

precipitates for those substances with barium or platinum chloride. Its behaviour with nitrous acid is interesting. Upon adding to an acid solution of sulphuryl diamide a few drops of the solution of a nitrite nitrogen is at once evolved, in the cold, and sulphuric acid is formed.

Sulphuryl diamide does not combine with acids. Alkalies appear to be only capable of removing one amido group, converting the diamide into sulphamic acid, $\text{SO}_2(\text{NH}_2)(\text{OH})$.

As described in the course of the preparation of sulphuryl diamide, ammonia precipitates from a solution mixed with silver nitrate a silver compound. If the precipitate is allowed to remain in contact with the excess of the reagents for some time, it invariably yields numbers upon analysis which agree with the formula $\text{SO}_2(\text{NHAg})_2$. If, however, it is at once separated, it is found to consist of a mixture of this salt with the salt $\text{SO}_2(\text{NH}_2)(\text{NHAg})$.

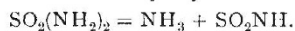
These silver compounds of sulphuryl diamide are amorphous, even after deposition from solution in hot water. When dry they are white powders very slightly sensitive to light. Upon heating to 200° they decompose with evolution of sulphur dioxide.

Sulphuryl diamide likewise forms a compound with mercuric oxide when its solution is mixed with one of mercuric nitrate. The composition of this precipitate, however, appears to vary with the degree of concentration of the solutions employed, and if chlorides are present a precipitate is only obtained with a very large excess of mercuric nitrate. Mercuric chloride produces no precipitate at all.

A somewhat similar lead compound is also formed when lead acetate is added to a moderately concentrated solution of sulphuryl diamide.

Sulphuryl Imide.

As previously mentioned, when sulphuryl diamide is heated for a considerable time above its melting-point it loses ammonia and becomes converted into sulphuryl imide :



The best temperature for the rapid production of sulphuryl imide is 200° - 210° . The evolution of ammonia at this temperature is very vigorous, occurring with much frothing, but after a time diminishes and finally ceases, the mass becoming eventually solid. To purify it from impurities the solution in water is treated with a solution of silver nitrate when the silver compound of sulphuryl imide, SO_2NAg , is precipitated, and may be recrystallised in long acicular crystals, first from water slightly acidified with nitric acid, and finally from pure water.

Upon decomposing the silver compound with the calculated quantity of dilute hydrochloric acid an aqueous solution of free sulphuryl imide is obtained, which reacts strongly acid, and liberates carbon dioxide from carbonates. Upon evaporation, however, it decomposes, and deposits hydrogen ammonium sulphate. Even evaporation *in vacuo* is sufficient to decompose it, so that crystals of the imide itself have not been obtained. It exists, however, in the solid form, although somewhat contaminated with smaller quantities of other products, in the residue obtained by heating sulphuryl diamide as previously described.

Salts of sulphuryl imide, however, are readily obtained, either by decomposition of the silver salt with metallic chlorides, or by the neutralisation of solutions of sulphuryl imide with metallic oxides or carbonates.

The potassium salt, SO_2NK , was obtained in the form of well-developed colourless crystals by adding a quantity of the silver salt to a hot solution of the calculated quantity of potassium chloride, removing the precipitated silver chloride by filtration, and evaporating the solution. Both the solution and the salt are very stable; it requires long boiling with acids to convert it into sulphuric acid. When the dry salt is heated it decomposes with considerable violence and production of flame. Nitrogen and sulphur dioxide escape, and potassium sulphate and sulphide are left.

The sodium salt, SO_2NNa , obtained by neutralising a solution of sulphuryl imide with caustic soda and subsequent evaporation, forms small crystals, which decompose upon heating in a manner similar to the crystals of the potassium salt.

The ammonium salt, SO_2NNH_4 , isomeric with sulphuryl diamide, was likewise obtained in colourless needles by neutralisation of the free imide with ammonia. It is interesting to note that this substance is not capable of being converted into its isomer by repeated crystallisation, but is partially so con-

verted by rapidly heating it to its melting-point over a small gas flame.

