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ON THE

# VARIATIONS OF THE AMOUNT OF CARBONIC ACID IN THE GROUND-AIR

## (GRUND-LUFT OF PETTENKOFER)

BY

C. HUNTER STEWART, B.Sc., M.B.

[With Three Plates.]



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# XXIX.—*On the Variations of the Amount of Carbonic Acid in the Ground-Air (Grund-luft of Pettenkofer).* By C. Hunter Stewart, B.Sc., M.B. (From the Public Health Laboratory of the University of Edinburgh.) (With Three Plates.)

(Read 6th June 1892.)

The chemical examination of ground-air, *i.e.*, the air which is contained in the pores of the soil, was first made by Boussingault and Levy in 1853.* Their results, however, attracted little attention till Pettenkofer, in 1857, pointed out that the determination of the amount of carbonic acid in the air of a given soil might be used as a means of estimating the organic decomposition going on there. In 1871 he first published his results, and since that time the subject has been worked at by many investigators both from the agricultural and hygienic point of view, including in the latter class Fleck at Dresden, Fodor at Buda-Pesth, Hesse in Saxony, and Nicholls in America. As researches of this nature have not attracted much attention in this country, a short account of the *modus operandi* may be interesting as a preliminary.

Iron tubes, with an internal diameter of 1 inch, and having lateral perforations for 4 inches from the lower end, are sunk into the ground. In sinking the tubes care must be taken to disturb the ground as little as possible, and, further, that neither the sunk open end nor the lateral perforations are tightly plugged. A solid pointed rod of the same diameter as the tube is first driven into the soil to make a hole of the required depth, and then withdrawn. The tube is now armed with a solid piece of iron, shaped like a spear head, and driven into the hole for 3 or 4 inches deeper than is desired. The tube is now withdrawn for 3 or 4 inches, which, separating the iron guard, leaves the open end of the tube quite patent. The iron guard having a slightly greater diameter than the tube, prevents the lateral perforations being plugged with the soil. The ground is carefully stamped round the tube to prevent the direct entrance of atmospheric air. To insure the complete settling of the soil round the tube, it is advisable to wait for a week before beginning experiments. For convenience of working, the upper end of the tube should project for about 3 feet above ground. This upper end, fitted with a perforated rubber cork, is connected by glass and rubber tubing with a Pettenkofer carbonic acid absorption tube, and this communicates with an ordinary water aspirator.† A solution of barium hydrate, about 13 grammes to the litre, is used for absorbing the carbonic acid. The pure barium hydrate of commerce often contains traces of alkaline salts, the presence of which interferes with the accuracy of the titration by oxalic acid. The addition of 0·2 grams neutral chloride of barium to each litre of baryta solution

* *Annales de Chemie et de Physique*, 1853.

† Fig. A shows the apparatus and arrangement of sunk tube.

removes this possible source of error. The Pettenkofer tube, with a capacity of about 130 c.c., is charged with 100 c.c. baryta solution, and the glass tube at A replaced. This tube should be contracted at the end, so as to break up the entering air into small bells, and thus insure the complete absorption of the carbonic acid. The air is aspirated at the rate of 1 litre per 45 minutes.* If aspirated at a greater rate, then two tubes in series, each charged with 100 c.c. baryta solution, are necessary. I have found by experiment that by aspirating through two tubes in series, at the rate of 45 minutes per litre, there was no change in the baryta solution in the tube nearest the aspirator, showing that entire absorption had taken place in the one tube. After the experiment the contents of the tube are emptied into a stoppered bottle, and set aside to allow the barium carbonate

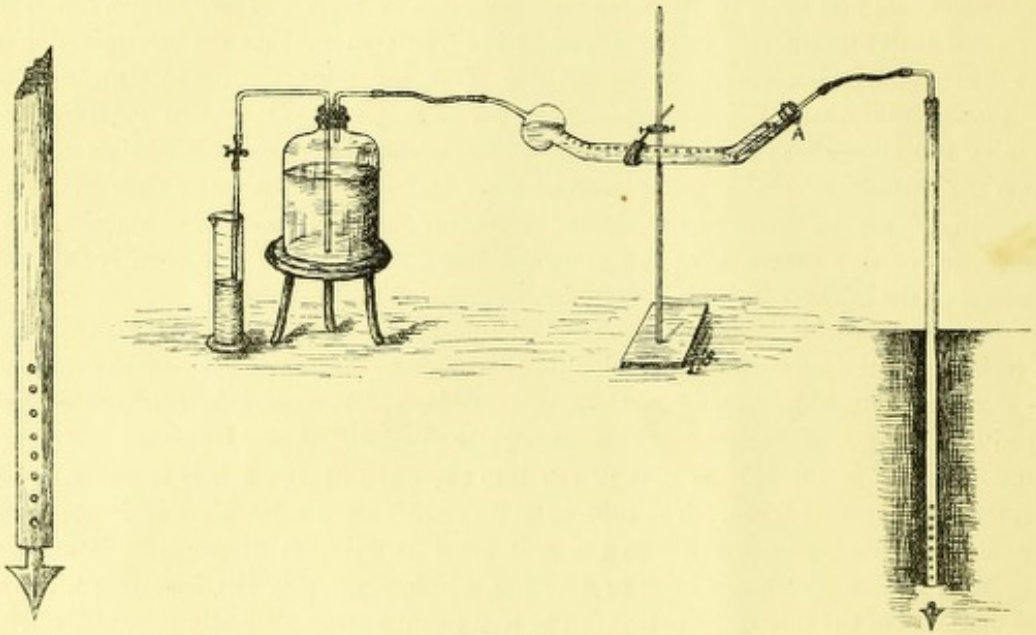



Fig. A.

to settle. The stopper should be paraffined to prevent absorption of carbonic acid from the air. Six or eight hours are necessary for the settling of the precipitate. It is sometimes stated that the baryta acts on the substance of the glass during these operations, and thus undergoes a change quite irrespective of the carbonic acid. If this were so, a serious error would exist in this method of carbonic acid estimation, especially when working with small quantities, *e.g.*, in examining outside atmospheric air. In connection with this, the following experiments were made:—Two Pettenkofer tubes, A and B, and two 120 c.c. white glass stoppered bottles, C and D, were taken, B and D being coated inside with a layer of solid pure paraffin. Each was then rinsed out with the baryta solution to absorb the carbonic acid of their contained air, drained, and charged with

* Before connecting the absorption apparatus, the air is directly aspirated from the iron tube to clear it of its contained air.

100 c.c. of the solution. The stoppers of the bottles were paraffined, and the Pettenkofer tubes carefully closed by rubber and glass rod stoppers. Three experiments of each were made:—

| | Original Strength of Baryta Solution in terms of the Oxalic Acid Solution. | 1. | 2. | 3. |
|---|---|---|---|---|
| Pettenkofer Tubes after 1 hour. | | | | |
| A, . . . . . | 45·2 c.c. | 45·2 | 45·15 | 45·2 |
| B, . . . . . | ,, | 45·15 | 45·2 | 45·25 |
| Glass Stoppered Bottles after 8 hours. | | | | |
| C, . . . . . | ,, | 45·2 | 45·15 | 45·15 |
| D, . . . . . | ,, | 45·15 | 45·2 | 45·15 |

These variations from the original titre of the baryta solution are fairly within the limits of error of observation, and cannot be attributed to any action of the glass.

