A CONTRIBUTION TO THE HISTORY OF RAIN GAUGES.[1]

By G. J. SYMONS, F.R.S.

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Owing to the absence of our President in Oriental countries, it was felt by the Council that he could not be asked to prepare the Address relative to the Annual Exhibition, and I was requested to do so.

This paper is therefore one of the series in which Hygrometers, Anemometers, Instruments for Travellers, Thermometers, Sunshine Recorders, Barometers, Marine Instruments, Apparatus for studying Atmospheric Electricity, Solar Radiation Instruments, and the application of Photography to Meteorology, have been successively dealt with. I regret that I cannot, in the time at my disposal, make this as nearly complete as some of its predecessors were. My difficulties have also been aggravated by the fact that I cannot ascertain that any one has ever attempted to deal with the subject—even Poggendorff, in his excellent *Geschichte der Physik*, devotes less than half-a-page to it, and has not carried the history back so far as I have been able to do.

We are indebted to Dr. Hellmann for directing attention to what is probably the earliest measurement of rain, but, as will be seen, it was merely an

[1] By one of those curious coincidences which frequently occur, Dr. Hellmann was at work upon this subject at the same time as I was, and he has most kindly allowed me to use his data in the verification and completion of this Paper.—G. J. S.

isolated experiment, there is no suggestion of a rain gauge, or of a continuous record.

In an extremely interesting article[1] in a German periodical, Dr. Hellmann calls attention to a letter dated June 10, 1639, and addressed by B. Castelli to Galileo, in which he relates that after going to see a lake which was exceptionally low, he, on his return to Perugia, passed for eight hours through an apparently exceptionally heavy rain. This suggested to him the problem how much such a rain might raise the lake, and so, on reaching home, he put out a glass cylinder about 5 inches in diameter and 9 inches deep, and at the end of an hour took it in, and measured the depth of water in it. He does not give it in figures, but in the letter draws a line about 0·4 inch long to represent the depth.

Further evidence that this was an isolated case, and that the idea of regularly recording the fall of rain did not occur to Castelli, seems to be afforded by the fact that all through the Cimento MSS., which range from 1654 to 1664, and in the record very carefully kept at the Monastery of the Angels at Florence from 1654 to 1670, there is no reference to a rain gauge, though frequent statements are made as to the fall of rain and of snow. Had such an instrument as a rain gauge been known, I feel sure that one would at once have been added to the instruments at the monastery.

Most curiously, the first rain gauge designed was not an ordinary one, but a recording one. In Birch's *History of the Royal Society* we read that on January 22, 166½, Dr. Wren (*i.e.* Sir Christopher Wren) showed his experiment of filling a vessel with water, which emptied itself when filled to a certain height. Later on, September 23, 1663, Dr. Wilkins was desired to write to Dr. Wren for his scheme of the instrument for recording all sorts of weather. On November 30, 1663, Dr. Wilkins acquainted the Society that he had received an answer from Dr. Christopher Wren concerning his promised weather-clock, together with the scheme thereof. The amanuensis was ordered to draw the scheme in great (*i.e.* to prepare a diagram) against the next meeting, at which it should be considered, together with the letter describing it. On December 9, 1663, Dr. Wren's description of his weather-clock, consisting of two wings that may be added to a pendulum clock, was read and ordered to be registered. I do not reproduce this drawing because for some reason Sir Christopher did not propose to record anything except wind—and we are dealing with rain gauges, not with anemometers. But the other Fellows wished it completed, and, after some debate, the matter was referred to the Council to consider of the expenses, and of the most convenient way of reducing the engine into practice, as also of additions to be made thereto, whereof some were mentioned by Mr. Hooke, one of the officers of the Society. The Council was evidently alarmed at these additions, for five days later (December 14, 1663) it was ordered that Dr. Wren be desired to make an estimate of the charges of a plain weather-clock, such as he himself had devised; and to consider of the easiest contrivance to put it in practice.

[1] *Die Anfänge der Meteorologischen Beobachtungen und Instrumente.* Himmel und Erde II. Jahrg. 3 u. 4 Heft.

In 1664 (August) Hooke was provided with a residence in Gresham College (then the headquarters of the Royal Society), and directly afterwards, September 14, 1664, it was ordered that Mr. Hooke contrive a pendulum clock applicable to the observing changes of the weather, as well and as cheap as he could, for the use of the Society. In the following January Hooke showed the way whereby a thermometer might be made to indicate in connection with the weather-clock.

Then for several years nothing was done, but finally, on May 19, 1670, it was ordered that a weather-clock should be bespoken by Mr. Hooke; such a one as Dr. Wren had formerly contrived, for observing [recording] not only the winds and their quarters and degrees of strength, but also the quantities of rain, and other particulars relating to the temperature of the air.

