ART. LIV.—*The Magnetic Field in the Jefferson Physical Laboratory.* Part II; by R. W. WILLSON.

IN the February number of this Journal I have given an account of some observations made upon the variations of the Horizontal Intensity in different parts of the Jefferson Physical Laboratory in 1886-7, and upon the disturbance in the magnetic field produced by the presence of iron steam pipes and other iron masses. I have recently received a copy of the dissertation of Dr. Gustav Rasch of Aix-la-Chapelle* giving the results of similar observations upon the effect of the heating apparatus in the Physical Laboratory at Würzburg and of passing railway trains, etc.

During the past summer an iron water-pipe six inches in diameter was laid for some hundreds of feet, nearly parallel with the west wall of the Jefferson Laboratory and passing it at a distance of about twenty feet. The question was raised whether this would produce any serious change in the magnetic conditions previously observed in the building, and at the request of the Director, Professor Trowbridge, I have made a re-examination of the variations of the Horizontal Intensity at the points observed in 1887. A further interest in the results lies in the fact that since the former observations were made both the stove and iron table top, to which I attributed certain disturbances, have been removed, and it may now be seen whether the disturbances have disappeared with their assumed causes. Whether there has been any change in the absolute value of H , about 0.170 C. G. S. units, I have not attempted to determine.

Rooms 12 and 17, were not included in the observations on account of the great variations caused by the proximity of the steam-pipes at A, B, C, F, near the east wall (fig. 4).

The same instrument was used and mounted upon the same stand, a small high table carrying the variometer, five feet from the floor and resting on three very easy casters. Attached to the stand at about two and a half feet from the floor is a magnetometer with mirror and scale which serves for the rapid orientation of the stand at each new station. The distance between the variometer and magnetometer is such that neither has any appreciable influence upon the readings of the other, and at no point of observation was their difference of meridian (from local disturbances, such as proximity of the magnetometer to the piers) sufficient to cause an error so great as $\frac{1}{200,000}$ in the concluded value of H .

* *Magnetische Untersuchungen.* Würzburg, 1888.

It will be remembered that the plane of observation was originally fixed at five feet from the floor to avoid any possible disturbance due to the brick-work of the piers. A few preliminary observations had seemed to show such an effect, amounting to about 1-1000 H, in the case of one pier, when the instrument was very near the brick-work; while observations taken at various points upon one of the piers in room 17 showed no apparent magnetic effect comparable with that due

Fig. 4. Plan of west wing of the Jefferson Physical Laboratory, with lines of equal directive force in plane 5 feet above first floor. Scale 16 feet to the inch.

to the steam-pipes. Recent observations show that this pier somewhat resembles pier 4, hereinafter discussed, and was unfortunately selected as a test.

The observations upon the magnetic declination at various levels in the elevator shaft, described on page 90, were originally made in order to see if any considerable amount of free magnetism was present in the walls of the central tower. The results showed a far greater effect due to the steam-pipes than any that could be ascribed to the brick-work, and it was this which first led to a careful examination of the pipes and a just estimation of their effect upon the magnetic field. These results are here noted to explain why the very considerable

Fig. 5. Plan of west wing of Jefferson Physical Laboratory, with lines showing disturbances of the earth's directive force due to causes other than presence of steam-pipes shown at A, B, C and F.

K. Soap-stone sink.

Scale sixteen feet to the inch.

effect due to the general magnetization of the bricks, soon to be recorded, should have escaped even a very superficial examination.

The result of the general survey undertaken to determine what change in the field may have been produced by the laying of the water-pipe mentioned above is exhibited in figs. 4 and 5.

Fig. 4 gives the lines of equal horizontal intensity recently determined and is to be compared with fig. 1, p. 88. These lines connect points at which the horizontal intensity is the same, the values at points in adjacent lines differing by $\cdot 0025$ H. It is evident that there is no change in the general character of the field except that due to the removal of the stove above G. This will be more evident on consulting fig. 5, which gives the results obtained by correcting the observed values for the disturbance due to the steam-pipes at A, B, C and F by the method explained on page 91 (fig. 5 may be compared with fig. 3, p. 92).

The disturbance in room 13 being unchanged although the iron table top to which it was ascribed has been removed, some other cause must be sought for this disturbance.