The oxalic acid solution used for titrating the baryta solution is made by dissolving 1·4107 gramme recrystallised and air-dried oxalic acid in 1 litre distilled water. Each c.c. of this solution is equivalent, in combining with barium hydrate, to 0·25 c.c. carbonic acid at 0° C. and 760$^{m}$. By using this strength of acid, PETTENKOFER pointed out that there is a gain in accuracy and quickness. 100 c.c. of the baryta solution, as we have seen, are used in each experiment. Now, instead of titrating the whole of the solution with an acid, each c.c. of which is equal to 1 c.c. of carbonic acid, we titrate one-quarter of this (25 c.c.) with an acid, each c.c. of which is equal to one-quarter of a c.c. of carbonic acid. In both cases the number of c.c.'s of oxalic acid used is the number of c.c.'s of carbonic acid which 100 c.c. of the baryta solution is equivalent to. Three separate titrations can be made from each experiment without disturbing the precipitated carbonate of barium, giving thus an opportunity of checking the work. Two out of three should be the same.

Oxalic acid solution decomposes if kept long, and on this account sulphuric acid, diluted to be equivalent to it, is sometimes used instead. In this research oxalic acid solution only was used, and was freshly prepared weekly. The tabulated results at the end of this paper are expressed in c.c.'s per litre at the temperature of 0° C.

The analysis of ground-air shows that it is simply atmospheric air with its oxygen in part replaced by carbonic acid, with the occasional presence of some other gases, *e.g.*, ammonia and carburetted hydrogen. Various observers have found that the sum of the oxygen and carbonic acid in it is nearly equal to the oxygen in atmospheric air.

BOUSSINGAULT and LEVY state that when the sum of the two gases is in excess of the

oxygen in the atmosphere, then putrefaction is going on in the soil. Under the action of anaerobic organisms the organic matter itself supplies the oxygen necessary for oxidising its own carbon.

Such excess of carbonic acid has generally been found at considerable depths, and in late autumn, when the deeper layers of the soil have their maximum temperature. In the deeper layers of an impure and rather impermeable soil, putrefaction is common if the suitable conditions of warmth and moisture are present : in an impure and permeable soil, on the other hand, there would be simply oxidation. Ammonia and carburetted hydrogen are present in very small quantity, but the amount is said to increase with the depth. The most of the ammonia formed in the soil is absorbed by the humus. The amount of these two gases is so small and so variable, and their estimation, moreover, so laborious, for practical purposes the determination of the carbonic acid is the best index to the amount of organic decomposition taking place.

The following are taken from FODOR's exhaustive work, *Luft Boden und Wasser* :—

| | Oxygen per cent. | | Carbonic Acid per cent. |
|---|---|---|---|
| 1 Metre deep, . . . . | 20·031 | ... | 1·019 |
| 4 Metre deep, . . . . | 17·9 | ... | 3·76 |

The amount of carbonic acid in the air of a given soil depends on (1) the amount of organic matter, (2) permeability, (3) depth, (4) temperature and moisture. PETTENKOFER found that the ground-air from the Desert of Sahara had the same composition as the atmosphere, the conditions for the development of carbonic acid being absent. But no reliable conclusions can be drawn as to the purity of a soil from the carbonic acid estimation unless its permeability be known. If the carbonic acid be determined in two soils, similar as regards organic impurity, temperature, and moisture, but of different permeabilities, the less permeable will contain more carbonic acid than the more permeable, because in the former the air is prevented from so easily diffusing vertically into the atmosphere, and horizontally into the adjacent soil. As regards temperature, the amount of carbonic acid is least in late winter and spring, and goes on increasing, reaching its maximum in summer and early autumn, and declining again to its minimum in winter. Unfortunately, I had no means of determining the temperature of the soil at the time that this work was in progress. In the curves appended will be found one of the mean temperature of the week, derived from the averages of the maximum and minimum temperature, and the temperature at 9 A.M. and 9 P.M. These show that at a depth of 3 feet the carbonic acid curve follows the temperature curve, but, on an average, about 3 weeks later. This, probably, may be taken as the time required for a variation of atmospheric temperature to be propagated to the depth of 3 feet, and to influence the rate of decomposition there. FODOR found the rainfall to exert a great influence, especially if rain followed a prolonged drought in the summer. As this investigation extends only over fourteen months, it does not permit of any conclusions on this point.

Fodor's work extended over three years. The amount of carbonic acid in the air of a *uniform* soil increases with the depth. This arises, not from increased chemical change taking place, nor necessarily from more organic impurity being present, but simply because the carbonic acid does not get so easy vent as in the more superficial layers.

The soils on which these experiments were made were—(1) the grounds of the Edinburgh Royal Infirmary, and (2) the grounds of Heriot's Hospital. On the Infirmary site, the part of the soil examined is for 3 to 4 feet made soil. Below this the soil is natural. The upper made soil had a medium permeability, and contained 12 to 13 per cent. of clay, and 73 per cent. sand, gravel, and small stones. It was part of a kitchen garden, but had not been used for 1 year before the experiments. The organic matter in it yielded 0·21 per cent. nitrogen.

The ground of Heriot's Hospital was stiff and clayey, under grass, and had not been disturbed for nearly 200 years. It may be taken as a typically pure soil. In the Infirmary grounds the determinations were made daily, morning and evening, from June 1, 1887, to July 20, 1888. At the 3-feet tube there was no intermission except for about three weeks in May 1888, and on rare occasions when, by the rise of ground-water, the tube was blocked. The tubes were sunk within a distance of 3 feet from each other, at depths of 3 feet, 6 feet, and 12 feet. From the low-lying nature of the soil, and the nearness of the clayey subsoil to the surface, the 12-feet and even the 6-feet tube were liable to frequent blocking with ground-water. This is the reason of the fewness of the determinations at these depths. In the Heriot's Hospital grounds the determinations were made in the morning only, on an average, three times weekly.

Plate 1 shows the comparison between the weekly averages of the morning and of the evening 3-feet determinations at the Royal Infirmary, with the weekly averages of the daily maximum and minimum temperatures.

It will be noticed that from September to the middle of December the evening determinations are lower than the morning. From the middle of December to the end of March they are higher, while from April to the end of June they are again lower, with a tendency to again become higher in July and August. In another paper on atmospheric air, I hope to discuss the bearings of this in fuller detail.

Plate 2 shows the weekly averages of the morning and evening 3-feet determinations combined, with the mean daily temperature.

Plate 3 shows the comparison between the monthly averages of the amount of carbonic acid at a depth of 3 feet in the ground-air of the typically pure soil of Heriot's Hospital grounds and the comparatively impure soil of the grounds of the Royal Infirmary. The small proportion of carbonic acid in the former, as compared with the latter, is very marked, especially as the former is less permeable.

Tables 1 to 6 show the detailed statement of all the experiments.

The amount of carbonic acid in the 3-feet determinations at the Infirmary ground being greater than that of those at 6 feet and 12 feet, is an exception to the rule that the amount of this gas in ground-air increases with the depth. But this is explained by the

fact already pointed out that the upper 3 or 4 feet is made soil, and not at all similar to the natural soil below. The increase with depth is seen in the following comparison between the 6 feet and 12 feet determinations at the Infirmary and the 3 feet and 6 feet determinations at Heriot's Hospital Grounds.

| | | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Infirmary Grounds, | 6 ft. | 9·85 | 10·7 | 13·8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | 12 „ | 15·99 | 16·0 | 17·1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Heriot's Hospital Grounds, | 3 „ | ... | 6 | 6·6 | 7·4 | 3·1 | 3·3 | 3·5 | 4·1 | 3·6 | 4·0 | 3·7 | 4·6 | 5·3 |
| | 6 „ | ... | 8·3 | 8·04 | 8·5 | 3·9 | 3·2 | 4·06 | 4·56 | 3·9 | 4·5 | 4·1 | 4·9 | 6·4 |

The importance of the rôle played by the soil in the etiology of disease, which has long been insisted on by PETTENKOFER and the Munich School, has been emphasised by the elaborate investigation and report made by Dr BALLARD to the Local Government Board in 1887 on the causation of summer diarrhœa. He attributes its epidemic occurrence to some decomposition taking place in organically contaminated soil under the influence of micro-organisms at the depth of about 4 feet. The marked feature in these epidemics is the great and sudden increase in the number of cases at the end of July and beginning of August, at which time he found the underground temperature at a depth of 4 feet to be at its maximum. This sudden rise is followed by a comparatively slow decline. A reference to the curves in the tables accompanying this paper will show that the carbonic acid in the ground-air reaches suddenly its maximum amount at the same period, and that its decline is similarly slow. Since carbonic acid is a product of bacterial action on organic matter, it is evident that the upper reaches of the soil are biologically most active at the time when summer diarrhœa attains its maximum intensity.

