II. *Magnetic Survey of the East of France in* 1869. *By the Rev.* Stephen J. Perry. *Communicated by the President.*

Received July 13,—Read November 23, 1871.

Magnetic Survey of the East of France, 1869.

This survey, which occupied a considerable portion of the months of August and September 1869, is a continuation of the series of observations made in the west of France during the preceding year. The instruments used were the same on both occasions, the only changes made for the second expedition being (1°) the substitution of a theodolite by Jones in lieu of Cooke's transit-theodolite, which was slightly too heavy for carrying in the hand, and (2°) the procuring, through the kindness of Dr. Stewart, a second tripod stand similar to our own, which rendered the series of observations with two observers much more rapid than on the previous occasion. The observations were undertaken, as before, by the Rev. W. Sidgreaves and myself, the Vibrations and Deflections falling to his share, and the Declination and Chronometer comparisons remaining in my hands, whilst the Dip was in general observed by both. The method of reduction is almost identical with that adopted for the observations taken in the west of France.

The geographical positions of the different stations have been calculated, as far as possible, from the data given in the 'Connaissance des Temps,' but where this could not be done I have had recourse to the most reliable sources of information at my command. For the accurate determination of the positions of Mont Rolland (near Dôle), of N. D. de Myans (near Chambéry), of Mongré (near Villefranche-sur-Soane), of Iseure (near Moulins), and of our station at Marseilles I am indebted to the kindness of the Rev. N. Larcher, S.J., Membre de la Société Météorologique de France. The coordinates of Vaugirard were readily obtained from a good map of Paris, and for Issenheim and Monaco I have to depend on Cassini's 'Carte Générale de la France' and on Philip's 'Imperial Atlas.' The Imperial Observatory at Paris is chosen as the natural position for the origin of coordinates, in lieu of our central station of observation at Vaugirard, which lies on the outskirts of the city; the resulting mean values will thus require no correction, and will be immediately comparable with those of most other observers.

TABLE I.

Station.	Latitude.	Longitude.	Difference in miles of		Place of observation.
			Latitude.	Longitude.	
	° ′ ″	m s			
Paris Observatory.........	48 50 11	0 0			
Vaugirard	48 50 2·5	− 0 10·4	− 0·2	− 2·1	Garden of College.
Rheims	49 15 15	+ 6 47	+ 29	+ 77	Place Ruinart.
Metz	49 7 14	+15 22	+ 20	+174	Coll. S. Clement.
Strasburg	48 34 57	+21 40	− 18	+248	9 Rue des Juifs.
Issenheim	48 0 32	+19 49	− 57	+228	Garden of College.
Mont Rolland	47 8 30	+12 34	−117	+148	Château.
Dôle	47 5 33	+12 38	−120	+149	4 Rue du Collége.
Dijon	47 19 19	+10 48	−105	+127	Garden of the Hospital.
Lyons	45 45 45	+ 9 57	−212	+120	8 Terrasse de Fourvières.
Avignon	43 57 13	+ 9 53	−337	+123	62 Rue des Lices.
Marseilles	43 17 55	+12 10	−382	+153	Missions de France.
Monaco	43 43 2	+20 21	−352	+255	Garden near Palace.
Montpellier	43 36 44	+ 6 10	−361	+ 77	13 Rue Rondelet.
Grenoble	45 11 12	+13 34	−252	+166	On hill-side facing town.
N. D. de Myans	45 30 50	+14 36	−230	+177	Promenade.
Mongré	45 59 25	+ 9 29	−197	+114	Garden of College.
St. Etienne	45 26 9	+ 8 13	−235	+100	Collége S. Michel.
Clermont Ferrand	45 46 46	+ 3 0	−211	+ 36	College.
Iseure (Moulins)	46 33 59	+ 4 4	−157	+ 48	Petit Séminaire.
Douay	50 22 15	+ 2 59	+106	+ 33	English College.
Boulogne	50 43 33	− 2 54	+131	− 32	41 Rue Brecquerecque.

The Magnetic Dip.

The Dip observations were made with three different needles at each station with the following results:—

TABLE II.

Station.	Date.	G. M. T.	Number of readings.			Dip.			Mean.
			1.	2.	3.	No. 1.	No. 2.	No. 3.	
	1869.	h m				° ′ ″	° ′ ″	° ′ ″	
Vaugirard	Aug. 6	10 52 A.M.	36	...	34	65 52 12	....	65 49 2	
		11 47 A.M.							
	„ 7	8 28 A.M.	...	32	...	....	65 46 50	....	65 49 21
Rheims	„ 10	8 50 A.M.	32	...	...	65 57 43			
		10 8 A.M.	...	34	...	....	65 56 34		
		11 10 A.M.	...	...	38	....	....	65 48 15	65 54 11
Metz	„ 12	9 28 A.M.	32	...	...	65 31 37			
		2 5 P.M.	...	36	...	....	65 20 24		
		3 44 P.M.	...	...	32	....	....	65 24 29	65 25 30
Strasburg	„ 14	4 35 P.M.	...	...	38	....	....	64 39 33	
	„ 15	2 58 P.M.	36	...	...	64 43 32			
		5 40 P.M.	...	36	...	....	64 34 25	....	64 39 10
Issenheim	„ 17	9 50 A.M.	36	...	...	64 38 39			
		11 0 A.M.	...	34	...	....	64 28 23		
		2 37 P.M.	...	...	32	....	....	64 35 4	64 34 2
Mont Rolland	„ 19	4 14 P.M.	36	...	...	64 13 29	....	....	64 13 29
Dôle	„ 19	9 9 A.M.	32	...	...	64 15 18			
	„ 20	9 24 A.M.	...	32	...	....	64 8 11		
		11 0 A.M.	...	...	34	....	....	64 8 35	64 10 41
Dijon	„ 21	10 15 A.M.	32	...	...	64 28 4			
		2 56 P.M.	...	32	...	....	64 20 3		
		4 21 P.M.	...	...	38	....	....	64 19 3	64 22 23
Lyons	„ 23	9 3 A.M.	34	...	...	63 12 33			
		9 53 A.M.	...	36	...	....	63 15 1		
		10 55 A.M.	...	...	38	....	....	63 14 17	63 13 57
Avignon	„ 25	8 30 A.M.	36	...	...	61 44 32			
		9 30 A.M.	...	38	...	....	61 37 12		
		11 20 A.M.	...	...	32	....	....	62 3 17	61 48 20

TABLE II. (continued).

Station.	Date.	G. M. T.	Number of readings. 1.	2.	3.	Dip. No. 1.	No. 2.	No. 3.	Mean.
	1869.	h m							
Marseilles	Aug. 27	9 23 A.M.	34	...	...	60° 31′ 0″			
		10 28 A.M.	...	34	...	....	60° 28′ 20″		
		11 28 A.M.	...	...	34	....	....	60° 37′ 52″	60° 32′ 24″
Monaco	„ 29	9 50 A.M.	34	...	...	61 21 47			
		11 10 A.M.	...	34	...	....	61 15 21		
		3 33 P.M.	...	...	38	....	....	61 22 34	61 19 54
Montpellier	„ 31	9 10 A.M.	40	...	...	61 35 0			
		10 5 A.M.	...	32	...	....	61 39 25		
		4 15 P.M.	...	...	38	....	....	61 29 33	61 34 39
Grenoble	Sept. 3	10 27 A.M.	34	...	...	62 57 23			
		11 10 A.M.	...	34	...	....	62 47 52		
		4 28 P.M.	...	...	48	....	....	62 50 48	62 52 1
N. D. de Myans......	„ 4	1 50 P.M.	32	...	...	62 55 37			
		3 28 P.M.	...	32	...	....	62 47 58		
		4 52 P.M.	...	...	40	....	....	62 47 9	62 50 15
Mongré	„ 7	8 5 A.M.	46	...	...	63 27 40			
		9 10 A.M.	...	38	...	....	63 30 20		
		10 58 A.M.	...	...	42	....	....	63 24 57	63 27 39
St. Etienne	„ 8	10 13 A.M.	36	...	...	63 5 7			
		11 10 A.M.	...	34	...	}	62 59 7	63 0 28	63 1 34
	„ 9	8 12 A.M.	...	...	34				
Clermont	„ 10	10 15 A.M.	42	...	...	63 26 5			
	„ 11	8 15 A.M.	...	34	...	....	63 44 38		
		9 10 A.M.	...	...	34	....	....	63 32 2	63 34 15
Moulins...............	„ 12	9 13 A.M.	34	...	...	64 4 55			
		2 40 P.M.	...	32	...	....	64 18 1		
		4 23 P.M.	...	...	34	....	....	63 45 12	64 2 43
Vaugirard	„ 14	9 16 A.M.	32	...	...	65 54 43			
		10 10 A.M.	...	36	...	....	66 12 0		
		11 8 A.M.	...	...	34	....	....	65 48 57	65 58 33
Douay	„ 17	9 55 A.M.	36	...	...	66 46 44			
		11 35 A.M.	...	38	...	....	66 43 29		
		12 40 P.M.	...	...	32	....	....	66 44 7	66 44 47
Boulogne	„ 19	3 2 P.M.	32	...	...	67 3 5			
		4 9 P.M.	...	32	...	....	67 11 42		
		5 45 P.M.	...	...	34	....	....	67 0 55	67 5 14