It was thus nearly ten years between the date of Sir Christopher's suggesting his tipping-bucket rain gauge, and one being ordered for construction for the Royal Society. My impression is, however, that Sir Christopher, after showing his rain gauge to the Royal Society on January 22nd, 1662, took it home again, and recorded it regularly, although no trace of his observations can now be found. My reasons for this opinion are two: first that such a course was probable; secondly, that to a review of Perrault's *Origine des Fontaines* in the *Phil. Trans.* Nov. 22, 1675, there is the following note:—

"The like to which hath been attempted here, and proposed to the R. Soc. some years since, by Sir C. Wren, who by the contrivance of a rain bucket had taken an account of all the water that fell for a considerable time, and by his weather-clock had, among other particulars, not only taken in the measurement of the quantity of rain that falls, but also when it falls, and how much at each time."

It had long been supposed that the observations made by Mr. Townley, of Townley, near Burnley, Lancashire, which began on January 1st, 1677, were the earliest in the world, but Poggendorff has shown that an unknown correspondent residing at Dijon had supplied Mariotte with records from that city dating back to about 1674, or three years before the Townley ones.

On carefully reading Mariotte's works, I found a reference to a rather scarce anonymous book, entitled *De l'origine des Fontaines*, printed in Paris in 1674. It is, of course, in old French, but of such interest that I think a few lines from p. 200 should be reprinted *verbatim*.

"Par les obfervations que j'ay faites de la quantité des eaux de pluye & de neige, j'ay trouvé que depuis le mois d'Octobre 1668, jufques à pareil mois de 1669, il en eft tombé la hauteur de dix-huit poulces fept lignes: Depuis pareil mois de l'année 1670, jufques à pareil mois de 1671, il n'en eft tombé que la hauteur d'onze poulces fix lignes feulement; & depuis le mois de Ianvier 1673, jufques à pareil mois de 1674, la hauteur de vingt fept poulces fix lignes: Ie joins ces trois quantitez enfemble pour en faire celle d'vne année commune, qui fera par ce moyen de dix-neuf poulces deux lignes vn tiers."

I had, from internal evidence, arrived at the conclusion that these observations were made in Paris, but thanks to the help of Mr. White, the Assistant Librarian of the Royal Society, the veil of anonymity is removed, and the observations prove to have been made in Paris by M. Pierre Perrault, in whose collected works the above anonymous book is reprinted with his signature.

Perhaps a brief digression respecting what led Perrault and Mariotte to make, and to have made, these observations, may be excused. Science made rapid advances during the years following the discovery of the barometer in 1643: in 1648 there was Pascal's experiment on the variation of the barometer with altitude above sea-level, and in 1670 Mariotte proposed the synchronous study of winds over a large area, with a view to weather forecasting. Although the Biblical texts were perfectly clear as to the course of the vapour and the rivers (Job xxvi. 8; Isaiah lv. 10; Jer. x. 13; Eccl. i. 7); and Vitruvius, in his *Architectura*, had distinctly stated that springs were fed by stored-up rainfall, the matter had been so buried under false theories that the general opinion had swerved quite away from the truth, when Perrault took it up, and in the little book I have quoted, gave, first a thorough analysis of the many false explanations, and then the true explanation. For this he, of course, needed the returns of rainfall, and it is curious that his mean value for Paris 19″ 2½‴ corresponds to 20·45 English inches, or within half-an-inch of the value for that city assigned by Prof. Raulin as the result of modern observation. M. Perrault dealt with the matter with great skill, considering the epoch. He had the rainfall, he allowed for evaporation, he made an estimate of the area of the watershed of the Seine and the Marne, and compared the probable discharge, with that of the combined rivers when passing through Paris.

Having started this question of priority I proceed to deal with, and dispose of it. I have placed Sir Christopher first on the list, because I believe that he was first, but I have attached a ? to the entry because I have not actual proof.

Doubtless the tables which I have prepared have faults. They are virtually challenges to the meteorologists of all countries, to prove, if they can, that they are entitled to higher positions than I have awarded to them; and although I have taken pains to do justice to all, I include the tables in the paper that they may be corrected if, and where, they need it.

The first table gives a list of all rain-records commenced before 1700, viz.:

Country.	City or Place.	Observer.	Date.
? England,	London,	Sir Christopher Wren.	1662 ?
France,	Paris,	P. Perrault.	1668.
,,	Dijon,		1674 ?
England,	Townley, Lancashire,	R. Townley.	1677.
France,	Paris,	Sédileau.	1688.
,,	Lille,	Vauban.	1689.
England,	Gresham College, London,	R. Hooke.	1695.
,,	Upminster, Essex,	Rev. W. Derham.	1697.