As showing that the amount of carbonic acid in ground-air is to some extent a measure of organic matter present in the soil, I append the following experiments made in *January*:—

| | Averagely Pure Soil, 3 Feet. | | Disused Burying-Ground 3 Feet. |
|---|---|---|---|
| Organic Nitrogen, . . . | 0·065 per cent. | ... | 0·136 per cent. |
| Carbonic Acid in Ground-Air, . | 3·6 c.c. per litre. | ... | 13·5 c.c. per litre. |

| Grounds of Royal Infirmary. | | | | | | | Heriot's Hospital Grounds. | |
|---|---|---|---|---|---|---|---|---|
| Date. | 3 Feet Deep. | | 6 Feet Deep. | | 12 Feet Deep. | | 3 Feet Deep. | 6 Feet Deep. |
| 1887. | Morning. | Evening. | Morning. | Evening. | Morning. | Evening. | | |
| June 1 | 14·4 | ... | 7·8 | ... | ... | ... | ... | ... |
| 2 | 13·4 | ... | 8·0 | ... | ... | ... | ... | ... |
| 3 | 11·4 | ... | 6·2 | ... | ... | ... | ... | ... |
| 4 | 9·7 | ... | 6·5 | ... | ... | ... | ... | ... |
| 5 | ... | ... | ... | ... | ... | ... | ... | ... |
| 6 | 14·2 | ... | 8·1 | ... | ... | ... | ... | ... |
| 7 | 12·4 | ... | 7·5 | ... | ... | ... | ... | ... |
| 8 | 14·4 | ... | 8·0 | ... | ... | ... | ... | ... |
| 9 | 12·2 | ... | 4·8 | ... | ... | ... | ... | ... |
| 10 | 13·0 | ... | 5·5 | ... | ... | ... | ... | ... |
| 11 | 13·1 | ... | 5·8 | ... | ... | ... | ... | ... |
| 12 | ... | ... | ... | ... | ... | ... | ... | ... |
| 13 | 12·4 | ... | 5·0 | ... | ... | ... | ... | ... |
| 14 | 13·4 | ... | 5·9 | ... | ... | ... | ... | ... |
| 15 | 12·4 | ... | 6·0 | ... | ... | ... | ... | ... |
| 16 | 13·8 | ... | 6·2 | ... | ... | ... | ... | ... |
| 17 | 15·1 | ... | 5·7 | ... | ... | ... | ... | ... |
| 18 | 17·25 | ... | 7·3 | ... | ... | ... | ... | ... |
| 19 | 17·2 | ... | 8·8 | ... | ... | ... | ... | ... |
| 20 | 15·5 | 20·2 | 3·4 | 8·5 | ... | ... | ... | ... |
| 21 | 18·4 | 18·8 | 8·0 | 8·6 | ... | ... | ... | ... |
| 22 | ... | ... | ... | ... | ... | ... | ... | ... |
| 23 | ... | 20·5 | ... | 8·9 | ... | ... | ... | ... |
| 24 | 18·7 | 19·7 | 9·0 | 5·7 | ... | ... | ... | ... |
| 25 | 19·0 | 21·3 | 3·9 | 12·3 | 7·0 | 8·8 | ... | ... |
| 26 | 18·75 | 19·6 | 5·6 | 8·2 | 7·4 | 7·5 | ... | ... |
| 27 | 19·2 | 21·9 | 9·1 | 11·0 | 10·5 | 14·0 | ... | ... |
| 28 | 21·75 | 23·5 | 9·2 | 9·0 | 14·2 | 11·3 | ... | ... |
| 29 | 23·1 | 24·4 | 7·5 | 10·0 | 11·7 | 13·1 | ... | ... |
| 30 | 23·0 | 23·7 | 7·5 | 10·8 | 5·5 | 13·5 | ... | ... |
| July 1 | 17·4 | 21·6 | 8·6 | 9·4 | 13·0 | 15·05 | ... | ... |
| 2 | 22·7 | 22·6 | 9·2 | 9·0 | 13·9 | 16·2 | ... | ... |
| 3 | 19·7 | 20·4 | 7·8 | 9·8 | 13·8 | 16·3 | ... | ... |
| 4 | 20·1 | 22·6 | 9·2 | 9·1 | 15·0 | 14·9 | ... | ... |
| 5 | 20·3 | 22·3 | 8·4 | 5·6 | 14·1 | 12·45 | ... | ... |
| 6 | 21·7 | 20·9 | 8·6 | 8·8 | 12·6 | 15·1 | ... | ... |
| 7 | 23·1 | 20·5 | 9·7 | 10·2 | 14·6 | 17 | ... | ... |
| 8 | 24·55 | 25·1 | 10·5 | 10·4 | 15·35 | 18·3 | ... | ... |
| 9 | 26·0 | 25·4 | 12·7 | 12·5 | 16·85 | 17·65 | ... | ... |
| 10 | 25·4 | 24·5 | 10·65 | 12·0 | 17·0 | 18·3 | ... | ... |
| 11 | 26·2 | 26·2 | 11·2 | 11·1 | 18·4 | 17·14 | ... | ... |
| 12 | 25·5 | 26·6 | 10·75 | 11·0 | 17·8 | 17·9 | ... | ... |
| 13 | 27·85 | 29·1 | 12·3 | 11·7 | 16·55 | 17·1 | ... | ... |
| 14 | 27·9 | 27·5 | 10·7 | 9·9 | 17·45 | 13·1 | ... | ... |
| 15 | 25·3 | 26·1 | 10·6 | 11·2 | 16·45 | 16·65 | ... | ... |
| 16 | 25·6 | ... | 9·7 | 8·68 | 17·6 | 14·0 | 5·4 | ... |
| 17 | ... | 18·0 | 9·9 | 9·1 | 13·0 | 13·37 | ... | ... |