The observations furnish the following equations, which determine the inclination of the isoclinals to the prime meridian and their distance apart:—

$$5{\cdot}903=\delta-77x-29y$$
$$5{\cdot}425=\delta-174x-20y$$
$$4{\cdot}653=\delta-248x+18y$$
$$4{\cdot}567=\delta-228x+57y$$
$$4{\cdot}225=\delta-148x+117y$$
$$4{\cdot}178=\delta-149x+120y$$
$$4{\cdot}373=\delta-127x+105y$$
$$3{\cdot}233=\delta-120x+212y$$
$$1{\cdot}806=\delta-123x+337y$$
$$0{\cdot}540=\delta-153x+382y$$
$$1{\cdot}332=\delta-255x+352y$$
$$1{\cdot}578=\delta-77x+361y$$
$$2{\cdot}867=\delta-166x+252y$$
$$2{\cdot}838=\delta-177x+230y$$

$$3{\cdot}461=\delta-114\,x+197\,y$$
$$3{\cdot}026=\delta-100\,x+235\,y$$
$$3{\cdot}571=\delta-\ \ 36\,x+211\,y$$
$$4{\cdot}045=\delta-\ \ 48\,x+157\,y$$
$$6{\cdot}746=\delta-\ \ 33\,x-106\,y$$
$$7{\cdot}087=\delta+\ \ 32\,x-131\,y.$$

These equations of condition combine to form the three simultaneous equations,—

$$75{\cdot}454=\quad 20\delta-\quad 2521x+\quad 3057y,$$
$$-8544{\cdot}730=-2521\delta+421413x-447498y,$$
$$6571{\cdot}180=\quad 3057\delta-447498x+910595y,$$

which give as the most probable values of the three unknowns—

$$\delta=\ \ 5{\cdot}7816,$$
$$x=\ \ 0{\cdot}0028495,$$
$$y=-0{\cdot}0107928.$$

Thus the mean value of the Dip at the central station is $65^{\circ}{\cdot}7816$; whilst the distance between the isoclinals that differ by $30'$ is 44·8 miles, r being $=0^{\circ}{\cdot}01116$; and the angle formed by the isoclinals with the meridian is $-75^{\circ}\ 14'\ 34''$, *i. e.* their direction is from N. 75° 14′ 34″ E. to S. 75° 14′ 34″ W.

The substitution of the above values of δ, x, and y in the equations of condition forms the Table by which we can determine the most probable error in a single observation or in the mean.

TABLE III.

	Observed Dip.	Computed Dip.	Error.
Rheims	65·903	65·876	+0·027
Metz	65·425	65·502	−0·077
Strasburg	64·653	64·883	−0·230
Issenheim	64·567	64·527	+0·040
Mont Rolland	64·225	64·097	+0·128
Dôle	64·178	64·062	+0·116
Dijon	64·373	64·287	+0·086
Lyons	63·233	63·152	+0·081
Avignon	61·806	61·795	+0·011
Marseilles	60·540	61·223	−0·683
Monaco	61·332	61·256	+0·076
Montpellier	61·578	61·667	−0·089
Grenoble	62·867	62·597	+0·270
N. D. de Myans	62·838	62·796	+0·042
Mongré	63·461	63·331	+0·130
St. Etienne	63·026	62·961	+0·065
Clermont	63·571	63·403	+0·168
Moulins	64·045	63·951	+0·094
Douay	66·746	66·832	−0·086
Boulogne	67·087	67·287	−0·200

We thus find that the probable errors of any single observation, or rather of the mean value at any single station, $=\pm 0{\cdot}6745\sqrt{\frac{0{\cdot}765507}{19}}=\pm 0{\cdot}13538$, whilst that of the mean from all the observations $=\pm 0{\cdot}030274$.

The large error at Marseilles will probably be due to the difficulty experienced in finding a convenient site for the observations.

If, now, we turn to the series of observations taken at some of the above stations by Dr. LAMONT, and reduced to the epoch of Jan. 1st, 1858, and if we consider the epoch Sept. 1st, 1869 as common to all stations of our Survey (which we are able to do without sensible error), we arrive at the following Table for determining the secular variation of the Dip in the east of France:—

TABLE IV.

Station.	Dip, Jan. 1, 1858.	Dip, Sept. 1, 1869.	Diff. of Epoch.	Diff. of Dip.	Yearly rate of decrease.	Dip, Jan. 1, 1869.
Clermont	64°·202	63°·571	$11\frac{2}{3}$	−0°·631	−0°·054	63°·607
Dijon	64·917	64·373	”	−0·544	−0·047	64·409
Marseilles	61·675	60·540	”	−1·135	−0·097	60·576
Montpellier ...	62·255	61·578	”	−0·677	−0·058	61·614
Moulins	64·723	64·045	”	−0·678	−0·058	64·081
Paris	66·442	65·823	”	−0·619	−0·053	65·859
		Mean (omitting Marseilles)			−0·054	

Comparing this mean annual change with −0°·045, the rate for 1858 as deduced by LAMONT, we find the decrease to be accelerated annually by −0°·00082, which agrees closely with the acceleration for the period from 1780 to 1830, which General SABINE gives as −0·00085.

In our previous discussion of the series of observations taken in 1868 in the west of France, the deduced yearly rate of decrease in the Dip was found to be 0·062; the Dip would therefore seem to be decreasing rather more rapidly in the west than in the east of France.

In the Table of the Dip observations it will be noticed that at a few stations the readings differ very considerably from each other; but I have retained them all in forming the equations of condition, as I cannot see a sufficient reason for discarding any, since the same attention as to choice of position and accuracy of observation was maintained throughout. When at any station the readings of two of the needles agree fairly together, but differ much from the third, this could scarcely be considered conclusive against the correctness of the third, unless all three had been observed under precisely similar circumstances of time and place; since it is not impossible that an iron tube or other disturbing cause, of which we could obtain no information, had affected the two first needles and not the third. But to test the correctness of this view, I have solved the equations after omitting the most striking irregularities, viz. the three at Moulins, No. 3 at Avignon, and No. 2 at Clermont, and I find that these arbitrary exclusions do not tend to improve the results. It is, however, a different case with regard to the two stations of Marseilles and Grenoble, where we were unable to procure very convenient sites for the observations. Omitting, therefore, these two stations in our equations of condition, we obtain

$$\delta=65\cdot7658, \qquad r=0\cdot0108, \qquad u=-74^\circ\ 10'\ 13''\cdot56,$$

with $\pm0\cdot06550$ as the probable error at any single station, the probable error of the mean being $\pm0\cdot01544$. This diminution in the probable errors would seem to warrant the omissions.

Considering the limited time at our disposal we were unable in this survey of France to choose many stations at which Dr. LAMONT had previously observed; but this want of identity of locality may be balanced by a comparison of the general results obtained from all the observations made during the two surveys. Employing precisely the same method to reduce LAMONT'S values for 1858 as has been used above, we arrive at the following results:—

TABLE V.

