ '00012	- '00014	- '00001
21	...	- '00025	+ '00062	- '00030	- '00038	- '00036	- '00012	+ '00027	- '00009	- '00015	- '00011	- '00044	- '00021	- '00022	- '00030
22	...	- '00055	+ '00231	- '00047	- '00015	- '00053	- '00019	- '00031	- '00019	- '00034	- '00028	- '00062	- '00065	- '00031	+ '00061
23	...	- '00070	+ '00281	- '00024	- '00033	- '00050	- '00004	- '00015	- '00003	- '00042	- '00040	- '00062	- '00063	- '00027	- '00065
0	...	- '00073	- '00105	- '00037	- '00023	- '00020	- '00020	- '00031	- '00055	- '00037	- '00054	- '00069	- '00035	- '00034	- '00069
1	...	- '00068	- '00112	- '00030	- '00045	- '00034	- '00023	- '00040	- '00042	- '00051	- '00052	- '00082	- '00059	- '00039	- '00070
2	...	- '00086	- '00139	- '00039	- '00042	- '00022	- '00022	- '00052	- '00058	- '00043	- '00058	- '00070	- '00041	- '00042	- '00066
3	...	- '00090	- '00141	- '00035	- '00045	- '00031	- '00042	- '00046	- '00032	- '00053	- '00061	- '00075	- '00044	- '00043	- '00070
4	...	- '00083	- '00102	- '00039	- '00048	- '00028	- '00037	- '00034	- '00060	- '00041	- '00045	- '00088	- '00062	- '00042	- '00077
5	...	- '00105	- '00143	- '00042	- '00041	- '00026	- '00029	- '00032	- '00055	- '00054	- '00016	- '00081	- '00070	- '00036	- '00085
6	...	- '00115	- '00113	- '00048	- '00023	- '00048	- '00041	- '00050	- '00038	- '00061	- '00036	- '00110	- '00068	- '00043	- '00097
7	...	- '00104	- '00077	- '00055	- '00040	- '00052	- '00032	- '00052	- '00030	- '00055	- '00033	- '00107	- '00074	- '00043	- '00095
8	...	- '00067	- '00061	- '00043	- '00055	- '00023	- '00036	- '00027	- '00003	- '00042	- '00043	- '00098	- '00070	- '00034	- '00078
9	...	- '00030	+ '00001	- '00011	- '00025	+ '00022	'00000	- '00011	+ '00021	- '00011	+ '00003	- '00016	- '00011	- '00002	- '00019

The numbers in the last two columns are curved in Figs. 801 and 802.