| Date. | Grounds of Royal Infirmary. | | | | | | Heriot's Hospital Grounds. | |
|---|---|---|---|---|---|---|---|---|
| | 3 Feet Deep. | | 6 Feet Deep. | | 12 Feet Deep. | | 3 Feet Deep. | 6 Feet Deep. |
| 1887. | Morning. | Evening. | Morning. | Evening. | Morning. | Evening. | | |
| July 18 | 27·9 | 25·4 | 7·85 | 9·7 | 13·2 | 16·3 | ... | ... |
| 19 | 25·0 | 25·3 | 9·6 | 10·0 | 14·2 | 17·8 | 6·3 | 7·4 |
| 20 | 24·2 | 28·7 | 7·5 | 11·2 | 16·8 | 20·2 | ... | ... |
| 21 | 27·3 | 25·5 | 10·4 | 11·0 | 17·85 | 18·1 | 5·1 | 7·2 |
| 22 | 25·4 | 29·9 | 10·7 | 7·1 | 15·6 | 20·0 | ... | ... |
| 23 | 29·8 | 27·4 | 11·0 | 9·9 | 19·7 | 18·0 | ... | ... |
| 24 | 26·2 | 25·6 | 9·4 | 10·3 | 17·2 | 18·0 | ... | ... |
| 25 | 28·0 | 26·8 | 10·9 | 9·4 | 19·45 | 18·0 | ... | ... |
| 26 | 24·6 | 25·8 | 9·9 | 11·7 | 16·6 | 16·05 | ... | ... |
| 27 | 27·8 | 27·6 | 11·3 | 11·6 | 17·1 | 18·9 | ... | ... |
| 28 | 24·8 | 24·2 | 10·0 | 10·3 | 16·35 | 16·95 | ... | ... |
| 29 | 25·7 | 27·3 | 10·2 | 11·5 | 16·5 | 13·6 | ... | ... |
| 30 | 25·6 | 28·6 | 7·3 | 9·7 | 15·7 | 18·8 | ... | ... |
| 31 | 27·3 | 26·2 | 9·0 | 11·0 | ... | 16·1 | ... | ... |
| Aug. 1 | 23·2 | 25·2 | 10·2 | 10·1 | 16·1 | 14·35 | ... | ... |
| 2 | 24·4 | 24·0 | 9·7 | 11·0 | 16·85 | 14·8 | ... | ... |
| 3 | 25·8 | 29·1 | 10·1 | 12·3 | 16·55 | 14·25 | ... | ... |
| 4 | 26·1 | 23·6 | 12·0 | 12·3 | 19·1 | 16·6 | ... | ... |
| 5 | 23·9 | 26·8 | 11·9 | 12·7 | 16·8 | 18·4 | ... | ... |
| 6 | 29·2 | 27·77 | 12·8 | 12·95 | 16·95 | 18·4 | 4·3 | 8·2 |
| 7 | 27·63 | 27·4 | 12·85 | 13·4 | 18·95 | 18·9 | ... | ... |
| 8 | 26·3 | 24·5 | 11·7 | 10·4 | 20·1 | 16·9 | 4·4 | 7·1 |
| 9 | 23·6 | 25·2 | 10·9 | 9·57 | 16·5 | 19·25 | 5·7 | 7·7 |
| 10 | 22·6 | 22·05 | 9·0 | 9·5 | 18·1 | 14·6 | 6·9 | 7·8 |
| 11 | 20·95 | 19·27 | 8·7 | 9·1 | 15·1 | 14·6 | 6·8 | 8·2 |
| 12 | 23·15 | 22·88 | 7·75 | 8·4 | 16·3 | 12·65 | 7·9 | 9·3 |
| 13 | 20·93 | 21·3 | 8·85 | 8·7 | 12·2 | 17·3 | 8·6 | 9·5 |
| 14 | 20·62 | 20·5 | 8·7 | 8·4 | 14·75 | 15·2 | ... | ... |
| 15 | ... | ... | 7·0 | ... | 14·2 | ... | ... | ... |
| 16 | ... | ... | ... | ... | ... | ... | ... | ... |
| 17 | ... | 20·1 | ... | 8·95 | ... | 11·05 | ... | ... |
| 18 | 24·3 | 24·75 | 9·85 | 9·2 | 14·5 | 12·5 | 7·6 | 9·3 |
| 20 | 24·2 | 22·8 | 10·75 | 9·8 | 16·95 | 13·8 | 6·8 | 11·5 |
| 22 | 24·4 | 22·15 | 9·6 | 10·2 | 13·0 | 10·9 | 6·3 | 9·4 |
| 24 | 25·1 | 29·65 | 11·0 | 13·0 | 16·4 | 17·6 | 6·2 | 7·9 |
| 26 | 24·54 | 27·08 | 13·6 | 12·9 | 16·4 | 12·6 | 6·3 | 8·7 |
| 27 | 25·35 | 27·44 | 11·75 | 19·17 | 14·2 | 17·0 | ... | ... |
| 28 | 28·7 | 23·8 | 13·5 | 13·55 | 15·5 | 15·0 | ... | ... |
| 29 | 24·4 | 25·5 | 14·77 | 15·55 | 13·1 | 17·0 | 5·9 | 7·1 |
| 30 | 25·6 | 25·85 | 13·85 | 11·4 | 15·4 | 17·5 | 3·35 | 6·7 |
| 31 | 25·05 | 27·84 | 13·0 | 14·4 | 14·6 | 20·25 | 3·95 | 6·75 |
| Sept. 1 | 24·65 | 23·95 | 13·1 | 13·18 | 17·0 | 13·45 | 4·0 | 6·8 |
| 2 | 27·9 | 21·9 | 13·8 | 12·3 | 17·6 | 19·5 | 4·8 | 6·8 |
| 3 | 24·0 | ... | 10·25 | ... | 17·0 | 17·0 | 5·3 | 6·8 |
| 5 | ... | 18·8 | 13·3 | 9·9 | 16·9 | 13·5 | 6·2 | 8·4 |
| 6 | 21·1 | 19·2 | 14·0 | 12·0 | ... | ... | 6·8 | 8·7 |