Epoch.	Dip at Central Station.	Dist. of isoclinals differing by 0°·5.	Angle of isoclinals N.E. of meridian.	Number of observations.
	°	miles.	° ′ ″	
Jan. 1, 1858, W.	66·6291	40·36	70 23 25	16
Jan. 1, 1858, E.	66·4640	44·44	72 44 33	15
Sept. 1, 1868, W.	65·8796	43·84	73 32 50	13
Sept. 1, 1869, E.	65·7816	44·80	75 14 34	20

We thus obtain 0°·0703 as the annual variation of the Dip in the west of France, whilst in the east it only varies annually 0·0585; and the isoclinals appear to be receding much more rapidly from the meridians in the west than in the east.

The Magnetic Intensity.

We next proceed to discuss the observations for determining the lines of equal intensity.

TABLE VI.

Station.	Date.	G. M. T.	Temp.	Time of one vibration.	Log mX.
		h m			
Vaugirard	Aug. 6	2 37 P.M.	69°·7	5·164666	0·29102
		2 41	69·3	5·165396	0·29087
		2 45	69·1	5·165825	0·29081
Rheims	„ 10	7 3 P.M.	59·6	5·165342	0·28975
		7 8	59·7	5·165250	0·28976
		7 12	59·3	5·165158	0·28976
Metz	„ 12	12 25 P.M.	63·0	5·141960	0·29391
		12 29	64·3	5·141916	0·29401
		12 33	64·1	5·141875	0·29399
Strasburg	„ 14	4 55 P.M.	70·0	5·084250	0·30438
		5 0	68·8	5·084588	0·30423
		5 4	67·6	5·084825	0·30411
Issenheim	„ 17	2 4 P.M.	65·0	5·06998	0·30653
		2 8	65·2	5·06990	0·30656
		2 12	65·4	5·06971	0·30660
Mont Rolland	„ 19	2 13 P.M.	64·3	5·03573	0·31227
		2 18	64·4	5·03645	0·31216
		2 22	64·5	5·03730	0·31202
Dôle	„ 20	8 2 A.M.	60·4	5·03900	0·31069
		8 6	61·2	5·03903	0·31152
		8 10	62·0	5·03928	0·31152
Dijon	„ 21	2 35 P.M.	77·7	5·06046	0·30823
		2 39	77·6	5·06044	0·30822
		2 44	77·5	5·06030	0·30841
Lyons	„ 23	2 25 P.M.	77·5	4·97529	0·32367
		2 29	77·0	4·97502	0·32367
		2 33	76·5	4·97475	0·32369
Avignon	„ 25	11 13 A.M.	80·2	4·87966	0·34095
		11 34	81·3	4·88105	0·34035
Marseilles	„ 27	2 50 P.M.	79·8	4·82787	0·34982
		3 14	79·7	4·82735	0·34991
Monaco	„ 29	10 48 A.M.	80·6	4·86301	0·34360
		10 52	80·6	4·86277	0·34364
		10 56	80·7	4·86264	0·34367
Montpellier	„ 31	3 43 P.M.	79·7	4·87120	0·34219
		3 47	80·3	4·87192	0·34210
		3 51	80·9	4·87266	0·34201
Grenoble	Sept. 3	2 36 P.M.	76·3	4·982880	0·32211
		2 58	74·6	4·981167	0·32228
		3 2	74·6	4·980875	0·32233
		3 6	74·2	4·981729	0·32216
N. D. de Myans.........	„ 4	3 27 P.M.	69·9	4·954608	0·32663
Mongré	„ 7	10 27 A.M.	71·6	4·994708	0·31984
St. Etienne..............	„ 8	5 32 P.M.	70·5	4·964875	0·32483
		5 35	69·3	4·964740	0·32478
		5 40	68·0	4·964521	0·32473
Clermont	„ 10	4 53 P.M.	65·1	4·994458	0·31931
		5 12	62·4	4·995460	0·31896
Moulins	„ 12	11 26 A.M.	70·0	5·036300	0·31238
		11 44	69·7	5·035200	0·31256
		11 47	69·7	5·034379	0·31270
		11 52	69·7	5·033360	0·31287
Vaugirard	„ 15	6 0 P.M.	63·8	5·167092	0·28974
		6 52	64·0	5·167541	0·28967
		6 56	63·9	5·167288	0·28982
Douay.....................	„ 17	9 27 A.M.	62·5	5·245416	0·27660
		9 31	62·5	5·245062	0·27666
		9 36	62·4	5·244708	0·27671
Boulogne	„ 19	5 23 P.M.	58·9	5·272550	0·27192
		5 43	57·7	5·272808	0·27180
		5 47	57·4	5·272748	0·27178
		5 52	57·0	5·272758	0·27176

The following observations of Deflection at 1 foot and 1·3 foot serve as the complement of the above Table of vibrations, and furnish us with the Horizontal Component of the Earth's Magnetic Intensity.

TABLE VI. (bis).

Station.	Date.	G. M. T.	Temp.	Dist. of magnets.	Observed deflection.	Log $\frac{m}{x}$.
		h m	°		° ′ ″	
Vaugirard	Aug. 6	4 5 P.M.	67·4	1·0	13 11 34	9·06047
		4 17	68·3	1·3	5 58 5	9·06040
Rheims	„ 10	6 1 P.M.	60·2	1·3	5 58 9	9·05989
		6 14	59·8	1·0	13 12 0	9·06015
Metz	„ 12	3 32 P.M.	70·0	1·0	13 3 29	9·05628
		3 49	70·2	1·3	5 54 44	9·05647
		6 39	54·4	1·0	13 6 33	9·05684
Strasburg	„ 14	5 10 P.M.	66·5	1·0	12 46 54	9·04688
		5 21	65·9	1·3	5 47 9	9·04681
Issenheim	„ 17	3 41 P.M.	64·4	1·0	12 43 31	9·04485
		3 56	64·2	1·3	5 45 41	9·04485
Mont Rolland	„ 19	3 40 P.M.	64·1	1·0	12 32 28	9·03859
		3 51	63·5	1·3	5 40 55	9·03878
Dôle	„ 20	9 52 A.M.	64·8	1·0	12 34 5	9·03956
		10 4	65·1	1·3	5 41 35	9·03975
Dijon	„ 21	3 59 P.M.	76·4	1·0	12 37 1	9·04209
		4 12	76·7	1·3	5 42 43	9·04193
Lyons	„ 23	3 50 P.M.	73·4	1·0	12 11 30	9·02720
		4 1	72·7	1·3	5 31 24	9·02721
Avignon	„ 25	5 9 P.M.	81·0	1·0	11 42 10	9·01028
		5 19	80·7	1·3	5 18 22	9·01046
Marseilles	„ 27	4 33 P.M.	76·5	1·0	11 28 18	9·00138
		4 44	76·4	1·3	5 11 52	9·00119
Monaco	„ 29	2 37 P.M.	78·1	1·0	11 36 47	9·00676
		2 50	77·9	1·3	5 15 55	9·00690
Montpellier	„ 31	5 3 P.M.	76·4	1·0	11 40 55	9·00916
		5 15	76·3	1·3	5 17 51	9·00941
Grenoble	Sept. 3	3 53 P.M.	72·5	1·0	12 14 1	9·02862
		4 5	72·4	1·3	5 32 15	9·02830
N. D. de Myans	„ 4	4 16 P.M.	69·0	1·0	12 5 36	9·02341
		4 47	68·6	1·3	5 28 22	9·02292
Mongré	„ 7	11 14 A.M.	69·3	1·0	12 17 9	9·03019
		11 24	69·8	1·3	5 33 46	9·03007
St. Etienne	„ 8	3 38 P.M.	73·4	1·0	12 8 15	9·02530
		4 8	73·3	1·3	5 29 57	9·02536
Clermont	„ 11	7 58	62·5	1·0	12 20 17	9·03150
		8 8	62·8	1·3	5 35 3	3·03122
Moulins	„ 12	2 35 P.M.	65·5	1·0	12 31 7	9·03793
		2 47	65·5	1·3	5 40 7	9·03791
Vaugirard	„ 14	2 18 P.M.	69·9	1·0	13 12 53	9·06135
		2 27	69·6	1·3	5 58 52	9·06144
Douay	„ 17	10 36 A.M.	64·0	1·0	13 36 14	9·07330
		10 46	65·1	1·3	6 9 10	9·07335
Boulogne	„ 20	9 3 A.M.	58·7	1·0	13 47 34	9·07879
		9 25	59·0	1·3	6 14 18	9·07889

From these Tables, combined with those of the Dip observations, we deduce the following values of the Horizontal and Vertical Components, and of the Total Magnetic Intensity. The last column contains the calculated mean values of the magnetic moment of the deflecting magnet at each station.