In the next table I have had to deal not merely with meteorology, but with politics. The map of Europe, and of the World, is not the same now as it was 224 years ago, and this has caused some difficulty in forming a list of the countries of the world, in the order of date of first systematic record of rainfall—which is what I have tried to compile. I do not think that the first five entries will be easily wrested from France, England, Italy, Switzerland, and Ireland respectively, but that very probably the entries of the later dates, *e.g.* for the nineteenth century, will require both modifications and additions.

Quarters.	Countries.	Towns.	Dates.
Europe	France	Paris	1668
,,	England	Townley	1677
,,	Italy	Pisa	1707
,,	Switzerland	Zürich	1708
,,	Ireland	Londonderry	1711
,,	Wurtemburg	Ulm	1712
,,	Holland	Leyden	1717
,,	Prussia	Breslau	1717
,,	Scotland	Edinburgh	1731
,,	Russia	St. Petersburg	1738
North America	South Carolina	Charleston	1738
Europe	Sweden	Upsala	1739
Africa	Madeira	Funchal	1747
West Indies	Antigua	———	1751
,,	Martinique.	St. Pierre	1751
,,	St. Domingo	Haïti	1761
Europe	Austria	Kremsmünster	1763
,,	Norway	Bergen	1765
,,	Denmark	Copenhagen	1769
Asia	Madras	Madras	1777
Europe	Belgium	Brussels	1779
,,	Spain	Barcelona	1780
West Indies	Guadaloupe	La Point à Pitre	1782
Europe	Portugal	Lisbon	1783
Asia	Bengal	Calcutta	1784
Africa	Mauritius	Port Louis	1786
South America	French Guiana	Cayenne	1788
West Indies	Cuba	Havanah	1811
Asia	China	Canton	1812
Europe	Bavaria	Baireuth	1814
Asia	Bombay	Bombay	1817
Europe	Baden	Freiburg	1817
Africa	Réunion	St. Denis	1818
,,	Sierra Leone	Freetown	1819
South America	Brazil	S. L. de Maranhao	1821
West Indies	St. Vincent	Langley Park	1822

Quarters.	Countries.	Towns.	Dates.
North America	Mexico	Vera Cruz	1822
Asia	Burmah	Moulmein	1828
Europe	Iceland	Reikavik	1829
Africa	Guinea	Christiansborg	1829
South America	British Guiana	Georgetown	1831
Asia	Ceylon	Kandy	1833
Africa	Egypt	Cairo	1835
,,	Algeria	Algiers	1838
,,	Constantine	Constantine	1838
Australia	South Australia	Adelaide	1839
,,	Victoria	Melbourne	1840
,,	Tasmania	Hobart	1841
Asia	Java	Buitenzorg	1841
Africa	Oran	Oran	1841
West Indies	St. Thomas	———	1842
Oceania	Tahiti	Papéiti	1846
West Indies	Barbados	Husbands	1847
Africa	Senegal	St. Louis	1848
South America	Chili	Santiago	1849
West Indies	Jamaica	Up Park Camp	1853
Asia	Persia	Ooroomiah	1853
Africa	Madagascar	Nossi-Bé	1855
South America	Venezuela	Caracas	1860
Oceania	New Caledonia	Noumea	1860
Europe	Roumania	Bucharest	1862
South America	British Honduras	Belize	1862
West Indies	Sombrero	———	1863
Asia	Cochin China	Saïgon	1864
West Indies	Porto Rico	St. John's	1868
South America	Peru	Lima	1869

Early Rain Gauges.

I have not been able to find any details respecting the gauges used in Paris by Perrault in 1668, but that at Dijon in 1674 is stated by Mariotte to have been :—

"Un vaisseau quarré qui avoit environ deux pieds de diamètre, au fond duquel il y avait un tuyau qui portoit l'eau de la pluie qui y tomboit dans un vaisseau cylindrique."

As regards the first English observations, those made at Townley, near Burnley in Lancashire, in 1677, it would have been very interesting to give a drawing of the gauge, but as no engraving exists, we must be content with Mr. Townley's description, which is as follows :—"I fixed a round tunnel of 12 inches diameter to a leaden pipe which could admit of no water, but what came through the tunnel, by reason of a part soldered to the tunnel itself, which went over the pipe, and served also to fix it to it, as well as to keep out any wet that in stormy weather might beat against the under part of the tunnel; which was so placed, that there was no building near it that would give occasion to suspect that it did not receive its due proportion of rain that fell through the pipe some nine yards perpendicularly, and then was bent into a window near my chamber, under which convenient vessels were placed to receive what fell into the tunnel; which I measured by a cylindrical glass, at a certain mark containing just a pound, or 12 ounces troy, and had marks for smaller parts also."

