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ON THE RADIATION RECORDS OBTAINED IN 1911 AT SOUTH KENSINGTON, TOGETHER WITH A COMPARISON BETWEEN THEM AND THE CORRESPONDING ABSOLUTE OBSERVATIONS OF RADIATION MADE AT KEW OBSERVATORY.

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ON THE RADIATION RECORDS OBTAINED IN 1911 AT SOUTH KENSINGTON, TOGETHER WITH A COMPARISON BETWEEN THEM AND THE CORRESPONDING ABSOLUTE OBSERVATIONS OF RADIATION MADE AT KEW OBSERVATORY.

A CONTINUOUS record of the vertical component of the radiation from the sky is obtained at the Meteorological Office, South Kensington, by means of a Callendar radiation receiver, exposed on the roof of the office and connected with an electric recorder installed in the hall on the first floor. The receiver consists of a small square horizontal mica plate, mounted inside a sealed glass bulb and furnished with two platinum resistance wires coiled upon its surface and secured to the surface by means of special preparations applied in very thin layers, one being practically transparent, so that the bright wire can be seen beneath it, the other being black. Two leads are attached to the ends of each resistance wire. They pass through the bottom of the glass bulb, and so to the recorder by means of insulated copper wires.

The action of the instrument may be described briefly as follows:—A small current from two storage cells connected up in series passes through both resistances of the receiver. If the temperatures of both wires are the same, the receiver is so constructed that the resistances are equal, but by a well-known law, if the temperature of one wire exceeds that of the other, the electrical resistance of the former exceeds that of the latter, and the differences of temperature and resistance between the wires are connected by a relation which is almost exactly linear. Consequently, a record of the difference between the resistances is also a record of the difference between the temperatures of the wires; and it is also a measure of the radiation from the sky as received on a horizontal surface, since the temperature of the black wire is raised above that of the bright wire by an amount depending on the radiation falling on the plate.

The Callendar electrical recorder installed in the hall gives a continuous record of the difference between the resistances of the two wires. The recorder is in effect a self-balancing Wheatstone bridge, in which two of the resistances incorporated in the recorder are equal to one another. The two remaining resistances or "arms" of the bridge are made up of the two platinum resistances of the receiver, with their leads, together with small self-adjustable resistances in the recorder. The receiver, along with its recorder, is standardised by Prof. Callendar, who employs an Ångström pyrheliometer for this purpose, and issues a certificate giving the scale value for the combination. The record is made on daily charts, which are made to pass beneath the recording pen by being attached to a brass drum that revolves by clockwork about once in twenty-four hours. The charts are ruled to show hour lines and *rates* of radiation, measured either

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in gramme-calories per square centimetre per minute, or in practical units on the C.G.S. system (watts per square centimetre). The relation between the two units is

1 cal. per sq. cm. per min. = ·070 watts per sq. cm. nearly.

The distance of the pen from the zero of the record at any time is a measure of the rate at which, on balance, heat is entering or leaving the mica plate by radiation; excess of heat received being measured above the zero line, and excess of heat liberated below the zero. The radiation scale of the charts is taken to be linear.

The following are the general characteristics of the traces obtained. The chart is put on after sunset, usually at about 8.15 p.m. At that time it generally happens that the pen is on the zero line of the record, or very close thereto. Throughout the night the recorded variations of radiation are as a rule very small. Frequently the curve for the night is a straight line, but sometimes minor fluctuations occur towards the negative side. On no occasion hitherto has a decided record of negative radiation, that is radiation outwards from the receiver in excess of that inwards, been obtained. The fluctuations which have been actually observed during the night hours may more properly be attributed to changes of temperature of the bulb and the air enclosed therein. At sunrise, or very shortly after, the pen begins to move in the positive direction, showing that radiant heat received on the mica plate is in excess of that emitted. If the day is cloudless, the pen continues to rise steadily, with but slight fluctuations, until it reaches its maximum at about noon; after which it falls again in a curve similar to that for the morning, but in the opposite sense, and returns to the zero just before sunset. The maximum height attained in summer is considerably in excess of that in winter. This, as well as the gradual rise to noon followed by a gradual fall to sunset, is partly accounted for by the fact that the mica plate is exposed horizontally, so that a broader pencil of direct rays of radiation from the sun falls on it when the sun has a high altitude than when it has a low one. It is easy to see that the effective area of the mica plate, so far as direct radiation from the sun or any part of the sky is concerned, as compared with its actual area is reduced in the ratio $\sin \alpha : 1$, where α is the angular altitude of the sun or part of the sky considered, and therefore that the instrument records only the *vertical component* of radiation.