TABLE VII.

Station.	H. F.	V.F.	T. F.	m.
Vaugirard	4·1232	9·1840	10·0672	0·47388
Rheims	4·1198	9·2113	10·0907	0·47304
Metz	4·1570	9·0904	9·9958	0·47342
Strasburg	4·2531	8·9782	9·9346	0·47375
Issenheim	4·2743	8·9883	9·9528	0·47393
Mont Rolland	4·3325	8·9719	9·9632	0·47361
Dôle	4·3231	8·9341	9·9251	0·47365
Dijon	4·2974	8·9586	9·9361	0·47339
Lyons	4·4488	8·8195	9·8780	0·47364
Avignon	4·6254	8·6282	9·7897	0·47371
Marseilles	4·7238	8·3629	9·6048	0·47378
Monaco	4·6602	8·5233	9·7142	0·47341
Montpellier	4·6389	8·5713	9·7461	0·47391
Grenoble	4·4348	8·6554	9·7252	0·47358
N. D. de Myans.........	4·4847	8·7403	9·8236	0·47304
Mongré...	4·4143	8·8385	9·8796	0·47314
St. Etienne..............	4·4641	8·7711	9·8417	0·47321
Clermont	4·4044	8·8613	9·8956	0·47343
Moulins	4·3387	8·9135	9·9134	0·47346
Vaugirard	4·1132	9·1619	10·0429	0·47377
Douay	3·9964	9·3003	10·1226	0·47315
Boulogne	3·9491	9·3428	10·1431	0·47352

These values of H. F., combined with the second members of our previous set of equations, which remain unchanged, will give us the equations of condition for determining the lines of equal Horizontal Intensity. Reducing these equations by the method of least squares, we obtain :—

$$27{\cdot}3408 = 20\,h - 2521\,x + 3057\,y,$$

$$-3560{\cdot}9763 = -2521\,h + 421413\,x - 447498\,y,$$

$$4782{\cdot}1935 = 3057\,h - 447498\,x + 910595\,y;$$

$$\therefore\quad h = \text{H. F.} - 3 = 1{\cdot}1259,$$

$$x = -0{\cdot}000317,$$

$$y = \quad 0{\cdot}001316.$$

Hence $r=0{\cdot}00135$, or the lines whose H. F. differs by 0·1 are 73·7 miles apart; and $u = -76^\circ\,27'\,16''{\cdot}5$, or the direction of the lines is N. 76° 27′ 16″·5 E. to S. 76° 27′ 16″·5 W.

A substitution of these values in our original equations will enable us to form a Table of the computed Horizontal Force for each station.

TABLE VIII.

Station.	Computed H. F.	Observed H. F.	Obs. − Comp.
Paris	4·1259	4·1182	−0·0067
Rheims	4·1121	4·1198	+0·0077
Metz	4·1548	4·1570	+0·0022
Strasburg	4·2282	4·2531	+0·0249
Issenheim	4·2732	4·2743	+0·0011
Mont Rolland	4·3268	4·3325	+0·0057
Dôle	4·3310	4·3231	−0·0079
Dijon	4·3044	4·2974	−0·0070
Lyons	4·4429	4·4488	+0·0059
Avignon	4·6084	4·6254	+0·0170
Marseilles	4·6771	4·7238	+0·0467
Monaco	4·6699	4·6602	−0·0097
Montpellier	4·6254	4·6389	+0·0135
Grenoble	4·5101	4·4348	−0·0753
N. D. de Myans	4·4847	4·4847	0·0000
Mongré	4·4213	4·4143	−0·0070
St. Etienne	4·4669	4·4641	−0·0028
Clermont	4·4150	4·4044	−0·0106
Moulins	4·3477	4·3387	−0·0090
Douay	3·9969	3·9964	−0·0005
Boulogne	3·9434	3·9491	+0·0057

Excluding Paris, which does not enter as a station into our equations of condition, we obtain for the probable error of the mean value of the observed H. F. at any single station

$$0·6745\sqrt{\frac{0·00956332}{19}}=\pm 0·01513,$$

whilst the error of the computed value for the central station will be $\pm 0·00338$.

It remains for us to deduce the secular variation of the Horizontal Force from the observations taken at those stations which are common to the two surveys of 1858 and 1869.

TABLE IX.

Station.	H. F., Jan. 1, 1858.	H. F., Sept. 1, 1869.	Diff. of Epoch.	Diff. of H. F.	Yearly rate of increase.	H. F., Jan. 1, 1869.
Clermont	4·3523	4·4044	$11\frac{2}{3}$	+0·0521	+·00447	4·4013
Dijon	4·2385	4·2974	,,	+0·0589	+·00505	4·2943
Marseilles	4·6332	4·7238	,,	+0·0906	+·00777	4·7207
Montpellier	4·5788	4·6389	,,	+0·0601	+·00515	4·6358
Moulins	4·2871	4·3387	,,	+0·0516	+·00442	4·3356
Paris	4·0685	4·1182	,,	+0·0497	+·00426	4·1151
		Mean (omitting Marseilles)			+·00467	

The yearly rate deduced from the observations of 1858 and 1868 in the west of France was $+0·00507$; hence the rate of increase appears to be slower in the east than in the west, whilst the mean rate for the whole of France is identical with that given by Dr. LAMONT for 1858, the yearly acceleration being less than 0·000007.

Were we to omit the observations taken at the stations of Marseilles, where the site was quite exceptional, and of Grenoble, where the geological formation appears very unfavourable for deducing a correct mean value, the solution of the remaining equations would give us a value for r identical with that already obtained, but would induce a very considerable change in the resulting angle between the lines of equal intensity and the prime meridian. The probable errors would be greatly diminished. The several quantities would become

$$4{\cdot}1260 \text{ for the H. F. at the central station.}$$

$$0{\cdot}00135=r \text{ and } u=-75^\circ\ 22'\ 35''.$$

Probable error at any one station $\pm 0{\cdot}00654$, and at the central station $\pm 0{\cdot}00154$.

I will now form a Table, similar to that for the Dip, for comparing the general results obtained during the two surveys of 1858 and 1868–69.

TABLE X.

Epoch.	H. F. at Central Station.	Distance between lines of equal H. F. which differ by 0·1.	Angle of lines of equal H. F., N.E. of meridian.	Number of stations.
		miles.	° ′ ″	
Jan. 1st, 1858, W.	4·0521	68·0	72 40 51·7	20
Jan. 1st, 1858, E.	4·0707	73·5	78 49 36·0	22
Sept. 1st, 1868, W.	4·1150	71·4	74 25 31·5	13
Sept. 1st, 1869, E.	4·1259	74·1	76 27 16·5	20

We see at once that the lines of equal Horizontal Force lie much closer in the west of France, but that this difference is diminishing rapidly at present, although it still remains considerable. The mean angle formed by these lines with the meridian of Paris is only slightly different for 1858 and for 1868 and 1869, whilst the angle deduced from both sets of observations taken in the east is very much greater than that found for the west; the difference, however, is here again less for 1868–69 than for 1858.

The secular variation for the W. $+0{\cdot}00590$, and for the E. $+0{\cdot}00473$, obtained from the preceding Table, agrees well with the results deduced from the few stations which are common to the two surveys.

We next come to the discussion of the values of the Total Force, found by combining the observations of the Dip and Horizontal Force taken at each successive station.

