



XXV. On the hydrometer

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portion of inflammable air take fire at the electric shock, and produce those luminous and fiery meteors so astonishing to mankind; while those which contain less inflammable matter, but a greater quantity of the ferriferous principles, are formed into fire-balls or ferruginous stones of different magnitudes, which descend on the earth; whilst the more light, or those which are composed only of inflammable gases, mount into the upper regions of the atmosphere, where, taking fire, they fly off in luminous vapours. The height to which some of these vapours are carried before they are decomposed is amazing; reaching into regions where we should imagine the atmosphere would not be of sufficient density to sustain them. But the natural history of the terrestrial atmosphere has not yet been fully investigated; nor the power and effects of electricity in the formation of lithological, mineralogical, vegetable, and animal substances;—subjects that demand the attention of the most able chemists and sagacious philosophers.

Dublin,
Sept. 16, 1802.

XXV. *On the Hydrometer.* By WILLIAM SPEER, Esq.
Supervisor and Assayer of Spirits in the Port of Dublin.*

THE hydrometer, or areometer, as it is called, is an instrument which ascertains the density of liquids, weighing unequal masses with the same weight.

This instrument is of great antiquity, and until lately it was supposed to have been invented at the end of the fourth century, by Hypatia, the daughter of Theon, the celebrated mathematician of Alexandria: but M. Uebe Salverte, in a memoir on this subject, in the *Annales de Chimie*, vol. xxii. has demonstrated its having been invented by Archimedes three hundred years before the period in which Hypatia was born; and the very elegant Latin description he gives of this instrument, from an author of great antiquity, shows that, in the form, several of those now in use differ but little from that of the original invention.

This instrument, from the facility and expedition with which it may be applied, has long been in use for ascertaining the specific gravity of various kinds of liquids; but its application to the particular purpose to which it is now used is comparatively of modern date.

* Extracted from his "Enquiry into the Causes of the Errors and Irregularities which take place in ascertaining the Strengths of Spirituous Liquors, &c. London 1802."

Until within a period of about forty years, the strengths of spirituous liquors were mostly ascertained by other modes, both in Great Britain, Ireland, and on the Continent.

Proof by oil, by agitation, by firing gunpowder, by alkaline salts, and by glass bubbles, has been used, but in every case found defective; and the hydrometer was at length resorted to, as an instrument calculated to ascertain these strengths with less trouble and greater accuracy.

To obtain indications of strengths by it correctly, however, depends on circumstances that have not, until lately, been sufficiently understood or ascertained; on which account the instrument has been complicated in various ways, by weights and sliding rules: these, in some cases, have rather increased than diminished its irregularity.

The object of the following inquiry is therefore to bring into one view all the causes of those imperfections and irregularities, and, by so doing, to prepare the way for their removal.

Those irregularities have arisen from several causes. In the first place, when Clarke's hydrometer was constructed (forty years ago), the effects of expansion by heat, and contraction by cold, on the specific gravity of spirituous liquors, had not been accurately ascertained; nor was the diminution of bulk by penetration (or concentration, as it is improperly called,) well understood.

In this state of ignorance of these effects, Clarke's hydrometer was conceived to be a great improvement on that which had been in use before it. Precisely the same kind of advance in improvement had been made in the Irish hydrometer, somewhat nearly about the same period. The duty on spirits in both kingdoms previous to this time was paid only on two denominations, viz. single and double spirits: the former was proof, or under it, and the latter all such as were over proof; and this discrimination of strength was made either by a rude sort of instrument which hardly deserved the name of hydrometer, or by dropping oil into the spirit: if the oil floated, it was called single; if it sunk, it was double.