The observations upon which the system of lines depend were made at points distant five feet from each other and only the general features of the system can be thus determined. In order to settle definitely the cause of the disturbance in room 13, observations have recently been made at distances of one foot apart in the eastern part of the room, and the lines of equal directive force thus much more accurately drawn. As the object was simply to determine the position of the disturbing body, the plane five feet from the floor was abandoned in these observations, and the arrangement adopted which had been used in the examination of the piers, which greatly lessens the labor and increases the accuracy of observations made at points very near together. The results of this examination pointed unmistakably to a soap-stone sink, shown at K, fig. 5, as the *main* cause of the disturbance. (This sink showed a considerable free south magnetism on its upper surface, tending to decrease H at points north and above; some further account of this will be given later.)

The only disturbances remaining unaccounted for are that in room 15-16 and that in room 14; which I now believe to be almost entirely due to magnetic action of the bricks of the piers and walls of the building itself. If this is the case, the whole system of lines of figs. 4 and 5 must be looked upon as giving only the most prominent characteristics* of the field,

* Compare with fig. 10, which gives a portion of the field more in detail, but for a different plane.

since many of the points observed are so near the piers as to be unduly affected by their presence. As the magnetic effect of the mass of the building upon the Horizontal Intensity at any point is too complex to admit of estimation, I have confined myself principally to an investigation of the effect of the piers.

To facilitate these observations a board 28 feet long, and 8 inches wide was carefully smoothed and brought to a straight edge and wooden horses, put together with copper nails, were prepared of just the height of the piers; a sliding piece 15 inches long with a guide bearing upon the edge of the board, carried the variometer with its needle in a plane seven inches above the top of the piers and 3 feet 3 inches above the floor.

The long board being brought into position, supported by the piers or horses, the variation at different points could be rapidly observed without any sacrifice in point of accuracy, the instrument being slid from one point to another with very slight derangement in level and azimuth, so that the latter adjustment was made once for all while the former was very quickly accomplished. The changes of temperature are also less troublesome factors than when the observations extend over considerable periods of time. Variations of the horizontal intensity during the observations have usually been determined and corrected for by occasional observations at the same reference point.

The piers consist of rectangular columns of brickwork laid in Portland cement. They are 3 feet by 2 feet at the base, tapering to 2 feet square at the first floor, above which they rise 2 feet 4 inches, and are capped by slabs of blue stone 3 feet square and 4 inches thick. The foundations are 5 feet below the basement floor and the total height of the column is about 18 feet. As the building faces within $2\frac{1}{2}$ degrees of the magnetic South, and as the sides of the piers are parallel to the walls of the building, it will be sufficiently accurate in describing their magnetic effect to speak of either as if exactly oriented.

If the brick of which the piers are made contains magnetic material we should expect to find indications of a magnetic distribution depending upon the inductive action of the earth and the form and position of the piers, independent of any permanent magnetism existing in the bricks previous to their being placed in their present places, and which, on account of its random distribution, in so large a number of bricks, would have no effect except in causing small very local disturbances easily recognizable as such.

The effect of the earth's induction upon the piers would produce, on the whole, free south magnetism on the upper

surface of each pier, and owing to the length of the piers and the very considerable dip, 72 degrees,* the distribution would