The figures in Table VII. enable us to form at once the required equations of condition, and these combined furnish the three equations,—

$$17{\cdot}8759=20\,\text{F}-\ 2521\,x+3057\,y,$$

$$-2167{\cdot}3049=-2521\,\text{F}+421413\,x-447498\,y,$$

$$2352{\cdot}5148=3057\,\text{F}-447498\,x+910595\,y,$$

whose solution give $\text{F}=1{\cdot}0608$, $x=0{\cdot}0003444$, $y=-0{\cdot}0008084$.

Thus the isodynamics that differ by 0·1 are 113·8 miles apart, and they lie at an angle of $66^\circ\ 55'\ 24''{\cdot}9$ to the N.E. of the geographical meridian. The intensity of the earth's magnetism at the central station is 10·0608. The probable errors can now be deduced by a comparison of the values computed from the above data with the intensity at each station, found by combining the observations of the Dip and Horizontal Force,

TABLE XI.

Station.	From observed Dip and H. F.	Computed.	Error.
Rheims	10·0907	10·0577	+0·0330
Metz	9·9958	10·0171	−0·0213
Strasburg	9·9346	9·9608	−0·0262
Issenheim	9·9528	9·9362	+0·0166
Mont Rolland	9·9632	9·9152	+0·0480
Dôle	9·9251	9·9125	+0·0126
Dijon	9·9361	9·9322	+0·0039
Lyons	9·8780	9·8381	+0·0399
Avignon	9·7897	9·7360	+0·0537
Marseilles	9·6048	9·6993	−0·0945
Monaco	9·7142	9·6884	+0·0258
Montpellier	9·7461	9·7425	+0·0036
Grenoble	9·7252	9·7999	−0·0747
N. D. de Myans	9·8236	9·8149	+0·0087
Mongré	9·8796	9·8622	+0·0174
St. Etienne	9·8417	9·8364	+0·0053
Clermont	9·8956	9·8778	+0·0178
Moulins	9·9134	9·9174	−0·0040
Douay	10·1226	10·1351	−0·0125
Boulogne	10·1431	10·1777	−0·0346
Paris	10·0551	10·0608	−0·0057

These errors, omitting that for Paris, since it is not included in our equations, give as the probable error at any single station ±0·0253, whilst that for the mean is ±0·00566.

The stations common to the surveys of 1858 and of 1868–69 will furnish us with the data for calculating the secular changes of terrestrial magnetic intensity.

TABLE XII.

Station.	T. F., Jan. 1, 1858.	T. F., Sept. 1, 1869.	Difference of epoch.	Difference of T. F.	Yearly rate of change.
Clermont	10·0007	9·8956	$11\frac{2}{3}$	−0·1051	−0·0090
Dijou	9·9979	9·9361	„	−0·0618	−0·0053
Marseilles	9·7649	9·6048	„	−0·1601	−0·0137
Montpellier	9·8355	9·7461	„	−0·0894	−0·0077
Moulins	10·0356	9·9134	„	−0·1222	−0·0105
Paris	10·1793	10·0551	„	−0·1242	−0·0106
				Mean	−0·00947

The secular variation deduced from the general results of all the observations is considerably larger than the above, being 0·0118 for the west and 0·0119 for the east of France. These are obtained from the subjoined Table.

TABLE XIII.

Epoch.	Intensity at Central Station.	Distance between Isodynamics which differ by 0·1.	Angle of Isodynamics N.E. of meridian.	Number of stations.
		miles.	° ′ ″	
Jan. 1, 1858, W.	10·1951	91·7	63 52 40·6	16
Jan. 1, 1858, E....	10·2000	96·9	60 18 43·7	15
Sept. 1, 1868, W.	10·0688	113·9	70 39 17·8	13
Sept. 1, 1869, E.	10·0608	113·8	66 55 24·9	20

It is evident from these figures that the variations of the Dip and Horizontal Force combine to produce a very rapid alteration of the isodynamics, especially by increasing the distance between the lines.

The largeness of the error in the Total Force at Marseilles and Grenoble warrants a recalculation of the results with the omission of these two stations. The following are the values obtained by this reduction:—

T. F.$=10·0566$, $x=0·0003253$, $y=-0·0007253$, $r=0·000795$, $u=65° \ 50' \ 40''·8$.

The probable errors are thus very much diminished, being now only 0·01306 for a single station, and for the mean 0·00308.

The Magnetic Declination.

The determination of this magnetie element, which at a fixed observatory presents but little difficulty, is by far the most troublesome and the least to be relied upon when the observations have to be taken in the course of a magnetic survey. For not only must the magnetic instruments themselves be in perfect condition, as for the other observations, but any unknown change of rate in the chronometer, any error in the determination of the sun's position, is sufficient to introduce a serious inaccuracy in the results, to say nothing of the perturbations so much more frequent and more extensive in this element than in the others.

The Frodsham chronometer used during this survey has given perfect satisfaction, its rate having been remarkably constant during the whole journey, even more so than in 1868. This will be seen from the following comparisons:—

TABLE XIV.

Station.	Date.	G. M. T.	Error.	Daily rate.
		h m s	m s	s
Stonyhurst Observatory	July 20	9 21 5·5 P.M.	+5 4·77	
„	„ 21	9 51 25·0 P.M.	+5 6·77	+2·00
„	„ 25	9 57 10·0 P.M.	+5 15·71	+2·24
Paris Observatory...............	Aug. 7	10 20 A.M.	+5 39·65	+1·84
Marseilles Observatory.........	„ 27	9 43 A.M.	+6 18·97	+1·966
Paris Observatory...............	Sept. 14	1 0 P.M.	+6 54·70	+1·985
Stonyhurst Observatory	„ 25	7 15 40·5 P.M.	+7 13·30	+1·69
„	Oct. 9	6 54 45·0 P.M.	+7 34·58	+1·52
„	„ 24	7 15 15·5 P.M.	+7 57·27	+1·51

The rate appears to have been slowly diminishing from July to October, and to have suffered very little disturbance from the travelling. I was unable during the journey to make more frequent comparisons; but altitudes of the sun were taken as before at each station by way of check, though they were fortunately found to be unnecessary.

The observations for finding the sun's azimuth are much less trustworthy than in the preceding year, owing to a change of instrument. The transit-altazimuth of COOKE, which worked so steadily in 1868, was replaced, on account of its heaviness, by a Jones theodolite, which, though much more portable, had the great disadvantage of being far less steady, and thus interfering very considerably with the accuracy of the results.

In all the observations taken during this survey with the declination needle, the scale of the collimator magnet was inverted twice at each station, so as to render unnecessary any other determination of the zero of the scale, which might accidentally be slightly altered whilst travelling.

In the following Table the first readings of the azimuth of the fixed mark were taken throughout on the theodolite circle, and the second readings on the circle of the unifilar.

TABLE XV.

Station.	Date.	Chronometer.	Error at noon, G. M. T.	Daily rate.	Azimuth of Sun.	Azimuth of mark.	Azimuth of magnet.
		h m s	m s	s	° ′ ″	° ′ ″	° ′ ″
Rheims	Aug. 10	9 14 3·1 A.M.	+5 45·70	+1·97	169 52 45	20 48 15 178 3 5	188 52 1
Metz	„ 12	8 33 34·3 A.M.	+5 49·64	„	92 18 45	139 10 15 116 18 10	119 37 59
Strasburg	„ 14	2 35 26·0 P.M.	+5 53·57	„	165 39 45	141 38 0 178 48 0	125 26 38
Issenheim	„ 17	9 18 51·8 A.M.	+5 59·48	„	79 48 30	54 24 0 61 39 10	93 48 21
Dôle	„ 19	9 40 3·3 A.M.	+6 3·42	„	156 32 15	176 53 0 154 6 55	166 12 3
Dijon	„ 21	9 44 21·2 A.M.	+6 7·36	„	25 13 0	136 25 0 173 41 45	93 6 46
Avignon...........	„ 25	8 36 6·0 A.M.	+6 15·23	„	99 21 45	36 8 30 193 36 30	127 14 53
Marseilles	„ 27	11 50 58·3 A.M.	+6 19·16	+1·98	140 57 0	132 25 15 109 54 0	100 51 1
Monaco	„ 29	9 0 57·0 A.M.	+6 23·10	„	28 21 0	150 17 15 127 45 25	227 54 27
Montpellier	„ 31	8 35 28·1 A.M.	+6 27·04	„	74 35 40	92 30 25 130 4 45	161 12 24
Grenoble	Sept. 3	9 54 42·8 A.M.	+6 32·95	„	8 16 45	61 21 38 158 37 7	130 8 54
N. D. de Myans...	„ 4	1 30 31·9 P.M.	+6 34·92	„	140 8 0	158 17 15 195 34 15	122 18 5
Mongré	„ 7	8 35 32·0 A.M.	+6 40·83	„	21 22 45	70 55 30 108 25 10	103 45 39
St. Etienne	„ 8	9 6 12·8 A.M.	+6 42·80	„	62 53 15	170 13 15 267 42 20	197 51 13
Clermont	„ 10	8 51 30·2 A.M.	+6 46·74	„	53 1 55	109 31 30 146 53 5	131 45 25
Moulins...........	„ 12	8 36 4·0 A.M.	+6 50·68	„	64 4 0	110 50 45 148 15 25	145 2 26
Paris	„ 14	9 10 35·8 A.M.	+6 54·62	„	171 30 15	167 42 0 265 9 40	122 33 14
Douay	„ 17	11 58 28·9 A.M.	+7 0·56	„	152 27 20	159 14 45 256 45 25	228 56 0
Boulogne	„ 19	3 45 24·7 P.M.	+7 4·52	„	177 12 25	48 51 45 266 19 10	131 45 8