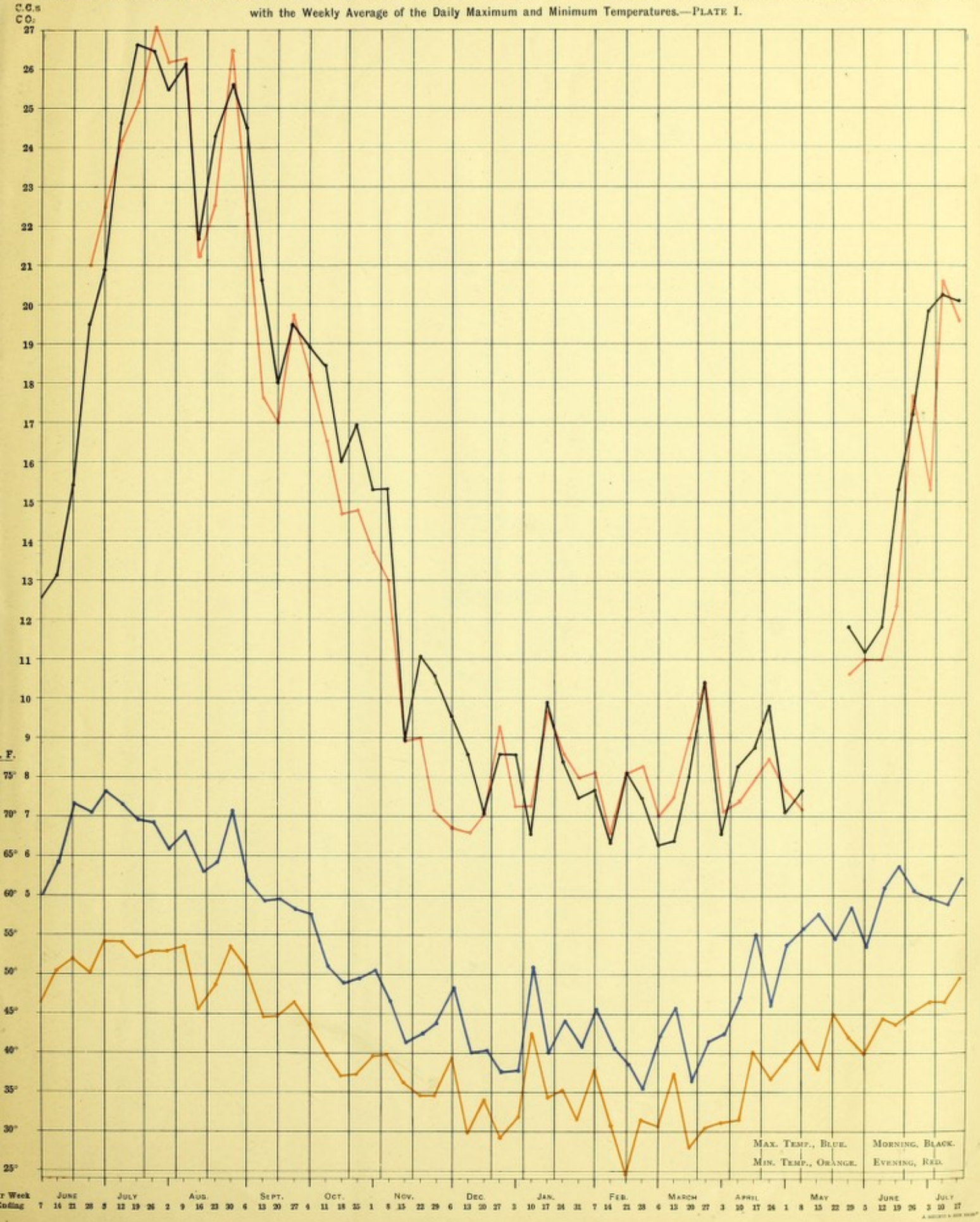
| Date. | Grounds of the Royal Infirmary. | | | | | | Heriot's Hospital Grounds. | |
|---|---|---|---|---|---|---|---|---|
| | 3 Feet Deep. | | 6 Feet Deep. | | 12 Feet Deep. | | 3 Feet Deep. | 6 Feet Deep. |
| 1887. | Morning. | Evening. | Morning. | Evening. | Morning. | Evening. | | |
| Sept. 7 | 19·0 | 18·2 | 13·9 | 16·9 | ... | ... | 4·5 | 8·8 |
| 8 | ... | 18·4 | 10·7 | ... | ... | ... | 7·4 | 8·4 |
| 9 | 23·16 | 17·86 | ... | ... | ... | ... | 3·1 | 6·7 |
| 10 | 19·66 | 17·05 | ... | ... | ... | ... | 5·75 | 5·9 |
| 11 | 19·63 | 19·3 | ... | ... | ... | ... | ... | ... |
| 12 | 21·36 | 18·6 | ... | ... | ... | ... | 6·9 | 6·95 |
| 13 | 21·5 | 14·0 | ... | ... | ... | ... | 7·3 | 5·8 |
| 14 | 17·35 | 15·0 | ... | ... | ... | ... | 7·5 | 8·8 |
| 15 | 17·45 | 16·75 | ... | ... | ... | ... | 6·2 | 6·8 |
| 16 | 18·95 | 17·3 | ... | ... | ... | ... | 5·4 | 7·9 |
| 17 | 18·4 | 19·3 | ... | ... | ... | ... | 6·7 | 7·9 |
| 18 | 17·53 | 16·3 | ... | ... | ... | ... | ... | ... |
| 19 | 17·05 | 15·2 | ... | ... | ... | ... | 7·2 | 7·5 |
| 20 | 19·6 | 18·8 | ... | ... | ... | ... | 6·9 | 8·15 |
| 21 | 17·7 | 16·7 | ... | ... | ... | ... | 6·3 | 7·8 |
| 22 | 20·55 | 19·55 | ... | ... | ... | ... | 8·45 | 8·5 |
| 23 | 19·3 | 19·0 | ... | ... | ... | ... | 7·4 | 9·1 |
| 24 | 19·1 | 23·6 | 15·65 | 16·35 | ... | ... | 8·0 | 9·8 |
| 25 | 17·9 | 21·1 | 14·6 | 15·3 | ... | ... | ... | ... |
| 26 | 22·2 | ... | 15·1 | ... | ... | ... | ... | ... |
| 27 | ... | 18·25 | ... | 13·25 | ... | ... | ... | ... |
| 28 | 19·55 | 18·85 | 21·1 | 16·9 | ... | ... | 8·7 | 10·05 |
| 29 | 17·65 | 17·4 | 12·3 | 13·67 | ... | ... | 10·1 | 11·35 |
| 30 | 18·65 | 18·8 | 11·6 | 13·1 | ... | ... | 8·75 | 9·4 |
| Oct. 1 | 19·05 | 16·7 | 15·7 | 14·0 | ... | ... | 9·5 | 9·0 |
| 2 | 19·5 | 20·06 | 14·1 | 14·3 | ... | ... | ... | ... |
| 3 | 19·6 | 18·0 | 13·55 | 13·15 | ... | ... | 9·0 | 10·6 |
| 4 | 18·3 | 17·4 | 14·78 | 15·35 | ... | ... | 9·2 | 9·3 |
| 5 | 19·4 | 18·1 | 16·2 | 16·4 | ... | ... | 8·35 | 9·6 |
| 6 | 21·3 | 19·6 | 16·1 | 13·25 | ... | ... | 9·1 | 9·9 |
| 7 | 23·7 | 19·5 | 14·66 | 13·7 | ... | ... | 8·85 | 10·4 |
| 8 | 18·8 | 17·1 | 12·95 | 11·34 | ... | ... | 9·1 | 10·0 |
| 9 | 15·65 | 13·75 | 12·56 | 11·74 | ... | ... | ... | ... |
| 10 | 15·87 | 13·8 | 8·48 | 9·5 | ... | ... | 8·1 | 10·35 |
| 11 | 14·3 | 14·0 | 5·57 | 8·55 | ... | ... | 8·05 | 11·3 |
| 12 | ... | 14·15 | 8·18 | 7·28 | ... | ... | 8·4 | 9·3 |
| 13 | 15·75 | ... | 7·9 | ... | ... | ... | 8·55 | 9·45 |
| 14 | ... | 12·83 | ... | 6·56 | ... | ... | ... | ... |
| 15 | 16·95 | 15·95 | 8·42 | 7·82 | ... | ... | 9·2 | 9·7 |
| 16 | ... | 15·05 | ... | 9·3 | ... | ... | ... | ... |
| 17 | 15·28 | ... | ... | ... | ... | ... | ... | ... |
| 18 | ... | 15·85 | 9·86 | 7·54 | ... | ... | 7·9 | 8·8 |
| 19 | 14·6 | 15·9 | 6·62 | 8·1 | ... | ... | 7·15 | 7·7 |
| 21 | 16·0 | 14·3 | 7·1 | 5·35 | ... | ... | 7·65 | 8·6 |
| 23 | 20·4 | 14·55 | 7·58 | 5·85 | ... | ... | ... | ... |
| 25 | 16·8 | 14·5 | 5·5 | 4·3 | ... | ... | 6·35 | 5·85 |
| 27 | 17·1 | 14·0 | 6·43 | 5·4 | ... | ... | 1·85 | 5·7 |