The present Irish hydrometer was adopted about two or three years after Clarke's hydrometer in England; both of which purporting to discriminate the increase of strength by *per centages**, so as to proportion the additional rate of duty

* As this term occurs frequently in the following essays, and may not, perhaps, be clearly understood by all my readers, it may not be amiss to explain it here:—A spirituous liquor is said to be ten per cent. over hydrometer proof when it is so strong that one hundred gallons of it will admit

to the relative increase of overproof, were considered great improvements; and though, from the construction of Clarke's hydrometer, it was evident that the variations occasioned by change of temperature were then *somewhat* known; yet in Ireland the effects of these variations were conceived so immaterial, and the numerous weights attached to this instrument, the difficulty of understanding it, the certain delay and probability of mistake, were considered to be so objectionable, that it was deemed better to use an hydrometer which paid no regard to temperature, than to use one liable to so many other objections. The variations by the ordinary change of temperature being, however, from one to fifteen *per cent.*, this defect in the construction of the Irish hydrometer is so manifest, that it is presumed it would be a waste of time to attempt any demonstration of its incompetency.

Although Clarke's hydrometer has not been constructed without a reference to temperature, yet this has been attended to only in part; and the instrument being otherwise very defective, it will be necessary to exhibit these defects, in order that they may be guarded against in such hydrometer as shall be adopted instead of it.

Till Clarke's hydrometer was adopted, which, from the best information I can obtain, took place about the year 1762, proof spirit was made by mixing equal portions of water and the strongest spirit which could be procured: but it being sometimes difficult to obtain this proof spirit for comparison, such a mixture was made by order of the honourable board of excise; and it was found, that when six gallons of it were mixed with one gallon of water, a wine gallon of the mixture weighed seven pounds thirteen ounces avoirdupois: the board therefore declared, that the spirituous liquor, of which the gallon weighed seven pounds thirteen ounces, should be reckoned one *to six*, or one *in seven under proof*.

This definition of proof was adopted in order to accord with a mode of examination which had been long in use, and sanctioned by the board.

The hydrometer said to be invented by Mr. Clarke * was
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admit an addition of ten gallons of water to reduce it to the strength of proof; and it is said to be ten per cent. under proof when one hundred gallons contain ten gallons of water more than proof contains.

* In 1772 the States of Languedoc offered a premium for the best memoir on the subject of ascertaining the strength of brandies. This premium was adjudged, by the Royal Society of France, to M. Bories, M. D. whose investigation and experiments on this difficult subject have, I humbly conceive, been surpassed only by those of the Royal Society in this country. Speaking of the various methods he had tried, he says: "*J'eus recours*

at this period brought forward, which having a set of weights corresponding to the above-mentioned mixture of water and proof spirit, and the mixture of one to six, or one in seven, being that only which weighed an exact number of pounds and ounces, without a fractional part, per gallon, by the statute of the 2d of George III. this obscure mode of ascertaining proof was adopted. At this time, the effects of heat and cold, on the trial of the strength of spirits by the hydrometer, had not been clearly understood; and though Clarke's hydrometer, which was then adopted, by having, in addition to the weights used for ascertaining the strengths of spirits, another set of weights called weather weights, adapted to several temperatures, is a demonstration that these effects were not altogether unknown; yet they were considered so immaterial as not to require the mention of temperature in the act of parliament. This omission has added considerably to the irregularities of the various hydrometers since in use, as by it the legal standard for proof is rendered very uncertain, and will, by the ordinary change of temperature, vary from five to six per cent.

I here beg leave to quote an observation of Sir Charles Blagden, from the Proceedings of the Royal Society in 1790, in his Report on the best Method of proportionating the Excise upon Spirituous Liquors made by Desire of Government:

“ By the act of 2d George III. it is ordered, that the gallon of brandy or spirits, of the strength of one to six under proof, shall be taken and reckoned at seven pounds thirteen ounces (which is understood by the trade to mean 55 of heat). Hence taking the weight of a gallon of water at the same heat to be 8 lb. 5 oz. and 66 parts, the specific gravity of this diluted spirit will be found 9335 at 60: this specific gravity indicates a mixture of 107 grains of water with 100 grains of pure spirit; whence, by a computation founded on the tables in this report, the specific gravity of proof spirit will come out 916: but the rules of correction belonging to Dicus and Quin's hydrometer give the specific gravity of proof spirits about 922, at 55, equivalent to 920, at 60. The former, 916, corresponds to a mixture of 100 parts of spirit with 62 by measure, or 75 by weight of water; and the latter, 920, to a mixture of 100 parts of spirit, and 66 by mea-

recours à la méthode de Fahrenheit: j'ai vu depuis, qu'elle avoit été mise en usage par M. Brisson. J'entends par cette méthode celle de l'aréomètre *invented* par Fahrenheit, et suivi par Clarke et Desaguliers.” He afterwards describes the instrument, and condemns it for its complications, and being improperly graduated: from this it would appear that this instrument was invented by Fahrenheit, and not by Clarke.