To complete the above, we have to calculate the azimuth of the sun at the time of each observation, which gives us the south point for the several stations. These south points together with the observed angles will then at once furnish the Declinations.

TABLE XVI.

Station.	Azimuth of Sun.	West Declination.
	° ′ ″	° ′ ″
Rheims	58 21 30·0	16 37 4·0
Metz	66 3 34·1	15 52 15·1
Strasburg	61 54 43·3	15 28 23·7
Issenheim	52 25 20·6	15 41 11·3
Dôle	48 24 26·8	15 58 33·8
Dijon	46 52 35·0	16 30 10·0
Avignon	66 21 15·2	15 56 7·2
Marseilles	2 1 58·8	15 34 45·3
Monaco	56 29 55·8	14 24 38·8
Montpellier	65 28 20·7	16 25 56·7
Grenoble	40 18 20·5	15 41 40·5
N. D. de Myans	39 56 14·4	15 3 45·6
Mongré	60 49 3·4	16 49 34·4
St. Etienne	52 16 26·4	14 47 33·4
Clermont	57 42 27·4	16 20 29·9
Moulins	59 55 50·5	16 22 4·5
Paris	50 43 42·6	17 8 23·6
Douay	3 9 41·9	17 52 13·1
Boulogne	64 48 22·8	18 6 16·8

This Table supplies the data from which the three following equations are deduced:—

$$37{\cdot}551 = 18D - 2253x + 2728y,$$

$$-3727{\cdot}065 = -2253D + 385109x - 404742y,$$

$$4120{\cdot}753 = 2728D - 404742x + 851962y,$$

whose solution gives $D = 3{\cdot}4493$, $x = 0{\cdot}0079430$, $y = -0{\cdot}0024348$.

Therefore the declination at the central station is 17°·4493, the distance between the isogonics of places whose declinations differ by 30′ is 60·2 miles, and the angle formed by the isogonics with the geographic meridian 17° 2′ 30″·5 to the N.E.

The Table of errors will show the weight to be given to the various observations.

TABLE XVII.

Station.	Observed Declination.	Computed Declination.	Error.
Rheims	16°618	16°908	−0·290
Metz	15·871	16·116	−0·245
Strasburg	15·473	15·435	+0·038
Issenheim	15·687	15·499	+0·188
Dôle	15·976	15·974	+0·002
Dijon	16·503	16·184	+0·319
Avignon	15·935	15·652	+0·283
Marseilles	15·579	15·404	+0·175
Monaco	14·411	14·567	−0·156
Montpellier	16·432	15·958	+0·474
Grenoble	15·695	15·518	+0·177
N. D. de Myans	15·067	15·583	−0·516
Mongré	16·826	16·064	+0·762
St. Etienne	14·793	16·483	−1·690
Clermont	16·342	16·649	−0·307
Moulins	16·368	16·686	−0·318
Douay	17·870	17·445	+0·425
Boulogne	18·105	18·022	+0·083
Paris	17·140	17·449	−0·309

The largeness of these errors is mainly, I think, due to the unsteadiness of the Jones altazimuth, which had been substituted, on account of its lightness, in lieu of the Cooke transit-altazimuth used during the survey of the west. This unfortunately diminishes greatly the value of the results, and makes them scarcely comparable with those obtained for the west of France. The probable error for a single station is found to be $\pm 0{\cdot}35884$, and for the mean $\pm 0{\cdot}08458$. Omitting the two worst results, viz. those for Mongré and St. Etienne, we obtain

$$D=3{\cdot}4989,\ x=0{\cdot}0083462\ y=-0{\cdot}0021920,\ r=0{\cdot}00863,\ u=14^\circ\ 42'\ 57''{\cdot}2;$$

with probable errors of $\pm 0{\cdot}21389$ and $\pm 0{\cdot}05347$.

The results, if we may judge of them by the amount of the probable error, will be still more improved if, besides casting out the two worst results, we correct each individual observation for the disturbance occurring at the time in this magnetic element. The correction to be applied may be obtained from measurements of the Stonyhurst photographic curves, as explained in my former paper on the Survey of the west of France. The almost identical occurrence of these disturbances in neighbouring countries, with regard, at least, to the element under discussion, is now so well established as to render unnecessary any justification of the appliance of such a mode of correction; but, unfortunately for its present efficacy, no disturbance happened during any of the observations that will enable me to smooth very considerably the observed inequalities. From the solution of the equations formed with the corrected observations we obtain

$$D=3{\cdot}4757,\ x=0{\cdot}0082848,\ y=-0{\cdot}0021781,\ r=0{\cdot}00857,\ u=14^\circ\ 43'\ 48''{\cdot}6,$$

with probable errors of $\pm 0{\cdot}19745$ and $\pm 0{\cdot}04936$.

We will now pass on to the consideration of the secular variation of the Declination.

TABLE XVIII.

Station.	Declination, Jan. 1, 1858.	Declination, Sept. 1, 1869.	Difference of Epoch.	Difference of Declination.	Yearly rate of change.	Declination, Jan. 1, 1869.
Clermont	18°·568	16°·342	$11\frac{2}{3}$	−2°·226	−0°·191	16°·460
Dijon	17·932	16·503	„	−1·429	−0·122	16·612
Marseilles	17·068	15·579	„	−1·489	−0·128	15·691
Moulins	18·653	16·368	„	−2·285	−0·196	16·487
Paris	19·605	17·140	„	−2·465	−0·211	17·260
				Mean	−0·1696	

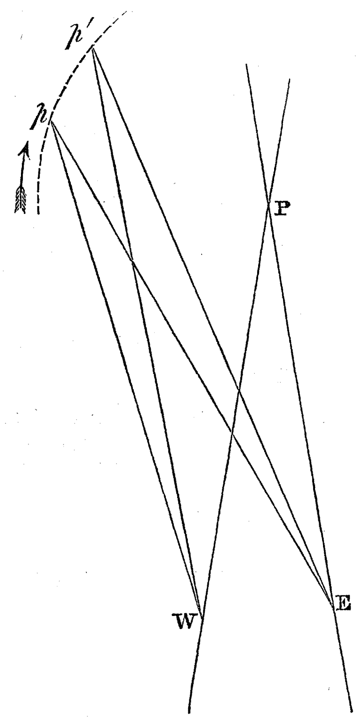
This result is somewhat larger than that found for the west of France, which was −0°·1533; and the greater difference between the results obtained from the observations at the several stations makes the result less trustworthy.

I will next proceed to collect in a single Table the chief results connected with the Isogonics of the surveys of 1858 and 1868–69.

TABLE XIX.