| Date. | Grounds of Royal Infirmary. | | | | | | Heriot's Hospital Grounds. | |
|---|---|---|---|---|---|---|---|---|
| | 3 Feet Deep. | | 6 Feet Deep. | | 12 Feet Deep. | | 3 Feet Deep. | 6 Feet Deep. |
| 1887. | Morning. | Evening. | Morning. | Evening. | Morning. | Evening. | | |
| Oct. 29 | 15·3 | 12·5 | 5·1 | 4·7 | ... | ... | 1·7 | 3·7 |
| 30 | 16·0 | 14·7 | 4·95 | 5·2 | ... | ... | 2·45 | 3·25 |
| Nov. 1 | 13·45 | ... | 5·25 | ... | ... | ... | 1·7 | 3·1 |
| 3 | 17·25 | 14·1 | 8·75 | 6·4 | ... | ... | 2·55 | 3·6 |
| 5 | 14·2 | 11·8 | 6·5 | 5·95 | ... | ... | ... | ... |
| 7 | 14·5 | ... | 7·2 | ... | ... | ... | 3·2 | 4·4 |
| 9 | ... | ... | ... | ... | ... | ... | 3·15 | 4·6 |
| 11 | 9·55 | 8·0 | ... | ... | ... | ... | 3·65 | 4·75 |
| 13 | 7·4 | 9·95 | ... | ... | ... | ... | ... | ... |
| 15 | 9·8 | ... | ... | ... | ... | ... | 3·4 | 4·2 |
| 18 | 11·5 | 9·5 | ... | ... | ... | ... | 3·15 | 3·7 |
| 20 | 12·25 | 10·07 | ... | ... | ... | ... | ... | ... |
| 22 | 9·28 | 7·42 | ... | ... | ... | ... | 3·8 | 3·8 |
| 24 | 12·2 | 8·27 | ... | ... | ... | ... | 4·1 | 4·5 |
| 26 | 9·02 | ... | ... | ... | ... | ... | 3·6 | 3·7 |
| 30 | 10·4 | 6·75 | ... | ... | ... | ... | 1·9 | 2·8 |
| Dec. 1 | 9·8 | 8·4 | ... | ... | ... | ... | 2·05 | 2·7 |
| 3 | 8·55 | 5·1 | ... | ... | ... | ... | ... | ... |
| 5 | 9·25 | 6·45 | ... | ... | ... | ... | 2·6 | 3·1 |
| 7 | 7·7 | 5·65 | ... | ... | ... | ... | 2·65 | 2·1 |
| 9 | 8·3 | 5·4 | ... | ... | ... | ... | 2·55 | 2·7 |
| 13 | 9·7 | 8·75 | ... | ... | ... | ... | 2·1 | 3·5 |
| 15 | 7·9 | 6·6 | ... | ... | ... | ... | 3·4 | 3·15 |
| 17 | 5·9 | 7·9 | ... | ... | ... | ... | 3·15 | 3·1 |
| 19 | 7·55 | 6·9 | ... | ... | ... | ... | 3·8 | 2·95 |
| 21 | 7·5 | ... | ... | ... | ... | ... | 4·7 | 3·9 |
| 24 | 10·0 | 8·8 | ... | ... | ... | ... | ... | ... |
| 26 | 8·56 | 9·9 | ... | ... | ... | ... | 4·1 | 4·2 |
| 28 | 8· | 7·45 | ... | ... | ... | ... | ... | ... |
| 31 | ... | ... | ... | ... | ... | ... | 4·9 | 3·9 |
| 1888. | | | | | | | | |
| Jan. 3 | 9·2 | 7·1 | ... | ... | ... | ... | 2·0 | 3·0 |
| 5 | 4·64 | 7·93 | ... | ... | ... | ... | 2·5 | 3·1 |
| 7 | 7·5 | 6·6 | ... | ... | ... | ... | 2·1 | 3·4 |
| 9 | 7·6 | 7·4 | ... | ... | ... | ... | ... | ... |
| 11 | 8·75 | 10·4 | 5·55 | ... | ... | ... | 2·8 | 3·3 |
| 13 | 9·9 | ... | 5·0 | ... | ... | ... | 4·05 | 4·15 |
| 15 | 9·8 | 10·3 | 4·5 | 5·15 | ... | ... | 5·7 | 5·6 |
| 17 | 11·2 | 8·35 | 4·65 | 4·9 | ... | ... | 3·9 | 3·75 |
| 20 | 9·45 | 9·3 | 4·35 | 4·15 | ... | ... | ... | ... |
| 22 | 10·0 | 7·8 | 5·35 | 4·7 | ... | ... | 3·65 | 3·8 |
| 24 | 5·9 | 8·7 | 4·6 | 5·8 | ... | ... | 4·1 | 3·95 |
| 26 | ... | 9·8 | 3·6 | 4·6 | ... | ... | 3·05 | 4·25 |
| 28 | 9·3 | 5·6 | 1·4 | 1·7 | ... | ... | 4·4 | 4·8 |
| 30 | 9·55 | 8·5 | 1·7 | ... | ... | ... | 4·0 | 5·6 |