In this description there are a few points to be noticed: (1) that Mr. Townley was careful not merely that his tunnel was firmly fixed (I have known modern observers have theirs blown away), but also that no rain could trickle down the outside of the funnel and find its way down for measurement (as has subsequently occurred). On the other hand, Mr. Townley, like most early observers, was wrong in putting the tunnel on the roof of his house; many persons would imagine that in the 27 feet of pipe there would be evaporation and loss, but from actual measurements of a similarly mounted gauge I have found this error to be almost imperceptible.

The next earliest gauge of which I have details was that used at Gresham College, London, in 1695; this is shown in Fig. 1. There is a wooden frame to support the glasses (the funnel was apparently of glass), a large bottle called a bolt-head with a neck 20 inches long, and capable of holding above two gallons. The funnel was 11·4 inches in diameter, and steadied by two stays or pack threads strained by two pins to hold the tunnel steady against the high winds. The pipe of the tunnel being no wider than ½ of an inch, the evaporation could be but little.

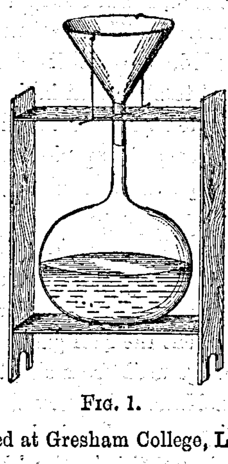

Fig. 1.

Rain Gauge used at Gresham College, London, in 1695.

The collected water was weighed every Monday morning in pounds, ounces and grains troy, and the amount was printed in that form, but the total was converted into, and printed as, the vertical depth which had fallen, viz. from August 12, 1695, to the same date in 1696, 131 lbs. 7 oz. 113 grains, or 29·11 inches.

I am not sure about the pattern of gauge used by the Rev. Mr. Derham, F.R.S., at Upminster, from 1697, but believe that it was very similar to Mr. Townley's, and similarly mounted.

As early as 1722 a close approach was made (by the Rev. Mr. Horsley, of Widdrington, Northumberland) to the modern principle. The following is the description :—

"The weighing the water and reducing it from weight to depth seemed pretty troublesome, even when done in the easiest method: to remedy this inconvenience (besides a funnel and proper receptacle for the rain) I use a cylindrical measure and gauge. The funnel is 30 inches in diameter, and the cylindrical measure exactly 3 inches, the depth of the measure is 10 inches, and the gauge of the same length with each inch divided into 10 equal parts; or, instead of a gauge, the inches and divisions may be marked on the side of the cylindrical measure. The apparatus is simple and plain, and it is easy to apprehend the design and reason of the contrivance; for the diameter of the cylindrical measure being just $\frac{1}{10}$ of that of the funnel, and the measure exactly 10 inches deep, 'tis plain that 10 measures of rain make an inch in depth, one measure 0·1 inch, one inch on the gauge 0·01 inch, and $\frac{1}{10}$ of an inch on the gauge 0·001 inch. By this means the depth of any particular quantity which falls, may be set down with ease and exactness, and the whole at the end of each month or year may be summed up without trouble."

I notice, however, that in 1742 the observer at Rome, Abbot Didacus de Revillas, speaks of his gauge, which closely resembled Mr. Horsley's as "Dr. Halley's method," so that possibly Mr. Horsley was not, after all, the originator of the pattern of rain gauge which he described.

Dr. Jurin was among the first, if not the first person, to draw up a code of rules for meteorological observers. It is not necessary to describe the rain gauge which he recommended, because it closely resembled the one just described, but it may be well to state that he is among the earliest to refer to the measurement of snow. He says: "Sextima et ultima altitudinem pluviæ, vel nivis in aquam resolutæ, quæ post superiorem observationem deciderit, per digitos *Londinensis* et earum partes decimales metiatur."

Considerable though not very satisfactory information respecting rain gauges is given in Leupold's '*Theatrum Staticum*,' folio, Leipzig, 1726. He devotes two and a half pages of text, and nine engravings to rain gauges, but his engravings are diagrams rather than drawings, and with the exception of Fig. 2 do not represent the rain gauges precisely as used.

He describes the rain gauge used from about 1717 at numerous stations by members of the Breslau Natural History Society as a sharp-edged glass funnel about 4 inches in diameter and 8 inches deep, divided to indicate the weight of water fallen into it, not the depth which it represented.