Epoch.	Declination at Central Station.	Distance of Isogonics differing by 0°·5.	Angle of Isogonics N.E. of geographic meridian.	Number of observations.
		miles.		
Jan. 1, 1858 W.	19°·6390	50·4	22° 18′ 24″·9	18
Jan. 1, 1858 E.	19·6053	46·0	16 37 16·9	17
Sept. 1, 1868 W.	17·9498	44·2	21 41 0·9	13
Sept. 1, 1869 E.	17·4493	60·2	17 2 30	18

This gives as the secular decrease of the Declination in the west and east 0·1583 and 0·1848 respectively, which are somewhat in excess of the values found from the few stations common to both the surveys.



The secular diminution of the Dip and Declination, and the increase of the Horizontal Force, in both the east and west of France, so clearly indicate the actual position of the North magnetic pole, together with its motion round the extremity of the earth's axis of rotation, that we are led to examine whether this same motion of the pole may not also account, at least in part, for the differences observable in the results obtained from the east and west surveys.

In the annexed diagram let P represent the geographical pole, W and E the two portions of the country surveyed, and p, p' the positions of the magnetic pole corresponding to the epochs 1858 and 1869.

If λ stands for the magnetic latitude, and δ for the Dip, we shall have $\tan\delta = 2\tan\lambda$; and consequently the change of position of the pole from p to p' should cause a greater variation in the Dip at W than at E, W being nearer than E to the magnetic pole. On the other hand, since the line $p\,p'$ is inclined at a greater angle to the meridian E P than to W P, the change of Declination due to the motion from p to p' should be less rapid at W than at E. With regard to the Intensity of the earth's magnetic force, the laws of distribution are too complex and irregular to warrant any certain conclusion in a particular case, unless the conditions of local magnetism are taken fully into account. Comparing these conclusions with the results derived from the observations discussed in this paper, we find a perfect agreement in the case of the Dip and Declination, and the observations of the Horizontal Force tend to show that greater nearness to the pole is combined with increased rate of variation in this element.

Turning, now, our attention from the consideration of the difference between the two sets of values of the magnetic elements to examine the secular changes in the curves of equal Dip, Declination, and Intensity, we do not expect to find a very close agreement between theory and observation. The distribution of the Isoclinals and Isogonics, and still more that of the Isodynamics, is so irregular, that such a slight difference of position as the east and west of France would probably have scarcely any apparent effect upon the resulting values, any small inequality being at least partially veiled by accidental errors from locality or observations. Still, however, as the Isoclinals and Isodynamics are approximately at right angles to the magnetic meridians, we may be justified in the assumption that, as the pole's path $p\,p'$ approaches parallelism to W E, the difference of angle in east and west for both sets of lines will become much less marked. Here, again, we find that the results of the observations taken in France agree well with the assumption made. The Isogonics present a precisely similar coincidence, as might be expected from their position in relation to the pole's actual path.

Since, moreover, $p\,p'$ is more nearly parallel with the Isogonics than with the Isoclinals and Isedynamics, there is a greater fixity in the mean angle for the whole of France in the case of the former lines than in that of the latter.

Lastly, the Isoclinals and Isodynamics are spreading out more quickly in the west than in the east, and there exists at present very little difference in the thickness of these lines in the two portions of the country, both of which conclusions would naturally follow from the fact that the pole is becoming more and more nearly equidistant from the east and west of France. The exceptional case of the Isogonics, which are spreading out in the east and drawing closer in the west, evidently arises mainly from inaccuracy of observation.

A general Table may now be formed of all the magnetic elements, reduced to the epoch Jan. 1, 1869, for the stations in the east of France.

TABLE XX.

Station.	Dip.	Declination.	Horizontal Force.	Total Force.
Avignon	61°·841	16°·046	4·6224	9·7927
Boulogne	67·126	18·227	3·9458	10·1511
Clermont	63·607	16·460	4·4013	9·9010
Dijon	64·409	16·612	4·2943	9·9418
Dôle	64·213	16·084	4·3201	9·9307
Douay	66·785	17·991	3·9931	10·1301
Grenoble	62·903	15·822	4·4317	9·7293
Issenheim	64·601	15·794	4·2714	9·9585
Lyons	63·268	....	4·4454	9·8826
Marseilles	60·576	15·691	4·7207	9·6092
Metz	65·458	15·976	4·1541	10·0012
Monaco	61·368	14·524	4·6571	9·7189
Mongré	63·498	16·942	4·4111	9·8853
Montpellier	61·614	16·545	4·6358	9·7512
Mont Rolland	64·260	....	4·3295	9·9692
Moulins	64·081	16·487	4·3356	9·9190
N. D. de Myans	62·875	15·182	4·4815	9·8293
Paris	65·859	17·260	4·1151	10·0618
Rheims	65·936	16·722	4·1170	10·0967
St. Etienne	63·063	14·910	4·4609	9·8472
Strasburg	64·687	15·578	4·2502	9·9405

In forming this Table the observed values have invariably been used, no correction or omission, however much it might tend to smooth down inequalities, being judged admissible. Should any such corrected elements be required, they can readily be obtained from the data furnished by the paper. A similar Table of uncorrected results given in the report of the Survey of the west completes the list of magnetic elements for the whole of France.

A comparison of the errors in the various elements with the geological character of the soil at the several stations of the survey seems to afford no indication of any decided disturbance due to igneous or other formations. The errors appear rather to arise from accidental causes, such as unknown masses of iron in the vicinity of the station of observation, imperfection of instruments, &c.; I have therefore omitted the geological Table.

Neither do I think it necessary to join to this paper maps of the Isoclinals, Isogonics, and Isodynamics, as those for the west of France sufficiently indicate the general lie of the lines.

It may not perhaps be thought superfluous if I add to this report, in the form of an Appendix, the observations and equations of conditions which have been deduced from LAMONT'S data, in order to compare the survey of 1858 with that discussed in the preceding pages.

It will also be well to remark that some of the results given in this paper for the west of France differ a little from those already published. This arises from the observations having been reduced afresh by a slightly different and more accurate method, similar in every respect to that used for the east of France, and in the discussion of all LAMONT'S observations.

Before concluding this paper I must express the great obligations I am under to the

Rev. J. HAWETT, S.J., without whose assistance in reducing and verifying the results I should have been forced to delay the presentation of these pages for a very considerable time.

APPENDIX.

In order to determine with greater exactness the secular variations of the Isoclinals, Isodynamics, and Isogonics, the values for 1858 have been calculated from LAMONT'S data by the same process as that adopted for the survey of 1868 and 1869. The data taken from Dr. LAMONT'S 'Untersuchungen über die Richtung und Stärke des Erdmagnetismus' are contained in the following Table.

TABLE XXI.