Acicular crystals of a hydrated barium salt, $(\text{SO}_2\text{N})_2\text{Ba} \cdot 2\text{H}_2\text{O}$, have been obtained by saturating a solution of the imide with barium carbonate and afterwards adding alcohol; also needles of a lead salt and a green amorphous copper salt.

The acid character of sulphuryl imide, so different from the neutral nature of sulphuryl diamide, is thus seen to be quite conclusively established.

A. E. TUTTON.

THE DENSITIES OF THE PRINCIPAL GASES.¹

IN former communications ("Roy. Soc. Proc.," February, 1888; February, 1892) I have described the arrangements by which I determined the ratio of densities of oxygen and hydrogen (15'882). For the purpose of that work it was not necessary to know with precision the actual volume of gas weighed, nor even the pressure at which the containing vessel was filled. But I was desirous before leaving the subject of ascertaining not merely the relative, but also the absolute, densities of the more important gases—that is, of comparing their weights with that of an equal volume of water: To effect this it was necessary to weigh the globe used to contain the gases when charged with water, an operation not quite so simple as at first sight it appears. And, further, in the corresponding work upon the gases, a precise absolute specification is required of the temperature and pressure at which a filling takes place. To render the former weighings available for this purpose, it would be necessary to determine the errors of the barometers then employed. There would, perhaps, be no great difficulty in doing this, but I was of opinion that it would be an improvement to use a manometer in direct connection with the globe, without the intervention of the atmosphere. With respect to temperature, also, it was thought better to avoid all further questions by surrounding the globe with ice, as in Regnault's original determinations.

The Manometer.

The arrangements adopted for the measurement of pressure must be described in some detail, as they offer several points of novelty.

The object in view was to avoid certain defects to which ordinary barometers are liable, when applied to absolute measurements. Of these three especially may be formulated:—

(a) It is difficult to be sure that the vacuum at the top of the mercury is suitable for the purpose.

(b) No measurements of a length can be regarded as satisfactory in which different methods of reading are used for the two extremities.

(c) There is necessarily some uncertainty due to irregular refraction by the walls of the tube. The apparent level of the mercury may deviate from the real position.

(d) To the above may be added that the accurate observation of the barometer, as used by Regnault and most of his successors, requires the use of a cathetometer, an expensive and not always satisfactory instrument.

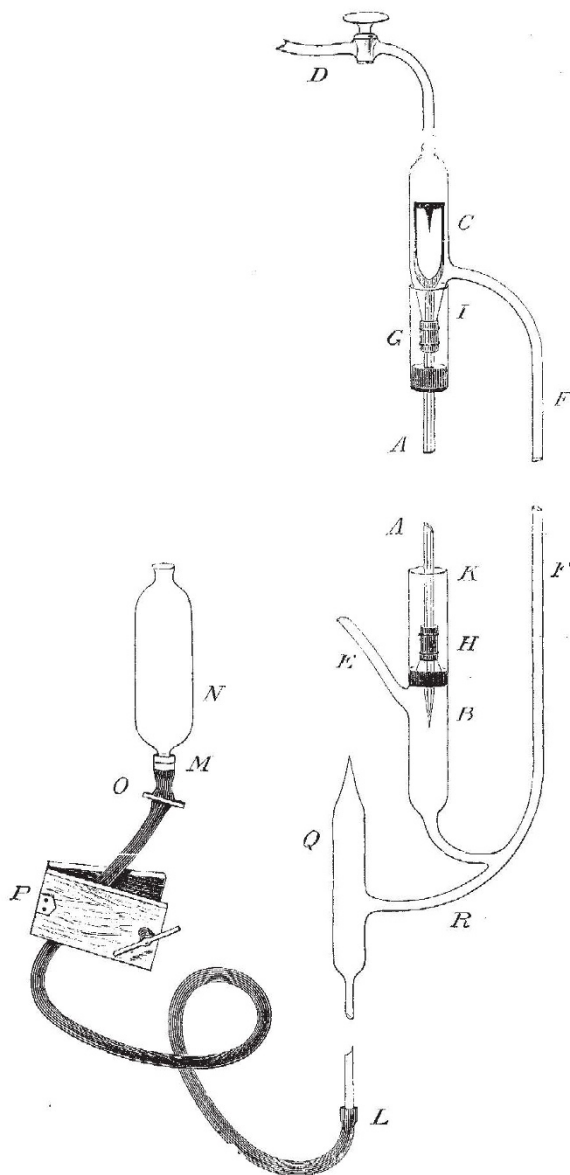
The guiding idea of the present apparatus is the actual application of a measuring rod to the upper and lower mercury surfaces, arranged so as to be vertically superposed. The rod AA, fig. 1, is of iron (7 mm. in diameter), pointed below B. At the upper end, C, it divides at the level of the mercury into a sort of fork, and terminates in a point similar to that at B, and, like it, directed downwards. The coincidence of these points with their images reflected in the mercury surfaces, is observed with the aid of lenses of about 30 mm. focus, held in position upon the wooden framework of the apparatus. It is, of course, independent of any irregular refraction which the tube may exercise. The verticality of the line joining the points is tested without difficulty by a plumb-line.