Dist. from south wall.	Nov. 22.	Nov. 21.	Nov. 23.	East Edge.	West Edge.	
4	+0003	-0001	-----	+0001	0000	} over pier 5.
4½	+0012	+0009	-----	+0005	-----	
5	+0029	+0025	-----	+0011	+0014	
5½	+0034	+0029	-----	+0009	+0018	
6	+0008	+0004	-----	-0008	+0003	
6½	-0020	-0027	-----	-0025	-0024	
7	-0050	-0055	-----	-0032	-0032	
7½	-0066	-0067	-----	-0040	-0037	
8	-0051	-0053	-----	-0033	-0036	
8½	-0034	-0033	-----	-----	-----	
9	-0021	-0023	-----	-0015	-0017	
9½	-0015	-0014	-----	-----	-----	
10	-0010	-0009	-----	-0008	-0006	
10½	-0007	-0006	-----	-----	-----	
11	-0004	-0002	-----	-0003	-0009	} over pier 6.
11½	+0001	+0002	-----	-----	-----	
12	+0004	+0007	-----	+0006	+0002	
12½	+0008	+0013	-----	-----	-----	
13	+0012	+0016	-----	+0013	+0008	
13½	+0017	+0021	-----	-----	-----	
14	+0022	+0024	+0020	+0012	+0012	
14½	+0014	+0018	+0013	-----	-----	
15	-0001	-----	0000	0000	+0001	
15½	-0005	-----	-0008	-----	-----	
16	-0001	-----	+0001	+0006	-0001	
16½	-0004	-----	-0003	-----	-----	
17	-0010	-----	-0010	+0001	-0005	
17½	-0009	-----	-0008	-----	-----	} over pier 7.
18	-0004	-----	-0001	+0006	-0001	
18½	+0002	-----	+0007	-----	-----	
19	+0009	-----	+0015	+0014	+0007	
19½	+0017	-----	+0021	-----	-----	
20	+0022	-----	+0025	+0023	+0015	
20½	+0023	-----	+0027	-----	-----	
21	+0019	-----	+0023	+0011	+0009	
21½	+0004	-----	+0008	-----	-----	
22	-0008	-----	-0006	+0004	+0010	
22½	-0009	-----	-0005	-----	-----	
23	-0002	-----	+0002	+0009	+0007	
23½	+0005	-----	-----	-----	-----	} over pier 8.
24	+0011	-----	-----	+0017	+0017	
24½	+0018	-----	-----	-----	-----	
25	+0024	-----	-----	+0023	+0027	
25½	+0035	-----	-----	-----	-----	
26	+0051	-----	-----	-----	-----	
26½	+0069	-----	-----	-----	-----	
27	+0060	-----	-----	-----	-----	
27½	+0021	-----	-----	-----	-----	
28	-0008	-----	-----	-----	-----	
28½	-0006	-----	-----	-----	-----	
29	+0014	-----	-----	-----	-----	
29½	+0030	-----	-----	-----	-----	
30	+0039	-----	-----	-----	-----	
30½	+0044	-----	-----	-----	-----	

* Erroneously given in my last paper as 60 degrees.

be nearly uniform. The result would be that at points north of the center the field would be weakened and at points south strengthened, while in a line east and west through the center of the pier the field would be undisturbed by its presence.

The preceding table shows the variations of the Horizontal Force actually observed along a horizontal line passing 7 inches above the centers and edges of the piers 5, 6, 7, 8 in room 15, fig. 4.

Column 1 gives the distance of the point of observation from the south wall. Columns 2, 3 and 4 the corresponding difference in decimal parts of H , from its value assumed as normal in those parts of the room farthest removed from the influence of the piers. Columns 5 and 6 give the corresponding values on parallel lines 14 inches east and west of the central line. Columns 3 and 4 are introduced to furnish a means of judging of the accuracy of the individual observations, each of which rests upon *a single* reading of the instrument in each of the positions, N. pole east and N. pole west.

Although the differences on different dates amount in the maximum to $\cdot 0007 H$, owing to uncertainty in the diurnal variation of H , which has been assumed to be uniform during the time of observation, it will be noticed that the difference between consecutive points (upon which the important features of the disturbance depend) as observed on various dates, is the same for 32 out of 39 points, within $\cdot 0002 H$, which is practical identity, since any observation may be in error in either direction by $\cdot 0001 H$. In four cases the difference is $\cdot 0003 H$, in two cases $\cdot 0004 H$ and in one case $\cdot 0005 H$. This is remarkable testimony to the accuracy of the instrument when it is remembered that each determination required but little over two minutes for its completion.*

The results of column 1 are best exhibited to the eye by fig. 6, in which the abscissas represent distances from the south wall in feet while the ordinates give the corresponding differences from the normal undisturbed value of H for the whole room. The places of the piers are as indicated below.

It appears that in passing from south to north the value of H increases as we approach the pier 5 to a maximum almost exactly over the edge of the brick-work and six inches inside of the bluestone, then rapidly decreases to a minimum almost exactly over the northern edge of the brick-work, from which it increases, reaching the average value for the room at a point about half way to the next pier. Beyond this it still increases to a maximum over the edge of pier 6 and follows the same

* For a detailed account of the method of observation see the paper by F. Kohlrausch, Wied. Ann., vol. xix, p. 130. As my instrument was adjusted a difference of one division in the reading of $n_1 - n_2$ corresponds to $\cdot 00025 H$.

general course for that and for each of the other piers. The curves corresponding to the values in columns 4 and 5, observed nearly over the eastern and western edges of the brick-work, show maxima and minima at the same points but of about half the values reached on the center lines, the values being very nearly the same for each edge.