sure,

ture, or 80 by weight of water. The difference is considerable, but the first is undoubtedly most conformable to the existing acts of parliament: if, therefore, it be thought right to preserve the term *proof spirit* in our excise laws, it may be understood to mean spirit whose specific gravity is 916, and which is composed of 100 parts of rectified spirit at 825, and 62 parts of water, by measure, or 75 by weight; the whole at 60 degrees of heat."

From this extract it appears there are no less than three imperfections in this manner of defining proof spirits. First, the spirit defined is not proof, but another spirit, one *to fix*, or one *in feven*, under proof, requiring a subsequent process to make proof: secondly, the difficulty of procuring an exact gallon measure.

The late ingenious Mr. Ramsden, in a publication on this subject, printed in 1792, speaking of the standard of proof, says: "Hydrometer-makers differ on this point $7\frac{1}{2}$ per cent.; and government, to avoid disputes, have been under the necessity of passing an act to constitute Clarke's hydrometer (for a short time) the only legal one, though it is, in all probability, as vague as any of the others, particularly in spirits considerably higher than proof. An obstacle to ascertaining this term (says he) arises from the difficulty of obtaining *practically* the exact capacity of our gallon measure: it is, indeed, stated to contain 231 cubic inches; yet, notwithstanding the great pains taken by a committee of the house of commons, about the year 1758, for that purpose, assisted by several ingenious mechanics, this point was left undetermined. The method they used was making *hollow cubes* of different dimensions, from one inch upwards, which were executed with great care by the late Mr. J. Bird, and are now in the repository of the house of commons: but whoever considers the difficulty of making an exact cube, and that of ascertaining the inside calibre with precision, must be sensible that no great reliance can be had on the exactness of a gallon measure obtained by this method."

Thirdly, that no temperature being mentioned, the strength is doubtful; and though Sir Charles, in this part of his Report (which has not, I believe, been contradicted), says the trade considers the temperature to be 55, and that proof spirit should be as he states, by the unerring test of the specific gravity 916, at 60, (and which would be 918, at 55;) yet the specific gravity of proof spirit, by Clarke's hydrometer, is 924, at 55 of temperature.

From this it appears, that even Quin's and Dica's standards of proof are erroneous to an extent of three per cent.; and

and that Clarke's is nearly four and a half different from the strength prescribed by the statute: this is supposing the temperature to be what Mr Charles says it is considered by the trade.

In Ireland the standard of proof is still more uncertain, no definition of it whatever appearing on the statute, but resting solely on the practice which prevailed in England prior to the 2d of his present majesty, viz. mixing water with an equal portion of rectified spirits of wine, as it is called, no specific gravity of the spirit mentioned, and the spirit, called rectified spirit of wine, differing materially in point of strength: neither has the temperature been attended to, the hydrometer there having no thermometer attached to it: the standard of proof has consequently become just what the maker of the Irish hydrometer pleased: the generally received opinion, however, supposes it to be nine per cent. over English hydrometer proof.

Two material imperfections appear in Clarke's hydrometer, exclusive of its complexity; namely, that neither variations of temperature, nor the gradations of strengths, have been sufficiently attended to: with respect to the former of these, the same weather-weight (as it is called by the trade) is used, though the temperature should vary four or five degrees.

The inventor, foreseeing that this was liable to weighty objections, conceives he has guarded against it by the direction he gives in a N. B.: but this N. B., so far from removing doubts, only serves to increase them; the words *about* and *near* leaving room for much to be guessed at, and much more to be apprehended, where the important points it alludes to are so loosely and indistinctly defined.