In Fig. 2 he represents a square gauge of his own design, about 9 inches square, and of which the contents were to be measured in a glass tube. Except that the upper rim should be sharp, that taps are always undesirable as they leak, and that his glass tube should have been divided to show depth, not weight, there is nothing to complain of in this, which, be it remembered was described and engraved more than 150 years since.

Leupold next describes another gauge, a square funnel leading into two glass tubes, a terrible apparatus invented by M. Leutmann, but I hope never used. He then gives a sketch which contains the germ of what is (wrongly) known as Stutter's recording rain gauge, viz. a trough with a series of compartments driven by clockwork under the orifice of a funnel, so that by measuring the fall in each compartment one would get the quantity during the respective intervals.

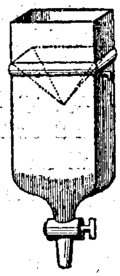

FIG. 2. Leupold's Rain Gauge.

Lastly, Leupold describes a second gauge of his own invention, which may be said to contain the germ of what is usually called Crosley's, and on the Continent (wrongly) Horner's. Leupold has under the point of his funnel a small bucket on one end of a balanced lever, when full it tips and empties, but in tipping turns a wheel one tooth, which carries a hand one division on a dial, and as there are four dials each 10 fold the other, the apparatus indicates up to 10,000 tips. There is an arrangement to prevent water passing out of the funnel while the emptying is in process. Leupold does not say that the instrument was ever tried.

In 1744 Mr. Pickering, F.R.S., proposed a gauge far inferior to that of Horsley (or Halley), and an engraving of it appears in the *Phil. Trans.* The funnel had an area of only one square inch; this led into a glass tube (of which in the engraving the diameter is exaggerated) ½ inch in diameter, and rather more than 2 feet long. In such a tube 1 inch of rain would stand about 5 inches deep, and Mr. Pickering says that he had each inch divided into 32 parts, the marks being lead pencil on white paint. He had this hung against the railings which went round the top of his house. I am not aware that any observations made with this gauge have been preserved.

I must not, however, dwell longer upon these antiquarian curiosities, but come down to modern times and try to point out the good and the bad features illustrated by the present Exhibition. I think that this will best be done by taking seriatim various features connected with rain gauges.

DIMENSIONS.

In the Exhibition we have a drawing of the largest rain gauge ever made (No. 121), and in (No. 15) almost the smallest—one being more than two thousand times as large as the other, and yet their indications do not differ by any thing like 5 per cent. Very large gauges by radiation become cool, and being cool condense some vapour which the soil or a small gauge would not; this makes them slightly exceed small ones. But in the experiments originated by Colonel Ward and subsequently continued with the same instruments by the Rev. C. H. Griffith and the Rev. F. W. Stow, it was proved that the difference between a gauge 1 inch in diameter[1] and one five hundred times its size was less than 2 per cent. Similar comparisons have been made elsewhere, both in this country and abroad, almost always, I believe, with the same result. This, however, does not prove that either very small or very large

[1] The smallest ever used.

gauges are desirable. With gauges less than 8 inches in diameter great care in measuring is necessary, because even one drop of water represents an appreciable depth of rain. With gauges exceeding 10 inches in diameter the volume of water to be measured becomes inconveniently large and heavy, *e.g.* in the large gauge at Rothamsted 1 inch of rain must weigh more than 2 cwt. That gauge excellently fulfils its object—the measurement of small falls, and the collection of water for analysis; but no one would suggest the general use of so formidable an apparatus.

Rims.

It was found out at a very early date that a rim round the funnel of a rain gauge was an improvement; and this is one of the points in which until a comparatively recent period there had been deterioration rather than progress. Among the gauges used in the eighteenth century (perhaps not so much in England as on the Continent) it was not at all unusual to surround the funnel with a vertical rim 6 inches high. In England, however, until the introduction of the Snowdon pattern gauge in 1864, the funnel nearly always reached *almost* to the top of the gauge. This was a pity, because if the funnel is not surrounded by a rim, if a fall of snow is accompanied by wind, hardly any of the snow will be left in the funnel; and I am afraid that most of the early English records are (for the winter months) too small, owing to insufficient attention to the measurement of snow.