Fig. 6. Variations of the Horizontal Intensity in a line seven inches above piers.

The general form of the curve is accounted for by the assumption that free south magnetism is distributed nearly uniformly over the upper surface of each of the piers, strengthening the field on the south side and weakening it on the north as before described, while over the center the Horizontal Force has nearly its normal value.

The fact that the values of the maxima over the edges are about half those in the central line strengthens this assumption of a uniform distribution of the magnetism over the surface, since, if the pier be supposed divided by a vertical plane passed meridionally through the center, the half of the pier farthest removed contributes but little to the disturbance over the edge, while if transferred parallel to itself so that the two edges coincide, each half would be similarly situated with respect to the points observed, and the effect would be doubled and should obviously give the same value of the disturbance as that actually observed on the central line.

The double maximum observed in the case of pier 6 appears to be owing to an irregularity in the distribution of the magnetism, perhaps due to a single brick or bricks near the surface of the pier possessing permanent magnetism, not produced by the induction of the earth upon it in its present position.

Such permanent polarity has been observed in varying degree in many bricks and portions of bricks of the same manu-

facture. With this exception the magnetism shown by the piers is exactly what might be expected to result from the effect of the earth's nearly vertical induction upon a mass containing a relatively small amount of magnetic matter in the form of isolated particles, disseminated through a non-magnetic shaft nearly 20 feet high and of relatively small diameter.

The nearly uniform distribution of the magnetism is further confirmed by observations of the other piers, the results of which are shown in figs. 7 and 9.

Fig. 7. Variations of the horizontal intensity in a line seven inches above piers.

In fig. 7 the variations of the horizontal force along the central line are shown for piers 1, 3, 4, 9, 11, 13. The abscissas give the distance in feet from the center of the pier in each case, positive toward the North, and the ordinates in the same manner as before give the variations of H from its normal value, which is here assumed to be the mean of observations North and South at a distance of 3 feet from the center.

Let $2l$ be the length in centimeters of the side of a square pier, σ the density per sq. cm. of the magnetism uniformly distributed over its upper surface. Then a unit pole h cm. above the pier, and in its meridian plane at a distance x_0 cm. from the axis, is urged horizontally toward the axis by a force in C. G. S. units

$$F=2\sigma \log_e \frac{(l+\sqrt{(x_0-l)^2+h^2+l^2})((x_0+l)^2+h^2)}{(l+\sqrt{(x_0+l)^2+h^2+l^2})((x_0-l)^2+h^2)}.$$

For our piers $l=30^{\text{cm}}$, and $h=28^{\text{cm}}$.

The value of F for different values of x_0 computed from the above expression is given in the following table:

x_0	F.	x_0	F.
0 cm	0.000 σ	30 cm	2.698 σ
5	0.570 σ	35	2.833 σ
10	1.114 σ	40	2.856 σ
15	1.626 σ	45	2.796 σ
20	2.080 σ	50	2.682 σ
25	2.446 σ	60	2.390 σ

Plotting the coefficients of σ we obtain a curve very similar to that of pier 5, fig. 6, showing that the assumption of uniform distribution agrees well with the observed values.

The maximum observed value is about .005 H=.00085 absolute units and corresponds to the computed value 2.8 σ ; hence $\sigma=.0003$ and the total amount of free magnetism on the surface of the piers, 3600 sq. cm., is 1.08 C. G. S. units.

PIER 5.