May I be permitted in this place to explain the consequences of this mode of including four or five degrees of temperature to be indicated by the same weight, by stating a case that has frequently occurred?—A merchant in Ireland ships for London a quantity of spirit, and previous to its shipment examines the strength by Clarke's hydrometer: he adjusts the strength to be somewhat less than 10 per cent. (suppose 9 $\frac{1}{2}$) over hydrometer proof, the strength allowed to be importable without an augmentation duty: this spirit is per specific gravity 910, temperature 55. Suppose it to be arrived in London, but the temperature is then 60; notwithstanding this increase of temperature (of 5 degrees) the same weather-weight continues to be used in trying the strength in England which was applied in Ireland: by this increase of temperature, the specific gravity being diminished to 907ths, when it comes to be proved in London, by the same hydrometer,

meter, it then appears to be full one and a half per cent. stronger than when it was shipped, and will now be found to be 11 per cent. over proof. Should this spirit be a foreign one, viz. brandy or geneva, it must pay the entire augmentation duty of 11 per cent.; whereas, if the temperature was sufficiently discriminated, it should have paid no augmentation duty whatever.

That this case is not merely a supposition, is, I believe, well known to several respectable merchants in London, to whom consignments of foreign spirits have been made from Ireland, and who, in several instances, have been obliged to pay this augmentation duty of 11 per cent. Here, therefore, the instrument proves its own errors; nor can additional weights remedy it.

The principle on which it is constructed supposes that the ratio of expansion by heat is the same in strong as in weak spirits; the same weight for temperature is therefore applied to both: this is totally erroneous, and is demonstrable thus:

Suppose a weak spirit to be tried, the specific gravity of which, at the temperature of 35, is 960.48, let the temperature be increased to 70, the specific gravity will be 948.13; the diminution, consequently, is 12.35.

Suppose next, the spirit under trial to be a strong one, and is per specific gravity at 35, 843.49; increase the temperature, as in the first, to 70, the specific gravity will be only 827.01: diminution in this spirit 16.48; *difference* in the ratio of expansion 4.13; this difference making full three per cent. by the hydrometer, and thus demonstrating a radical defect in the instrument which *cannot be cured by additional weights*.

The spirituous liquors of commerce being mixtures of pure spirit and water, and the value of this, and the duty to be paid on it, depending on the quantities of the former which are contained in the mixture, it becomes necessary to ascertain the proportion in which it enters into every such mixture.

The easiest and most expeditious mode of ascertaining this is by an hydrometer, which acts on the following well-known principles of hydrostatics.

A solid body descends in a liquid, because it is heavier than an equal bulk of the liquid: and it descends with a force or weight equal to the excess of its own weight, over the weight of an equal bulk of the liquid; or, if it be lighter than an equal bulk of the liquid, it ascends with a force proportioned to the difference of weights; but if it be of the same weight as an equal bulk of the liquid, it will remain where it is placed.

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Hence it is evident that every variation of gravity in the liquid will affect the indication on the hydrometer.

This gravity is known by the term *specific gravity*; and as the specific gravity of liquids is not absolute, but relative, this can only be determined by comparison: the first operation, therefore, consists in getting one whose absolute weight is known, in order to serve as a fixed point, and to determine, in its turn, a comparison of the density of the liquid. Pure water having always been considered the best standard for this purpose, the term specific gravity is most readily defined, by saying, that it is as the weight of the liquid is comparatively with pure water: for instance, if a phial, which holds precisely 1000 grains of water, holds only 922 grains of a spirituous liquor, the specific gravity of this spirit is said to be 922.

But as spirits expand by heat, and contract by cold, this specific gravity varies according to the degree of the heat of the liquor, which is called its temperature: therefore it is necessary first to ascertain what that may be, and it is done very accurately by the thermometer. And in the experiment mentioned, supposing the temperature to have been 55, if the spirit be heated to 70, the specific gravity will be diminished to $915\frac{1}{2}$; and, if afterwards it be cooled down to 35 degrees of temperature, it will be found to have increased to $930\frac{1}{4}$.

This is a very convenient manner of trying and expressing what the specific gravity of the liquor may be; and as I shall hereafter have occasion to use the term frequently, I hope I shall be excused for explaining it in this place.

All the variations of the specific gravity of spirituous liquors, and the causes of them, may be comprised under the following heads, viz.