I said just now *almost* to the top of the gauge, because, for nearly half a century, it has been the English practice, and is now nearly universal, that the actual top of the gauge shall be a turned brass rim. These rims deserve a word or two, because many observers buy rain gauges with bad rims. The objects of the rim are three: (1) by its solidity to keep the funnel in shape and prevent warping; (2) to define accurately the area within which rain drops are to be collected; (3) to cut any rain drop which falls upon it so that the true proportion of the drop shall go into the gauge for measurement, and the rest shall go away. As regards (1) solidity, any one can judge whether the rim is adequately firm. As regards (2) whoever verifies the gauge is responsible—and it will be a good day when the purchase of unverified gauges is abandoned. The third object is one which even opticians do not seem to understand. To cut a rain drop and send the two portions to their proper destinations a nearly vertical rim with an edge almost like that of a razor is necessary. There is a very fine specimen of what a rim should be on the gauge sent by Prof. Mascart (No. 38). See also Nos. 19 to 27. On the other hand, gauges Nos. 1, 2 and 4, which are old patterns kindly made specially for the Exhibition by Messrs. Negretti and Zambra, may be quoted as specimens of what rims should *not* be. A drop falling with driving rain on the sloping brass rim, and wholly outside of the true area of the gauge, will break into spray, and much of that spray will be blown into the gauge.

Weighing the Rain.

I have already mentioned that at Gresham College the rain was always weighed. At Townley, and at Upminster, and at many continental observatories, it was long the custom to report the rainfall by weight. I do not think that it was actually weighed, but that vessels were selected which held various fractions of a pound, and by pouring into them, the total weight was arrived at. Many of the older engravings indicate that each gauge had several measures of different sizes so as to be adapted to the amount to be measured. We have, however, seen that as early as 1722 Mr. Horsley had given up this roundabout process, and adopted a glass jar graduated in inches and decimals such as is in general use now. Weighing is now resorted to only when extreme accuracy is needed. A photograph of the Rotherham weighing machine forms exhibit No. 83.

Float Gauges.

I am not sure who first employed the rising of a float to indicate the fall of rain. I believe it is a British idea, and I do not remember having seen a float gauge on the Continent except in Breguet's Self-Recording Rain Gauge. A float was employed in a complicated gauge used at Gravesend by Mr. Kite in 1787, and three years later it seems to have been in general use, for in 1790 George Adams, Mathematical Instrument Maker to His Majesty, in "A short dissertation on the barometer, &c.," describes only one pattern of rain gauge, viz. a 12 inch contracted float; he points out the necessity for setting it to zero by putting in a little water, says that it was so arranged as to prevent evaporation, and that it was to be put in an open place where no house or other object could shelter it. In his list of prices it is marked 18s., his best Mountain Barometer being £9 9s. Further evidence in this direction is afforded by the fact that this pattern of gauge is the only one quoted in Cavallo's *Elements of Natural Philosophy*, 4 vols., 1803.

Float gauges may be divided into six classes, of which the features are: (1) uniform; (2) contracted; (3) rod attached; (4) rod detached; and as (3) or (4) may be adapted to either (1) or (2), we get the six possible varieties.

(1) Uniform, is represented in the exhibition by the small 3-inch Fleming gauge (No. 14), and it has feature (3), viz. the rod attached. This is very bad, especially with so small a gauge, because rain rarely falls vertically, and as the rain falls the float rises, and carries up the rod. Now, suppose that only 2½ inches of rain have fallen (and this gauge is supposed to hold ten or more inches), the rod will have risen 2½ inches above the rim, and if the rain is falling at an angle of 45° the rod will be intercepting rain, which, but for the rod, could not, and should not, be led into the gauge. Few persons would credit how serious this error is—I must, therefore, give some facts, on the authority of the *Report on the Supply of Surplus Water to Manchester, &c.* by S. C. Homersham, C.E., 1848.

In 1844 the Manchester Literary and Philosophical Society put on the hills east of the city some rain gauges which possessed the features (1) and

(3). It shortly afterwards occurred to Mr. J. Wood, who was resident engineer to the Peak Forest Canal, and near to whose residence one of these gauges was erected, that the rod must intercept much rain which ought to go over the gauge—so he had a gauge made with a cover to it, and a rod of the same size as that in the Society's gauge, *i.e.* ½ inch diameter and 12 inches long, standing up through a hole 1 inch diameter in the centre of the said cover. The water intercepted by the stick and running down it and passing through the hole in the cover amounted to

		Ins.
1845	...	21·95
1846	...	15·40
1847	...	22·48
Mean	...	19·94

Nearly 20 inches a year. I have been told, but cannot vouch for the fact, that these faulty gauges led the Corporation of Manchester to grant compens a n water far in excess of the proper amount, and which they had to buy off for £120,000.

(2) Contracted float gauges—of which Messrs. Negretti have kindly made a specimen (No. 2)—are unsafe in any country liable to frost, because the contained water, on freezing, bursts the cylinder—and as they were always made with (3) the rods attached, and their rods (owing to the contraction) rise two, three, four, or even five inches for each inch of rainfall, the error arising from these rods intercepting the rain was very serious. It is sometimes stated that these rods can be pegged or tied down—but that merely substitutes a lesser evil for the greater; if the rods are fastened down, the floats are immersed; and if the floats are immersed, the water surface is uncovered and liable to evaporation.