Station.	Latitude.	Longitude.	Dip.	H. F.	Declination.
	° ′ ″	m s	° ′		° ′
Agen	44 12 48	6 53	63 21·6	2·0491	19 15·1
Amiens	49 53 24	0 4	....	1·8277	19 56·3
Angers	47 28 2	11 37	65 55·9	1·9112	20 16·3
Angoulême	45 38 34	8 45	64 39·1	1·9899	19 50·2
Arras	50 16 47	1 46	67 23·2	1·8201	
Bayonne	43 29 12	15 19	63 6·8	2·0691	19 57·8
Belfort	47 37 37	18 1	....	1·9545	17 11·7
Bordeaux	44 50 13	11 27	64 5·8	2·0163	20 0·2
Brioude	45 18 0	4 12	63 44·3	2·0321	18 21·9
Cette	43 24 36	5 24	....	2·1173	17 7·9
Chateauroux	46 48 14	2 31	65 6·9	1·9527	19 22·0
Clermont Ferrand	45 46 22	3 0	64 12·1	2·0068	18 34·1
Commercy	48 45 54	13 1	....	1·9044	
Dijon	47 19 53	10 46	64 55·0	1·9543	17 55·9
Dunkirk	51 1 33	0 5	67 56·3	1·7871	20 6·6
Epernay	49 2 52	6 27	66 35·6	1·8790	
Etampes	48 26 8	0 41	66 16·0	1·8886	
Lamothe	44 37 24	13 22	63 57·1	2·0235	
La Roche Chalais	45 9 39	9 25	....	2·0064	19 46·3
La teste de Buch	44 38 11	13 57	63 59·8	2·0222	20 3·9
Le Mans	47 59 34	8 39	66 13·0	1·8903	20 25·7
Le Puy	45 2 46	6 12	....	2·0473	
Limoges	45 50 3	4 21	....	1·9870	19 23·8
Marseilles	43 17 45	12 15	61 40·5	2·1363	17 4·1
Meaux	48 57 2	2 11	66 24·2	1·8765	19 16·4
Mont de Marson	43 53 18	11 19	63 19·0	2·0557	19 40·3
Montélimart	44 33 18	9 36	62 53·3	2·0750	17 35·5
Montpellier	43 36 44	6 10	62 15·3	2·1112	
Moulins sur Allier......	46 34 24	3 56	64 43·4	1·9758	18 39·2
Nancy	48 41 17	15 19	....	1·8985	17 45·6
Nantes	47 12 24	15 35	65 55·9	1·9096	20 57·8
Narbonne	43 11 8	2 38	62 6·4	2·1184	18 1·1
Orange	44 8 42	9 52	62 36·9	2·0931	17 27·7
Orleans	47 54 9	1 42	65 52·6	1·9079	19 25·4
Paris	48 50 13	0 0	66 26·5	1·8759	19 36·3
Périgueux	45 10 32	6 29	....	2·0149	19 26·5
Perpignan	42 42 9	2 15	61 47·8	2·1357	17 59·2
Poitiers	46 34 31	7 58	65 8·3	1·9523	19 56·4
Sarrebourg	48 43 57	18 53	....	1·8989	17 14·6
Toulouse	43 36 33	3 35	62 46·1	2·0861	18 45·0
Tournon	45 3 57	10 1	63 18·2	2·0543	17 40·9
Tours	47 23 5	6 36	65 44·3	1·9192	19 54·4
Vésoul	47 37 3	15 14	....	1·9496	17 28·8

The Horizontal Force is expressed above in the French units of the millimetre, the milligram, and the second of mean solar time. Its value is found from the formula

$(\text{H. F.})^2 = \frac{2\pi^2 K}{T^2 r^3 \sin u}$, where K, the moment of inertia of the magnet, is equal to $W\left(\frac{l^2}{12}+\frac{d^2}{16}\right)\frac{t^2}{t'^2-t^2}$, l, d, and r being distances. Hence, in order to transform the values of H. F. so that they may be expressed in the English units of a foot, a grain, and a second, we have only to multiply by the square root of the factor of mass, and to divide by the square root of the factor of distance, whose quotient is 2·1688. Effecting this transformation, and choosing for our coordinates the meridian of Paris, and a perpendicular to that meridian, the origin of coordinates being the Imperial Observatory, we obtain the equations of condition for determining the lines of equal Dip, Declination, and Intensity. As the second members of the equations are the same for the different elements, I will include in a single Table the first members of each set of equations, followed by the second members for the several stations.

TABLE XXII.

Station.	Dip.	Declination.	H. F.	T. F.	Second members.
Agen	° 2·360	° 2·252	1·4441	0·9111	$=z+\ 85{\cdot}45x+319{\cdot}30y$
Amiens	....	2·938	0·9639	....	$=z+\ 0{\cdot}74x-\ 72{\cdot}80y$
Angers	4·932	3·272	1·1450	1·1637	$=z+136{\cdot}03x+\ 94{\cdot}59y$
Angoulême	3·652	2·837	1·3157	1·0806	$=z+105{\cdot}96x+220{\cdot}60y$
Arras	6·387	....	0·9474	1·2661	$=z-\ 19{\cdot}56x-\ 99{\cdot}74y$
Bayonne	2·113	2·963	1·4875	0·9230	$=z+192{\cdot}46x+369{\cdot}46y$
Belfort	....	0·195	1·2389	....	$=z-210{\cdot}34x+\ 83{\cdot}56y$
Bordeaux	3·097	3·003	1·3730	1·0101	$=z+140{\cdot}63x+276{\cdot}24y$
Brioude	2·738	1·365	1·4072	0·9605	$=z-\ 51{\cdot}17x+244{\cdot}23y$
Cette	....	0·132	1·5920	....	$=z-\ 67{\cdot}94x+374{\cdot}75y$
Chateauroux	4·115	2·367	1·2350	1·0642	$=z+\ 29{\cdot}84x+140{\cdot}41y$
Clermont Ferrand	3·202	1·568	1·3523	1·0007	$=z-\ 36{\cdot}24x+211{\cdot}62y$
Commercy	....	....	1·1303	....	$=z-148{\cdot}63x+\ 4{\cdot}93y$
Dijon	3·917	0·932	1·2385	0·9979	$=z-126{\cdot}40x+103{\cdot}60y$
Dunkirk	6·938	3·110	0·8759	1·3190	$=z-\ 0{\cdot}91x-151{\cdot}31y$
Epernay	5·593	....	1·0752	1·2583	$=z-\ 73{\cdot}24x-\ 14{\cdot}61y$
Etampes	5·267	....	1·0960	1·1769	$=z+\ 7{\cdot}85x+\ 27{\cdot}69y$
Lamothe	2·952	....	1·3886	0·9838	$=z+164{\cdot}77x+290{\cdot}99y$
La Roche Chalais	....	2·772	1·3515	....	$=z+115{\cdot}00x+255{\cdot}01y$
La teste de Buch	2·997	3·065	1·3857	1·0035	$=z+171{\cdot}92x+290{\cdot}09y$
Le Mans	5·217	3·428	1·0997	1·1659	$=z+100{\cdot}28x+\ 58{\cdot}28y$
Le Puy	....	....	1·4402	....	$=z-\ 75{\cdot}87x+261{\cdot}80y$
Limoges	....	2·397	1·3094	....	$=z+\ 52{\cdot}50x+207{\cdot}38y$
Marseilles	0·675	0·068	1·6332	0·7649	$=z-154{\cdot}40x+382{\cdot}63y$
Meaux	5·403	2·273	1·0698	1·1669	$=z-\ 24{\cdot}84x-\ 7{\cdot}89y$
Mont de Marsan	2·317	2·672	1·4584	0·9283	$=z+141{\cdot}25x+341{\cdot}73y$
Montélimart	1·888	0·592	1·5003	0·8749	$=z-118{\cdot}48x+295{\cdot}57y$
Montpellier	1·255	....	1·5788	0·8355	$=z-\ 77{\cdot}32x+360{\cdot}79y$
Moulins sur Allier	3·723	1·653	1·2851	1·0356	$=z-\ 46{\cdot}84x+156{\cdot}33y$
Nancy	....	0·760	1·1175	....	$=z-175{\cdot}17x+\ 10{\cdot}25y$
Nantes	4·932	3·963	1·1415	1·1552	$=z+183{\cdot}96x+113{\cdot}74y$
Narbonne	1·107	1·018	1·5944	0·8207	$=z-\ 33{\cdot}25x+390{\cdot}25y$
Orange	1·615	0·462	1·5395	0·8692	$=z-122{\cdot}62x+325{\cdot}17y$
Orleans	4·877	2·423	1·1379	1·1244	$=z+\ 19{\cdot}74x+\ 64{\cdot}52y$
Périgueux	....	2·442	1·3699	....	$=z+\ 79{\cdot}18x+253{\cdot}90y$
Perpignan	0·797	0·987	1·6319	0·8009	$=z-\ 28{\cdot}63x+423{\cdot}97y$
Poitiers	4·138	2·940	1·2341	1·0710	$=z+\ 94{\cdot}86x+157{\cdot}35y$
Sarrebourg	....	0·243	1·1183	....	$=z-215{\cdot}77x+\ 7{\cdot}18y$
Toulouse	1·768	1·750	1·5243	0·8873	$=z+\ 44{\cdot}93x+360{\cdot}98y$
Tournon	2·303	0·682	1·4554	0·9170	$=z-122{\cdot}53x+260{\cdot}44y$
Tours	4·738	2·907	1·1624	1·1298	$=z+\ 77{\cdot}41x+100{\cdot}29y$
Vésoul	....	0·480	1·2283	....	$=z-177{\cdot}88x+\ 84{\cdot}21y$