On a windy day, with intervals of clear sky and detached clouds of the cumulus type with hard outlines, the record obtained is very striking. The passage of a cloud over the sun strongly affects the radiation, and the pen falls rapidly towards zero, only to rise again sharply when the cloud has passed from between the receiver and the sun. Owing, apparently, to the exceptional clearness of the atmosphere on these occasions, it frequently happens that the maximum rate of radiation on these days exceeds that on cloudless days, the latter often being somewhat hazy. The high maximum rate often recorded immediately the sun breaks out after the passage of a cloud may, however, be due to the black wire taking up its new temperature at a more rapid rate than the bright wire. The temperature of the latter is more dependent upon that of the air in the bulb than the former, and a sensible length of time is required to change the temperature of that air.

The record is usually interesting even on a very dull day. The small variations in the intensity of daylight are distinctly recorded, showing that they are associated with changes in radiant heat, and it is interesting to watch the instrument reproduce these changes on paper. On one day only since the instrument was installed has an in gramme-calories per square centimetre per minute, or in practical units on the C.G.S. system (watts per square centimetre). The relation between the two units is

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Examples of radiation records obtained at the Meteorological Office, South Kensington, during 1911. *(see p 59.)*

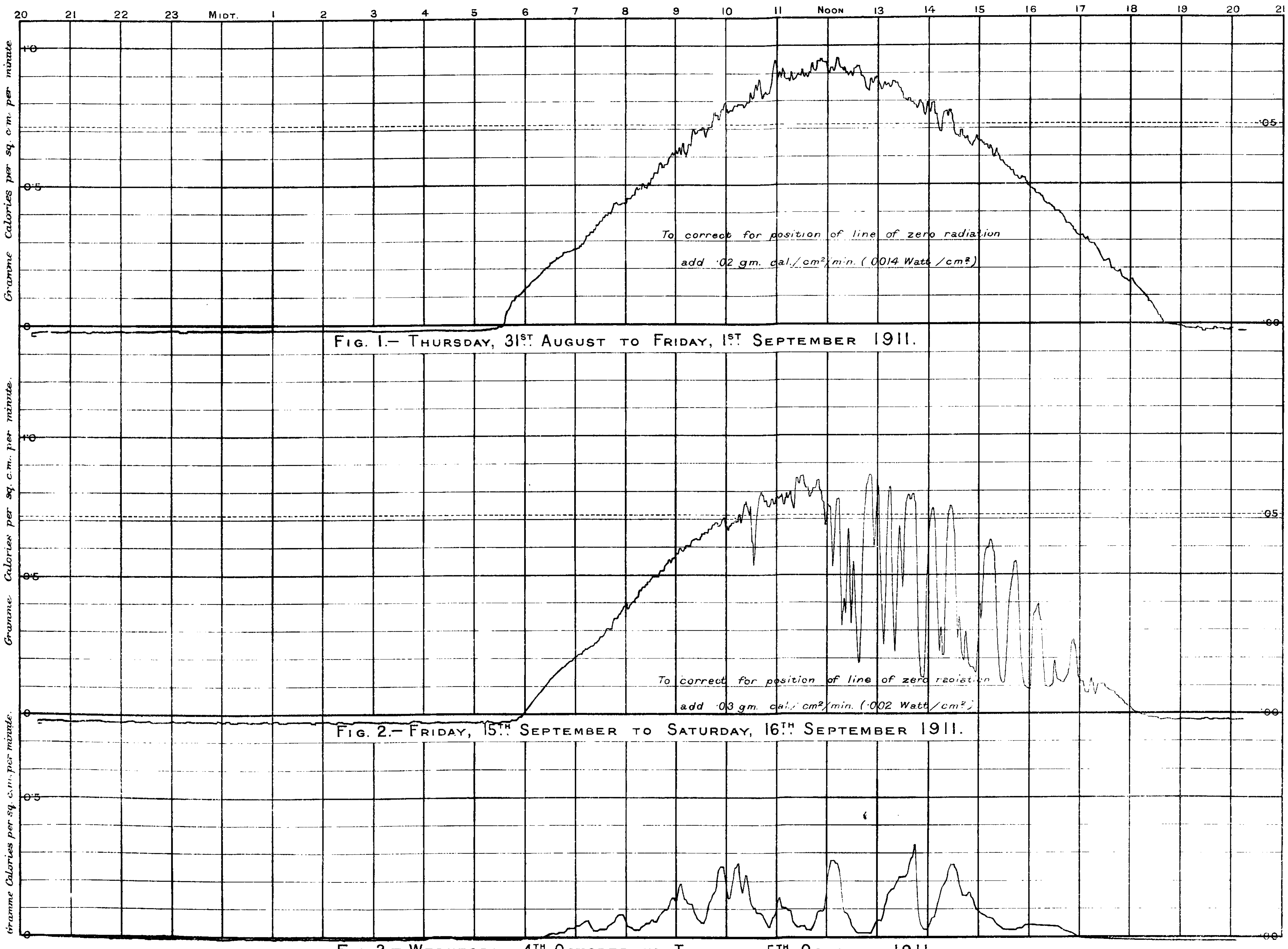

Fig. 1.– Thursday, 31st August to Friday, 1st September 1911.