1st, Those arising from heat and cold: 2^{dly}, A difference in the proportions of the spirit and water: and, 3^{dly}, The effects of penetration (or, as it is called, concentration), which takes place on the mixture; all of which, being so clearly defined by sir Charles Blagden, in his Report on this subject, in the second part of the 80th volume of the Transactions of the Royal Society, I shall beg leave to give it in his words, and lament that the proposed limits of this work will not permit me to give the entire Report, every paragraph of which I conceive to be important, and demonstrates the difficulties with which this subject is enveloped, and very clearly points out the way to remove them.

“ Though (says sir Charles) various indications of the strengths

strengths of spirituous liquors have been devised, applicable in a gross manner to a general use, it is well known that no method admits of real accuracy but that of the specific gravity. The weights of an equal bulk of water and pure spirit differ from one another by at least a sixth part of the weight of the former; whence it is obvious, that when those two fluids are mixed together, the compound must have some intermediate specific gravity, approaching nearer to that of water or pure spirit, as the former or the latter is the more predominant ingredient.

“ Were it not for a certain effect attending the mixture of water and spirit, which has been called their mutual penetration, the specific gravity of these compositions, in a given degree of heat, would be simply in the arithmetical proportions of the quantity of each of the fluids entering into them.

“ But whenever different substances, which have a strong tendency to unite together, are mixed, the resulting compound is found to occupy less space than the substances forming it held in their separate state; wherefore the specific gravity of such compounds is always greater than would be given by a simple calculation from the volume of their ingredients. Though it be a general fact, that such a decrease of bulk takes place on the mixture of substances which have a chemical attraction for each other; yet the quantity of this diminution is different in them all, and, under our present ignorance of the intimate composition of bodies, can be determined by experiment only. To ascertain, therefore, the quantity and law of the condensation resulting from this mutual penetration of water and spirit, was the first object to which the following experiments were directed.

“ All bodies, in general, expand by heat: but the quantity of this expansion, as well as the law of its progression, are probably not the same in any two substances. In water and spirit they are remarkably different. The whole expansion of pure spirit, from 30° to 100° of Fahrenheit's thermometer, is not less than $\frac{1}{25}$ th of its whole bulk at 30° ; whereas that of water, in the same interval, is only $\frac{1}{145}$ th of its bulk. The laws of their expansion are still more different than the quantities. If the expansion of quicksilver be, as usual, taken from the standard (our thermometers being constructed with that fluid), the expansion of spirit is, indeed, progressively increasing with respect to that standard, but not much so within the above-mentioned interval; whilst water kept from freezing to 30° , which may easily be done, will absolutely contract as it is heated, for ten or more degrees,

degrees, that is, to 40° or 42° of the thermometer, and will then begin to expand as its heat is augmented, at first slowly, and afterwards gradually more rapidly, so as to observe upon the whole a very increasing progression.

“Now mixtures of these two substances will, as may be supposed, approach to the less or the greater of those progressions, according as they are compounded of more spirit or more water; whilst their total expansion will be greater according as more spirit enters into their composition: but the exact quantity of the expansion, as well as the law of the progression, in all of them, can be determined only by trials. These were therefore the two other principal objects to be ascertained by experiment.” Sir Charles then proceeds to describe those various experiments, and which are too long to admit an insertion of them here; but from a perusal it will be perceived they were conducted with a degree of patient inquiry, minuteness of attention, and accuracy of investigation, seldom to be met with, and which, with the calculations grounded on them by Mr. Gilpin, clerk of the society, and published in the Transactions for 1794, have removed those obscurities with which the subject had heretofore been enveloped.

These celebrated experiments, and the table deduced from them, have been minutely examined by several of the ablest philosophers in France and various other parts of the continent, and they are allowed to be what Mr. Nicholson (who has also minutely examined them), in his Chemical Dictionary, says, may be considered as fundamental results; and it is somewhat remarkable that, since their publication in 1794, no person has hitherto availed himself of the important information they contain, as a foundation for putting a period to those irregularities and uncertainties which have been so long and so universally complained of.

That hydrometers should be complicated in their structures, and erroneous in their indications, previous to this period, is not to be wondered at.