(4) Detached rods. Float gauges with detached rods are, in my opinion, very useful for monthly gauges, and for engineering work. If the rod is absent, it cannot be tampered with, and no one without the proper rod can read the gauge. The float nearly covers the water, and so checks evaporation. The gauge being long is sunk deep into the ground where the water is not liable to be frozen, and the gauge will hold a large quantity. If it be desired to have records true to $\frac{1}{20}$th of an inch, all that is requisite is to contract the inner cylinder as in No. 24.

Side Tube Gauges.

We have in No. 1 a fine specimen of a pattern of rain gauge, introduced by Mr. Simms (of the firm of Troughton and Simms) in 1835, but now happily rejected. It was handy, and handsome, and if one could find a locality of which the temperature never fell below 40° or rose above 60°, a gauge of that sort would give tolerable results. It would show too little, because it is arranged to stand about 5 feet above the ground, where it would collect about 3 per cent. less than if its funnel were at the regular height of 1 ft. That, however, is its least fault. In hot weather the water in it becomes scaldingly hot and evaporates accordingly, and in winter the water freezes and bursts both the copper body and the glass tube. Add to that the fact that taps soon corrode and begin to drip, and it will be sufficiently evident why I say that it is a pattern to be avoided.

I ought here to refer to the continental, or perhaps I should have said, French variety of this gauge. In its early form there was no contraction, the water therefore simply rose in the tube according to the rainfall, an inch for an inch. I never saw a gauge of this pattern, but it was engraved in Pouillet's *Elemens de Physique* in 1832, and has been copied into similar works *ad nauseam*. This copying, however, has one advantage, it indicates plainly what a large proportion of most treatises on Physics consists of repetition; but that is a digression. The modern French modification of this gauge is shown in No. 39, which must be very trying to those who use it during driving snow storms. The lamp, to prevent the water in the body from freezing, must be kept alight in spite of the wind; it must give heat enough to warm the body and melt the snow, and yet not enough to send off the melted snow as vapour. Moreover it holds very little, and if it overflows the record is lost. No. 38 is a far more trustworthy gauge.

Howard's Gauges and Modifications thereof.

Howard's 5-inch funnel, bottle, and measure, are so well known that it seems almost heresy to suggest that it was not wholly original, but really there is not much room for absolute originality in a rain gauge. Dr. John Dalton, F.R.S., in his *Meteorological Observations*, 1788, does not give full details as to his rain gauge, but I think that it was a 10-inch diameter circular funnel leading into a glass bottle, and the measurement by a jar, just such as we use now. Dr. Garnett also (*Trans. R. I. Acad.* V. (1724) p. 257) used a funnel, bottle, and jar, and he represents his funnel as provided with an "umbrella," *i.e.* a shield to prevent rain on the *outside* of the funnel running down into the bottle and being measured. To Howard, however, I think that we are indebted for two features, of which one was entirely new, viz. the turning of the brass rim so as to ensure great accuracy as to size and shape, and also for directing attention to the importance of the horizontality of the funnel. As regards the modifications, they are set out clearly in the Catalogue Nos. 6 to 10, and 21 and 22, and therefore need not be dealt with here.

Taps.

I do not know that taps are made better on the Continent than they are in England, or that continental climate has less effect upon out-of-door taps than is the case in England, but if neither of these conditions are true, it is difficult to understand the frequent use of taps in foreign rain gauges. In this country, after four or five years' exposure to the weather, a tap nearly always begins to drip. Are continental taps better? or do our continental friends regard the drip as trivial? I am very glad to see that Dr. Hellmann's latest pattern No. 43 has no tap, and Prof. Mascart's No. 38 has none. That almost looks as if the days of taps for rain gauges were drawing to an end.

Mechanical Gauges.

As already mentioned, the first rain gauge in which the collected rain water was utilised to register its amount was designed by Sir Christopher Wren; it was a wedge-shaped bucket which, when filled to a certain height, tipped and emptied itself.

In 1725 we have a very similar arrrangement shown in Leutmann's *Instrumenta Meteorognosiæ inserventia.*

About 100 years later, in 1827, Mr. J. Taylor[1] had a gauge made in which the water was led over a sort of water wheel with heliacal buckets; the increase of the weight of water in one bucket caused the wheel to turn until its weight became such that it passed from under the conducting tube and another took its place, each change causing a hand to advance one division over a clock-like dial.