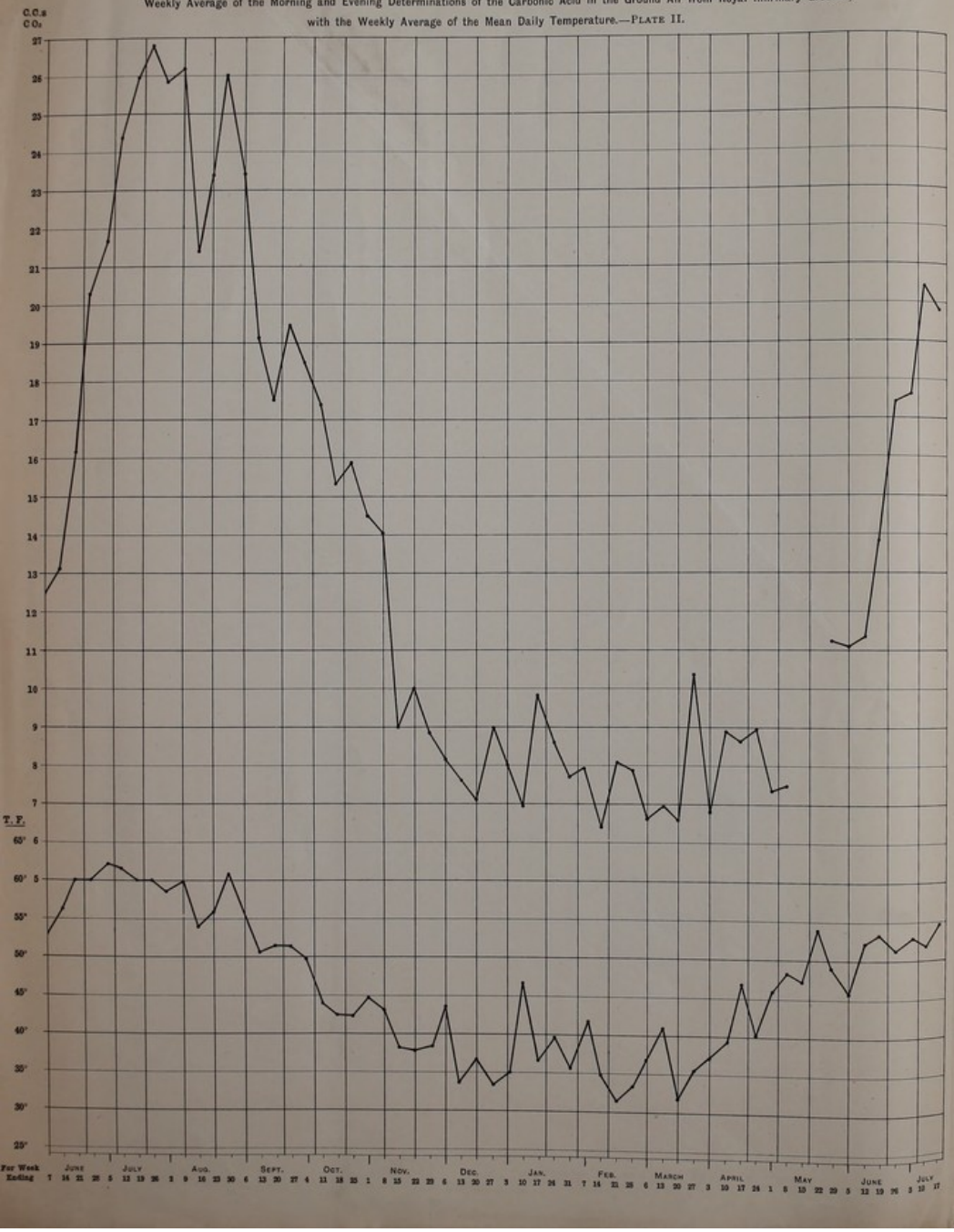
| Date. | Grounds of Royal Infirmary. | | | | | | Heriot's Hospital Grounds. | |
|---|---|---|---|---|---|---|---|---|
| | 3 Feet Deep. | | 6 Feet Deep. | | 12 Feet Deep. | | 3 Feet Deep. | 6 Feet Deep. |
| 1888. | Morning. | Evening. | Morning. | Evening. | | | | |
| Feb. 1 | 8·9 | 8·8 | ... | ... | ... | ... | 4·0 | 5·15 |
| 3 | 7·35 | 6·6 | ... | ... | ... | ... | 4·4 | 3·7 |
| 5 | 6·7 | 9·0 | ... | ... | ... | ... | ... | ... |
| 7 | 7·85 | 7·85 | ... | ... | ... | ... | 3·0 | 4·2 |
| 9 | 7·1 | 7·75 | ... | ... | ... | ... | 4·35 | 4·3 |
| 11 | 4·8 | ... | ... | ... | ... | ... | 4·7 | 4·25 |
| 13 | 7·1 | 5·25 | ... | ... | ... | ... | 4·05 | 4·6 |
| 15 | 8·85 | ... | ... | ... | ... | ... | 4·15 | 4·15 |
| 17 | 7·1 | 8·1 | ... | ... | ... | ... | 2·6 | 4·8 |
| 21 | 8·4 | 8·1 | ... | ... | ... | ... | 3·1 | 4·75 |
| 23 | 5·25 | 8·3 | ... | ... | ... | ... | 4·6 | 5·1 |
| 27 | 9·8 | ... | ... | ... | ... | ... | 4·5 | 5·3 |
| 29 | 4·8 | 8·0 | ... | ... | ... | ... | 5·8 | 4·4 |
| March 2 | 7·2 | 5·7 | ... | ... | ... | ... | 4·1 | 4·3 |
| 4 | 5·7 | 7·3 | ... | ... | ... | ... | ... | ... |
| 6 | 7·45 | ... | ... | ... | ... | ... | 4·35 | 4·65 |
| 8 | 7·0 | 7·2 | ... | ... | ... | ... | 2·25 | 4·2 |
| 10 | 3·4 | ... | ... | ... | ... | ... | ... | ... |
| 12 | 8·8 | 7·8 | ... | ... | ... | ... | ... | ... |
| 14 | 8·8 | ... | ... | ... | ... | ... | 3·0 | 3·65 |
| 16 | 6·45 | ... | ... | ... | ... | ... | ... | ... |
| 19 | 8·7 | 5·05 | ... | ... | ... | ... | 3·1 | 3·0 |
| 21 | 12·5 | 12·2 | ... | ... | ... | ... | 3·2 | 4·4 |
| 23 | 8·3 | 8·4 | ... | ... | ... | ... | 5·4 | 4·9 |
| 27 | ... | ... | ... | ... | ... | ... | 3·6 | 4·4 |
| April 2 | 6·53 | 7·1 | ... | ... | ... | ... | 3·7 | 5·6 |
| 4 | 8·0 | 7·1 | ... | ... | ... | ... | 4·5 | 4·3 |
| 6 | 7·36 | 9·86 | ... | ... | ... | ... | ... | ... |
| 8 | 8·3 | 9·25 | ... | ... | ... | ... | 5·0 | 5·5 |
| 10 | 9·53 | 3·5 | ... | ... | ... | ... | 4·0 | 3·7 |
| 12 | 8·75 | ... | ... | ... | ... | ... | 4·8 | 4·7 |
| 23 | 9·8 | 8·5 | ... | ... | ... | ... | ... | ... |
| 27 | 4·04 | 5·5 | ... | ... | ... | ... | 4·1 | 4·3 |
| 29 | 8·6 | 9·6 | ... | ... | ... | ... | 2·0 | 3·1 |
| May 1 | 8·6 | 8·0 | ... | ... | ... | ... | 2·8 | 4·8 |
| 3 | 8·8 | 7·0 | 9·1 | 9·25 | ... | ... | ... | ... |
| 5 | 8·55 | 7·55 | 8·15 | 6·25 | ... | ... | 5·3 | 3·3 |
| 7 | 5·77 | 7·1 | 6·4 | 7·4 | ... | ... | 2·3 | 3·2 |
| 9 | 6·7 | ... | 6·8 | ... | ... | ... | ... | ... |
| 28 | ... | 9·0 | ... | 9·95 | ... | ... | ... | ... |
| 29 | 11·86 | 12·24 | 10·2 | 11·1 | ... | ... | 4·1 | 5·5 |
| 31 | 13·15 | 10·9 | 15·45 | 9·6 | ... | ... | 3·9 | 4·0 |
| June 1 | 12·55 | 9·75 | 9·7 | 7·3 | ... | ... | 3·6 | 4·2 |
| 2 | 9·98 | ... | 9·98 | ... | ... | ... | 4·5 | 4·8 |