Fig. 2.– Friday, 15th September to Saturday, 16th September 1911.

Fig. 3.– Wednesday, 4th October to Thursday, 5th October 1911.

almost perfectly blank record been obtained. This happened on January 23, 1912, which was a miserably dark day in London, artificial light being required indoors throughout the day. The record was almost indistinguishable from a straight line on that occasion.

For many purposes, both practical and theoretical, a knowledge of the total amount of radiation received by the earth in a given time is important, and the radiation recorder is provided with an arrangement from which this information can be derived. Since ordinates of the record represent *rates* of radiation and abscissæ represent times, it follows that the *area* of the curve comprised between the record itself, the zero line, and two ordinates corresponding with two different times is a measure of the radiation received between those times.

Attached to the recording pen of the instrument is the free end of one arm of a planimeter, of which the fixed end of the second arm rotates about a pin attached to the frame of the recorder. The rolling wheel on the second arm rests against the drum, and is rotated by the motion of the drum. The amount of rotation of the wheel per revolution of the drum depends on the distance of the pen from the zero of the record, that is, upon the rate of radiation. In this way the area between the curve and the base line is automatically measured. From readings of the planimeter at the times of putting on and removing the daily sheet can be deduced the area of the curve; and thus, on multiplying by the appropriate factor, the total radiation for the day in calories per square centimetre or in watt-hours per square centimetre can be obtained.

Fig. 1, Plate 14 (September 1, 1911) shows a typical record for a cloudless day, in which the rising and falling portions are almost optical images of one another about the noon line. The total radiation received on that day, as determined by the area of the curve, was 450 calories per sq. cm.; in other words, if all the radiant heat received on each square centimetre on that day were applied to the heating of 100 grams of water it would raise the temperature of the water by $4\frac{1}{2}°$ C., assuming that no heat escapes by conduction or convection. The maximum rate of radiation occurred at about 12h. 20m., and was ·069 watts per sq. cm.; while the mean rate of radiation between sunrise and sunset was ·039 watts per sq. cm.

Fig. 2, Plate 14 (September 16, 1911) is an example of a day which opened with a cloudless sky, and remained clear until about 10.30 a.m., when a passing cloud diminished the radiation for a short time. At noon the character of the trace changed completely, and the record for the afternoon shows the effect of the frequent passage of clouds over the sun, with intervals of blue sky. Small variations are shown during the night. The total radiation received was 324 calories per sq. cm., the maximum rate being ·062 watts per sq. cm. at 13h., and the mean rate between sunrise and sunset being ·030 watts per sq. cm.

Fig. 3, Plate 14 (October 5, 1911) is remarkable in that it shows fluctuations of radiation quite definite in character but of no great magnitude. The maximum ordinate for the day is shown at about 13h. 50m., when the rate of radiation was ·024 watts per sq. cm. The curve is interesting from the fact that the record of bright sunshine for South Kensington on that day, obtained from a Campbell-Stokes sunshine recorder exposed near the radiation receiver, was nil. The quantity of radiation received, as obtained from the area of the curve, is, however, 64 calories per sq. cm., and the mean rate of radiation between sunrise and sunset is ·007 watts per sq. cm.

The lowest maximum rate of radiation for the day throughout the year was

·003 watts per sq. cm. on January 1 and 8 and on December 22. Excluding the period May 20 to July 20, for which the records were unreliable, the highest maximum for a day was ·088 watts per sq. cm. at 11h. 30m. on August 4. The maximum radiation on August 9, the hottest day for London on record, when an air temperature of 98°·6 F. was registered at South Kensington, was ·071 watts per sq. cm. at 12h. 15m. This value was frequently exceeded on less warm days.

Appended is a table showing a comparison between the maximum recorded rates of radiation at South Kensington and the absolute observations of solar radiation made at Kew Observatory on certain days when no visible cloud appeared in front of the sun at the time of observation. The two sets of figures refer to corresponding days. The Kew observations were made between 11h. and 13h. by means of an Ångström pyrheliometer. The receiving surface of the instrument is directed towards the sun during an observation, and therefore what is measured at Kew is the rate of the whole of the solar radiation. In order to bring the values into a form more nearly comparable with the South Kensington results, each value of radiation at Kew has been multiplied by the sine of the angular elevation of the sun at noon, so as to obtain the vertical component of the radiation. The values so obtained are entered in the fifth column of the table, and the ratios between the figures for South Kensington and Kew in columns 2 and 5 are entered in column 6.