The specific gravity of the spirit, which is the foundation of the hydrometer indication, was but little attended to; and those variations which take place in the specific gravity, through the several causes above mentioned, having never before that period been precisely ascertained, hydrometers, instead of being graduated by this unerring test, have been graduated by comparison with another instrument, called a standard, but no means have been pointed out to prove that this standard was correct.

These tables of Mr. Gilpin, however, furnish such elemen-

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tary information as has enabled me, by the addition of four columns, to remove all doubts and uncertainties on the subject, by demonstrating, from the specific gravity of the spirituous liquor, what the hydrometer indications should be of every gradation of strength.

In the Report, which accompanies these tables, sir Charles Blagden makes an observation which first suggested to me the utility of these additional columns.

“It may very probably be thought right (says he), for the future use of the revenue, to compute another set of tables, in which the degrees of heat standing at the head of each table, the first column of it shall be even numbers of specific gravity. This would be proper for looking out at once the quantities of spirit and water in a mixture from its heat and specific gravity.”

Sir Charles, by this observation, alludes not to the means of obtaining the hydrometer indication, but to an opinion he had given in his first Report, in 1790, that the simplest and the most equitable way of levying the duty on spirituous liquors would be to consider pure spirit as the true and only excisable matter, instead of the relation to the standard of proof, and for calculating which one column of the table is a decimal multiplier, to ascertain the proportion of this in any given quantity of a spirituous liquor; an idea which certainly is ingenious, and, at first view, appears to have the recommendation of simplicity: but as every discrimination of strength would require an operation of figures, fractions would unavoidably occur, from which, and the delay and danger of errors in these operations, this mode, I conceived, had been considered practically inconvenient, and therefore was not adopted.

The relation to the standard of proof having been long recognized by the different statutes, and in commerce, I thought it probable it would not be laid aside; nor was it, as I conceived, necessary to do so when a means presented itself of rendering this relation to proof equally correct as that which he pointed out: and the new set of tables, which at first I apprehended he was about to describe as useful for the revenue, were those which would deduce the hydrometer indication of strength from the specific gravity of the spirit at a given temperature. A table for this purpose would, I conceived, be importantly useful on several accounts: 1st, it would afford a mode of graduating an hydrometer on a certain principle; and, 2dly, that as it furnished a standard for every gradation of strength, errors could be discovered in those instruments that have been graduated by the delusive mode of

comparison, many of whose discriminations of strength being, as I had reason to believe, merely conjectural.

Before I proceed to explain Mr. Gilpin's tables, and the columns added to them, it becomes necessary to define what is meant by the term *pure spirit*, and to inquire whether the spirit which sir Charles describes can with propriety be called such.

"The first step (says he, in the Report made on this subject in 1790) towards a right performance of the experiments, was to procure the two substances with which they were to be made, as pure as possible. Distilled water is in all cases so nearly alike, that no difficulty occurred with regard to it; but the specific gravity of pure spirit, or alcohol, has been given so very differently by the authors who have treated of it, that a particular set of experiments appeared necessary for determining to what degree of strength rectified spirit could conveniently be brought. The person engaged to make these experiments was Dr. Dollfus, an ingenious Swiss gentleman, then in London, who had distinguished himself by several publications on chemical subjects. Dr. Dollfus, having been furnished by government with spirit for the purpose, rectified it, by repeated and slow distillations, till its specific gravity became stationary in this manner of operating: he then added dry caustic alkali to it, let it stand for a few days, poured off the liquor, and distilled it with a small addition of burnt alum, placing the receiver in ice. By this method he obtained a spirit whose specific gravity was 8188, at 60 of heat. Perceiving, however, that he could not conveniently get the quantity of spirit he wanted lighter than 82527, at 60, he fixed upon that strength as a standard.

Several highly respectable authorities might be produced to prove this specific gravity to be a proper standard for *pure spirit*.

[To be continued.]

XXVI. *A short Account of the Mammoth.* By Mr. REMBRANDT PEALE*.

THE mammoth is so called from the Russian name, supposed to have been derived from the Hebrew *Behemoth*, Job, chap. xl. It is properly continued, both words being expressive of a large and extraordinary animal.

For a number of years past many large and extraordinary

* Communicated by the Author.