| Grounds of Royal Infirmary. | | | | | | | Heriot's Hospital Grounds. | |
|---|---|---|---|---|---|---|---|---|
| Date. | 3 Feet Deep. | | 6 Feet Deep. | | 12 Feet Deep. | | 3 Feet Deep. | 6 Feet Deep. |
| 1888. | Morning. | Evening. | Morning. | Evening. | Morning. | Evening. | | |
| June 3 | 9·95 | 11·98 | 8·75 | 8·8 | ... | ... | ... | ... |
| 4 | 10·95 | 11·2 | 8·95 | 7·65 | ... | ... | ... | ... |
| 5 | 10·8 | ... | 8·15 | ... | ... | ... | 5·5 | 4·3 |
| 6 | 11·55 | 10·15 | ... | ... | ... | ... | ... | ... |
| 7 | 12·1 | 10·85 | ... | ... | ... | ... | 6·8 | 5·1 |
| 8 | 11·34 | 10·45 | ... | ... | ... | ... | 5·9 | 6·4 |
| 9 | 14·18 | 13·78 | ... | ... | ... | ... | 4·5 | 4·4 |
| 10 | 10·24 | 8·08 | ... | ... | ... | ... | ... | ... |
| 11 | 9·65 | 12·77 | ... | ... | ... | ... | 4·2 | 4·8 |
| 12 | 13·66 | 10·44 | ... | ... | ... | ... | 3·8 | 5·0 |
| 13 | 11·6 | ... | ... | ... | ... | ... | 2·0 | 4·3 |
| 16 | ... | 12·15 | ... | ... | ... | ... | ... | ... |
| 17 | 14·6 | 12·5 | 11·95 | 8·13 | ... | ... | ... | ... |
| 18 | 14·68 | ... | 9·85 | ... | ... | ... | ... | ... |
| 19 | 16·75 | ... | 9·65 | ... | ... | ... | ... | ... |
| 20 | 14·05 | 15·3 | 9·08 | 12·6 | ... | ... | 4·3 | 5·5 |
| 21 | 16·1 | 13·5 | 9·4 | 9·6 | ... | ... | 4·6 | 5·4 |
| 22 | 16·0 | 15·6 | 12·0 | 9·6 | ... | ... | 5·1 | 5·7 |
| 23 | 16·8 | 19·9 | 15·55 | 12·7 | ... | ... | 4·5 | 5·1 |
| 24 | 17·6 | 20·0 | 14·8 | 13·15 | ... | ... | ... | ... |
| 25 | 19·15 | 18·3 | 11·0 | 13·1 | ... | ... | 4·5 | 3·7 |
| 26 | 21·0 | 20·75 | 14·4 | 14·35 | ... | ... | 4·9 | 3·5 |
| 27 | 22·0 | 12·6 | 11·8 | 12·3 | ... | ... | 2·9 | 3·6 |
| 28 | 18·85 | ... | 13·2 | ... | ... | ... | 4·9 | 5·4 |
| 29 | 21·0 | ... | 13·1 | ... | ... | ... | 5·9 | 5·3 |
| 30 | 19·1 | ... | 12·4 | ... | ... | ... | ... | ... |
| July 1 | 16·0 | 13·5 | 11·07 | 15·05 | ... | ... | ... | ... |
| 2 | 22·0 | 16·6 | 20·3 | 13·75 | ... | ... | 4·2 | 5·0 |
| 3 | 19·93 | 18·46 | 13·8 | ... | ... | ... | 4·6 | 4·8 |
| 4 | 21·9 | 23·45 | ... | ... | ... | ... | 4·6 | 6·0 |
| 5 | 24·3 | 20·45 | ... | ... | ... | ... | 6·2 | 7·6 |
| 6 | 14·86 | 28·0 | ... | ... | ... | ... | 4·2 | 6·6 |
| 7 | 22·55 | 22·1 | ... | ... | ... | ... | 4·7 | 8·1 |
| 8 | 21·8 | 18·0 | ... | ... | ... | ... | ... | ... |
| 9 | ... | 14·45 | ... | ... | ... | ... | 4·1 | 4·2 |
| 10 | 15·75 | 18·0 | ... | ... | ... | ... | ... | ... |
| 11 | 20·9 | 19·5 | ... | ... | ... | ... | 4·3 | 4·5 |
| 12 | 16·0 | 19·3 | ... | ... | ... | ... | 6·6 | 6·8 |
| 13 | 19·75 | 19·2 | ... | ... | ... | ... | 5·1 | 7·1 |
| 14 | 21·35 | ... | ... | ... | ... | ... | 6·2 | 4·6 |
| 15 | 22·3 | ... | ... | ... | ... | ... | 7·0 | 7·6 |
| 16 | 20·1 | 20·6 | ... | ... | ... | ... | 7·3 | 10·3 |

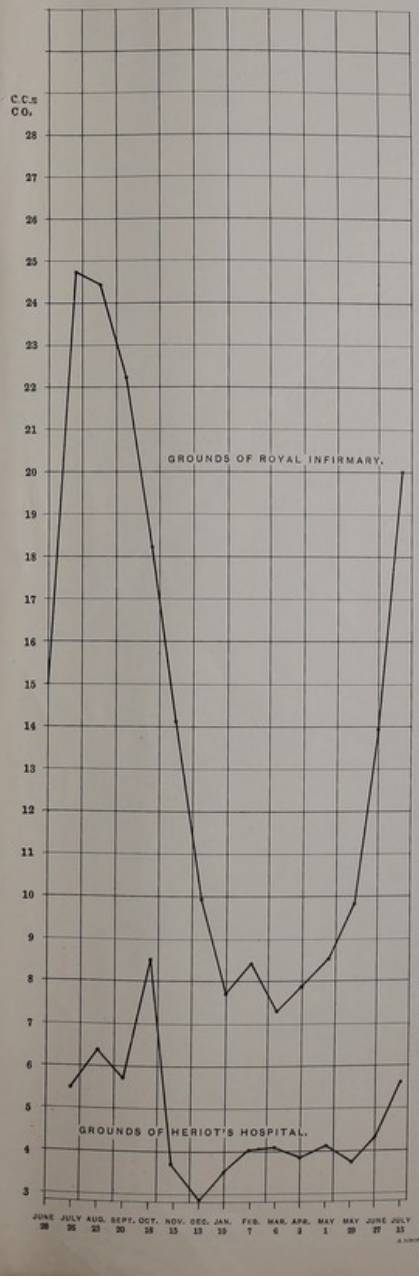
Comparison between the Weekly Average of the Morning and of the Evening Determinations of the Carbonic Acid in the Ground Air from the Royal Infirmary Grounds, with the Weekly Average of the Daily Maximum and Minimum Temperatures.—PLATE I.



Weekly Average of the Morning and Evening Determinations of the Carbonic Acid in the Ground Air from Royal Infirmary Grounds, with the Weekly Average of the Mean Daily Temperature.—PLATE II.




Monthly Average of the Daily Determinations of the Carbonic Acid in the Ground Air of the soil in (1) the Royal Infirmary Grounds, (2) the Heriot's Hospital Grounds.—PLATE III.



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| IX. | 1 0 0 | 0 17 0 |
| X. | 0 19 0 | 0 16 0 |
| XI. | 0 14 6 | 0 12 0 |
| XII. | 0 14 6 | 0 12 0 |
| XIII. | 0 18 0 | 0 15 0 |
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| Part 2. | 0 10 0 | 0 7 6 |
| Part 3. | 0 10 0 | 0 7 6 |
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| XXI. Part 1. | 0 15 0 | 0 11 6 |
| Part 2. | 0 10 0 | 0 7 6 |
| Part 3. | 0 7 0 | 0 5 3 |
| Part 4. | 0 18 0 | 0 13 6 |
| XXII. Part 1. | 1 5 0 | 1 1 0 |
| Part 2. | 0 10 0 | 0 7 6 |
| Part 3. | 1 5 0 | 1 1 0 |
| XXIII. Part 1. | 0 15 0 | 0 11 6 |
| Part 2. | 1 15 0 | 1 8 6 |
| Part 3. | 1 18 0 | 1 10 0 |
| XXIV. Part 1. | 1 5 0 | 1 1 0 |
| Part 2. | 1 8 0 | 1 3 0 |
| Part 3. | 1 10 0 | 1 5 0 |
| XXV. Part 1. | 0 18 0 | 0 13 6 |
| Part 2. | 2 2 0 | 1 11 0 |
| XXVI. Part 1. | £1 0 0 | £0 16 0 |
| „ Part 2. | 1 4 0 | 1 0 0 |
| „ Part 3. | 0 16 0 | 0 12 6 |
| „ Part 4. | 0 12 0 | 0 9 6 |
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| „ Part 3. | 1 1 0 | 0 16 0 |
| „ Part 4. | 1 0 0 | 0 16 0 |
| XXVIII. Part 1. | 1 5 0 | 1 1 0 |
| „ Part 2. | 1 5 0 | 1 1 0 |
| „ Part 3. | 0 18 0 | 0 13 6 |
| XXIX. Part 1. | 1 12 0 | 1 6 0 |
| „ Part 2. | 0 16 0 | 0 12 0 |
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| XXXI. | 4 4 0 | 3 3 0 |
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| „ Part 3. | 2 10 0 | 1 17 6 |
| „ Part 4. | 0 5 0 | 0 4 0 |
| XXXIII. Part 1. | 1 1 0 | 0 16 0 |
| „ Part 2. | 2 2 0 | 1 11 0 |
| „ Part 3. | 0 12 0 | 0 9 6 |
| XXXIV. | 2 2 0 | 1 11 0 |
| XXXV.* Part 1. | 2 2 0 | 1 11 0 |
| „ Part 2. | 1 11 0 | 1 3 6 |
| „ Part 3. | 2 2 0 | 1 11 0 |
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| „ Part 2. | 1 1 0 | 0 16 0 |
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