It will be seen that the agreement between the South Kensington figures and those for Kew in the fifth column of the table is usually fairly good. The mean value of the ratios in the last column of the table is 1·09. It is not surprising that large differences should exist sometimes. On some occasions the maximum rate at South Kensington occurred at a time outside 11h.–13h., which is the observation period at Kew, and it usually happens on these occasions that the South Kensington figure is in excess of the Kew value. Again, the process of finding the vertical component at Kew by multiplying by the sine of the elevation of the sun at noon does not take into account the influence of the remainder of the sky and of any clouds that may be present. Further, the observation at Kew generally occupies not longer than thirty minutes, so that there are opportunities of higher rates of radiation between 11h. and 13h. outside the precise interval selected at the observatory. Finally, the two places are situated about seven miles from one another, and while Kew is in rural surroundings in a suburban neighbourhood, the exposure at South Kensington may be said to be under suburban conditions within the vast urban district of London.

TABLE showing a comparison between the maximum rates for the day of vertical radiation at South Kensington with the times of their occurrence, and absolute measurements of solar radiation at Kew Observatory by means of Ångström's pyrheliometer between the hours 11h. and 13h. on specified days in 1911.

Date 1911.	South Kensington. Maximum Vertical Radiation.		Kew.		Ratio,
	Watts per cm².	Time, Hours.	Observed Total Radiation, Watts per cm².	Approximate Vertical Component, Watts per cm².	Column 2 / Column 5.
9 March	·054	13¼	·087	·063	·86
21 ,,	·038	11½	·037	·029	1·31
24 ,,	·043	11½	·044	·035	1·23
25 ,,	·060	10¼	·072	·057	1·05
28 ,,	·043	11½	·051	·041	1·05
3 April	·072	12¼	·083	·069	1·04
10 ,,	·067	11¼	·061	·052	1·29
12 ,,	·059	11	·067	·058	1·02
13 ,,	·061	12½	·072	·062	·98
20 ,,	·069	12	·080	·071	·97
22 ,,	·066	12¾	·079	·070	·94
24 ,,	·064	13	·088	·079	·81
26 ,,	·076	13¼	·087	·078	·97
28 ,,	·076	12½	·083	·076	1·00
29 ,,	·074	12½	·091	·083	·89
4 May	·078	13¼	·090	·083	·94
8 ,,	·066	13¾	·047	·044	1·50
10 ,,	·064	11	·051	·048	1·33
11 ,,	·067	11	·053	·050	1·34
13 ,,	·062	11	·062	·058	1·07
22 ,,	? ·069	12½	·060	·057	1·21
3 July	? ·093	11½	·082	·079	1·18
5 ,,	? ·069	12¼	·082	·079	·87
6 ,,	? ·062	11	·070	·068	·91
7 ,,	? ·059	11¾	·059	·057	1·03
18 ,,	? ·074	12	·088	·084	·88
21 ,,	·076	12¼	·084	·080	·95
24 ,,	·074	11¼	·061	·058	1·27
25 ,,	·079	13¼	·061	·058	1·36
27 ,,	·083	12¼	·087	·082	1·01
28 ,,	·064	10½	·058	·055	1·16
1 Aug.	·079	12¾	·082	·077	1·03
4 Aug.	·088	11½	·088	·082	1·07
8 ,,	·072	11½	·083	·077	·94
9 ,,	·071	12¼	·074	·069	1·03
6 Sept.	·057	12	·055	·047	1·21
7 ,,	·057	12½	·066	·056	1·02
8 ,,	·057	11¾	·063	·054	1·06
18 ,,	·054	13	·066	·053	1·02
21 ,,	·062	11	·073	·058	1·07
22 ,,	·048	13¾	·051	·040	1·20
23 ,,	·054	11½	·051	·040	1·35
25 ,,	·059	12½	·075	·058	1·02
26 ,,	·052	12	·070	·054	·96
27 ,,	·057	11¾	·068	·052	1·10
29 ,,	·060	13	·063	·048	1·25
30 ,,	·060	12¼	·071	·054	1·11
6 Oct.	·043	12	·024	·017	2·53
7 ,,	·015	11¾	·031	·022	·68
11 ,,	·034	12¾	·041	·028	1·21
12 ,,	·034	13¾	·026	·018	1·89
22 ,,	·038	13	·052	·034	1·12
25 ,,	·045	12	·068	·043	1·05
6 Nov.	·033	12¼	·071	·041	·80
7 ,,	·030	11¾	·062	·036	·83
9 ,,	·028	12¼	·060	·034	·82
29 ,,	·015	12¾	·036	·018	·83
4 Dec.	·016	13	·046	·023	·70
5 ,,	·018	11½	·038	·019	·95
8 ,,	·026	12¼	·050	·024	1·08
11 ,,	·018	12¾	·057	·027	·67
13 ,,	·016	11¼	·057	·027	·59
19 ,,	·016	13¼	·030	·014	1·14