Distance North of Center. (inches.)	Distance East of Center (inches).							
	-14	-10	-6	-2	+2	+6	+10	+14
+18	-.0012	-.0023	-.0023	-.0026	-.0026	-.0021	-.0020	-.0016
+14	-.0018	-.0029	-.0033	-.0038	-.0037	-.0032	-.0031	-.0019
+10	-.0016	-.0026	-.0034	-.0038	-.0038	-.0034	-.0029	-.0024
+6	-.0012	-.0022	-.0028	-.0026	-.0028	-.0024	-.0021	-.0013
+2	-.0004	-.0008	-.0009	-.0007	-.0011	-.0007	-.0010	-.0009
-2	+0010	+0008	+0011	+0012	+0007	+0006	+0002	-.0001
-6	+0025	+0025	+0031	+0033	+0029	+0025	+0017	+0011
-10	+0038	+0042	+0049	+0052	+0051	+0045	+0037	+0022
-14	+0042	+0048	+0055	+0057	+0059	+0052	+0046	+0026
-18	+0036	+0041	+0047	+0048	+0049	+0046	+0043	+0027

PIER 4.

Distance North of Center. (inches.)	Distance East of Center (inches).					
	-15	-9	-3	+3	+9	+15
+18	-.00005	-.00040	+.00010	-.00005	+.00020	+00025
12	-.00025	-.00020	+.00030	+.00065	+.00030	+00020
6	-.00025	00000	+.00040	+.00040	-.00020	+00010
0	+.00010	+00020	+.00020	-.00020	-.00090	-.00020
-6	+.00080	+00075	+.00060	+.00050	+.00050	+00040
-12	+.00160	+00170	+.00160	+.00160	+.00170	+00130
-18	+.00170	+00190	+.00195	+.00190	+.00155	+00140

The length of the pier being about 6 meters, this corresponds to a magnetic moment of 6500 C. G. S. units or rather more than that which may be readily given to a hard steel magnet of 1 sq. cm. section and 20 cm. long.

Piers 1, 2, 3, 5, 7, 8, 9, 11, 12, figs. 6, 7 and 9 show variations nearly as described for a typical pier; while 4 and 13 show the same irregularity as 6*. I may here note that the pier in room 17, which was superficially examined in 1887 for the purpose of detecting local influences was of this class, the variation over a large part of its surface being very small.

The nature of this deviation from this normal type is made more striking by comparison of the adjacent piers 4 and 5, the former presenting the case of least and the latter of greatest local effect of piers. The variations of H from its value at the center are given in the preceding tables, and fig. 8 shows the lines of equal horizontal force in a plane seven inches above each pier. The field above 4 although the extreme variation amounts to but $\cdot 0025 H$, indicates a distribution of magnetism far from uniform. The existence near the northeast corner of free north magnetism would account for the observed variations. In the case of pier 5 the effect of the pier, though large, is quite symmetrical, indicating a very uniform distribution.

Fig. 8. Lines of equal directive force in a plane seven inches above piers 4 and 5.

The magnitude of the disturbance is noteworthy. Above pier 5, for instance, the Horizontal Force at the two edges varies by one per cent, while a change of one tenth of one per cent is caused by passing over two inches near the center, so

* Pier No. 10 has been omitted being covered with a heavy stone. Piers in rooms 11 and 17 are not included for reasons before given.

that the position of an instrument must be determined with considerable precision to ensure even ordinary accuracy. Moreover all of the points observed are distant at least 11 inches from the nearest brick-work. It is plain then that the observations made 5 feet from the floor and 2 feet 8 inches above the brick-work of the piers are by no means unaffected by the presence of the latter.

The effect of the walls too may extend to points at some distance. The magnetism due to the earth's induction pro-

Fig. 9. Variations of the Horizontal Intensity on a line seven inches above piers 2 and 12.

duces disturbances in the neighborhood of openings in the brick-work, such as doors and windows, where free magnetism appears, and the local effect of permanent magnetism in the single bricks can be in many places detected. The first point appears in the observations represented in fig. 9 which shows the variations along a line passing above the piers 2 and 12 and through the center of the wing.

The dotted curve gives in the same manner as before the variations of H from its normal value at the center of the wing, the position of the walls, piers and door-ways being indicated as on fig. 6. The line of observation passes 11 inches above the brick-work of the piers, 12 inches above that of the window sills, and $3\frac{1}{2}$ feet above the lower brick-work of the door opening in the tower wall. The door openings are 10 feet high and the instrument is therefore much nearer to the bricks below than to those above. The general increase of H toward the north shown in the dotted curve is due to the influence of the iron steam-pipes. Correcting the observed values for this effect the full line curve is obtained. Both curves show south magnetism in the vicinity of the walls and piers, the earth's induction producing free south magnetism in the lower surfaces of the window and door openings through which the line of observation passes. This results in a strengthening of the field on the south in the immediate

vicinity of the openings and a weakening on the north, as in the case of the piers. (The point of maximum disturbance is

Fig. 10. Lines of equal directive force in room 15, plane seven inches above piers. Scale, six feet to the inch.

not over the edge of the brick-work as in the case of the piers, owing to the different form of the surface, and in the case of the door, to the greater distance of the plane of observation.) The absence of local disturbance in the north doorway of the tower is due to the fact that there is on that side a corresponding doorway in the basement, and the opening in the brick-work extends to the ground level.