In (or before) 1829 a gas meter maker named Crosley brought out a gauge with a modification of Sir Christopher Wren's bucket, and attached to it a train of wheels similar to those he used for gas meters, and thus we have the so-called Crosley rain gauge, of which we have three forms in the Exhibition, Nos. 30, 31 and 32. If every observer would do as one of the earliest purchasers of one (now long deceased) told me he did, Crosley gauges would not have so bad a character as they now have. My friend, the Rev. W. Steggall, of Thurston, Bury St. Edmunds, bought his Crosley gauge in 1833, and he arranged that on New Year's Eve every year a watchmaker from Bury St. Edmunds should go out to Thurston Vicarage, thoroughly clean and oil the gauge, and start it at zero for the new year, finishing up with a substantial supper and a drive back to Bury St. Edmunds. Modifications of Sir Christopher's tipping bucket enter into many patterns of self-recording rain gauges.

In (or about) 1830 this was followed by J. K. Horner's vibrating double bucket gauge, which is fully described and illustrated in Kämtz's *Lehrbüch der Meteorologie*, Vol. I. p. 412 it is nearly identical with Crosley's.

Self-Recording Rain Gauges.

I mention these only that it may not be assumed that I have forgotten them. It is, however, quite impossible to say in this paper anything useful upon a subject to which I have already devoted more than 30 pages of different volumes of *British Rainfall*, and to which nearly another 30 pages would require to be added.

Storm Rain Gauges.

These are I think dealt with sufficiently in the Catalogue. *See* Nos. 28 and 29.

Peculiar Rain Gauges.

One of the queerest rain gauges of which I have read was the De Witt gauge, of which a large number was distributed in the United States between

[1] *Phil. Mag.* Vol. II. p. 406.

1827 and 1840. As regards the State of New York, this led to the spoiling of all the rainfall work at the Academies, for when these gauges were issued the observers were told to continue their old gauges for comparison with the new ones. As far as appears from the published volume, not one of them either did that, or reported the date at which the De Witt gauge was taken into use. The De Witt gauge (first pattern) was simply a tin cone, 9 inches deep and 5 inches in diameter—it had no receiver—the water remained in the funnel (except what dried up); the funnel had no rim; we are not told how it was to be stuck up and kept level; a cone of this size would when brimful hold only 3 inches, and even with two inches a very large proportion would splash out: and the measurement was very funny, a stick was to be graduated (of course unequally) in accordance with an elaborate table, and this stick was to be plunged into the funnel with no arrangement to secure verticality, and with no correction for the displacement which the stick would produce. The second form of De Witt's gauge was even more comical. I do not know how its contents were to be measured, but it consisted of two funnels, one base upwards, as in his first pattern, the other a smaller cone, base downwards, and resting in the other cone. Anyone would be doing a service to students of American rainfall who made a list of all places to which De Witt's gauges were supplied, and of the years during which they were used.

A spherical gauge is, in my opinion, another eccentricity, for the use of which no good reason can be given, and yet so able a man as the late Dr. Robinson used one at Armagh Observatory for many years from about 1836, and Mr. J. Atkinson (whose rain map No. 102 is one of the rarest items in the Exhibition) tried one near Carlisle in 1840. I do not understand what advantage is aimed at: a ball nearly as large as the funnel was placed in it, like an egg in an egg-cup, but the outsplashing must be enormous, hail could never get in, and with snow, the whole thing would become ridiculous.

Staff gauges were another eccentricity, arising probably from Mr. Wood's experimental demonstration of the errors of float gauges with attached rods. I do not know whether he or Mr. Homersham was responsible for introducing them; the latter, however, in his *Report, &c.*, 1848, sets out the theory of the gauge, and shows that he did not understand it, because he calculates upon intercepting a strip of rain equal to half the *circumference* of his rod, whereas he would really obtain one equal to its *diameter*, which gives him an error of rather more than 50 per cent. to begin with—but in so wild a scheme that is perhaps a small portion of the total error. Possibly, I ought to give an idea of what the scheme was. A rod was to project vertically into the air, which rod passed, without touching, through a hole the sides of which were everywhere ¼ inch distant from it. The length and surface of the stick *plus* the area of the hole through which it passed were made equal to the area of a 9-inch horizontal mouthed gauge, viz. 63·61 inches. The calculations were:

Diameter of rod 2 inches; semi-circumference 3·142
Length of rod 18·75 inches
Surface of rod = 3·142 × 18·75 = 58·7
Area of aperture ... ... 4·9

Total area ... ... 63·6

But evidently for the semi-circumference he should have taken the diameter, and then his area would have come out 42·4 instead of 63·6 The whole idea is, however, based on the fallacy that the rain falls ?! horizontally. Assume a vertical rain, the area exposed is less than 5 inches, and the water falling on it is to be measured by a glass adapted to a gauge more than twelve times as large. Moreover what record would a staff gauge give of a hailstorm!