The amount of irregular disturbance arising from nearness to walls is shown in fig. 10, which gives the lines of equal directive force in room 15 in a plane 7 inches above the piers, plotted from a very careful survey in which observations were made at points one foot apart over the whole room.

This shows the same general features as the former survey 5 feet above the floor.

This detailed observation, however, enabling a much more accurate determination of the lines brings out very clearly the connection of the piers with these disturbances.

The effect of the individual bricks is so great when the points are within 6 inches of the wall that I have only continued the lines within one foot of the bricks, although many observations were made within that limit to determine more accurately the position of the lines. It is worthy of notice that no considerable disturbance is produced by the small soap-stone sink near the chimney at L.

The normal value assumed is the mean of the values observed at 96 points taken in a parallelogram 15 feet $\times$ 5 feet about the arrow, fig. 10, no point being less than three feet removed from the nearest bricks.

Within this space the deviations though less than .001 H from the mean are plainly discriminated by the variometer, and it may be fairly said that there is no point in the room where the magnetic effects of the brick-work is not an easily measurable quantity.

It is hardly worth while to multiply observations or to treat of such points as the effect of change of temperature, since the magnetic effect of the bricks is so great. A few facts are, however, of interest. Bricks similar to those used in the Laboratory Building have been found to be in various degrees permanently magnetic, and to show the alterations in their temporary magnetism produced by change of position with respect to the earth's field, two or three specimens of brick from other sources show magnetic effects comparable with these.

Portions clipped from the piers and crushed to coarse powder delivered to a 2 oz. magnet many magnetic particles, which when examined under a microscope were seen to contain among their number octahedra of magnetite. Magnetic par-

ticles were separated in the same manner from the cement, as well as from the clay of the brick-yard where the bricks were made.

Far more striking results were obtained on examining the soap-stone sink which is connected with the disturbance in room 13, and which shows upon the upper surface and edges of its slabs free south magnetism of sufficient amount to deflect a compass needle several degrees when brought within an inch of its mass.

Sixteen grams of dust scraped with glass from the under side of the base gave 1 gram of dark *strongly* magnetic particles consisting mainly of magnetite in octahedra up to 1.2^{mm} in diameter, which were disseminated through the mass with considerable uniformity. Pencils cut from a similar slab and hung by a thread were strongly attracted by a magnet, though they received no permanent polarity. A chip of the same weighing over one third of a gram was lifted bodily by a one pound magnet with poles approaching each other within $\frac{1}{8}$ of an inch.

I am not aware that any observation has been previously made of so great a disturbance of the magnetic field from brick-work. In the magnetic observatory at Würzburg the brick for which was selected with great care, a variation of $\cdot 00025$ H has been noted.* Lamont† remarks upon a difference of $2' 18''$ in declination and 0.00014 in the value of H between observations made in the open field near the observatory (Munich) and upon an "aus Backsteinen und hydraulischen Kalk, ausserdem Starke Messingtheile enthaltenden Pfeiler" in the building itself. This discrepancy he does not appear to have investigated further.

It is possible that the Cambridge brick, of which the Jefferson Laboratory is built, contains an unusual amount of magnetic oxide, but it is a fact not to be slighted by those engaged in magnetic work that bricks, without special examination, cannot be assumed to have an insignificant magnetic effect.

In fact, I incline to the belief that in general it is safer to make exclusive use of wood for buildings and piers intended for refined magnetic measurements.

Jefferson Physical Laboratory.

* F. Kohlrausch, Wied. Ann., vol. xix, p. 142, 1883.

† Abhandl. d. k. bayr. Akad. d. Wiss.: Math.-Phys. Kl., v, p. 24, 1847.