The upper and lower chambers C, B are formed from tubing of the same diameter (about 21 mm. internal). The upper communicates through a tap, D, with the Töppler, by means of which a suitable vacuum can at any time be established and tested. In ordinary use, D stands permanently open, but its

¹ Abstract of a paper read by Lord Rayleigh before the Royal Society on March 23.

introduction was found useful in the preliminary arrangements and in testing for leaks. The connection between the lower chamber B and the vessel in which the pressure is to be verified takes place through a side tube, E.

The greater part of the column of mercury to which the pressure is due is contained in the connecting tube FF, of about 3 mm. internal diameter. The temperature is taken by a thermometer whose bulb is situated near the middle of FF. Towards the close of operations the more sensitive parts are protected by a packing of tow or cotton-wool, held in position between two wooden boards. The anterior board is provided



with a suitable glass window, through which the thermometer may be read.

It is an essential requirement of a manometer on the present plan that the measuring rod pass air-tight from the upper and lower chambers into the atmosphere. To effect this the glass tubing is drawn out until its internal diameter is not much greater than that of the rod. The joints are then made by short lengths of thick walled india-rubber H, G, wired on and drowned externally in mercury. The vessels for holding the mercury are shown at I, K.

The distance between the points of the rod is determined

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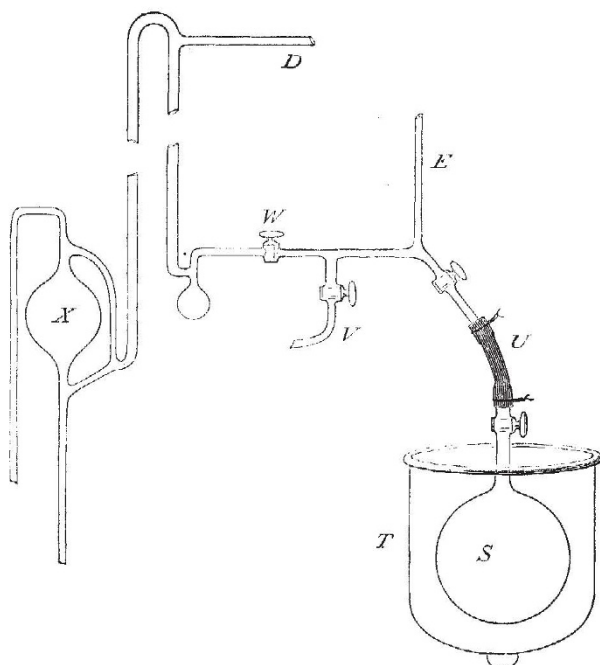
under microscopes by comparison with a standard scale, before the apparatus is put together. As the rod is held only by the rubber connexions, there is no fear of its length being altered by stress.

The adjustment of the mercury (distilled in a vacuum) to the right level is effected by means of the tube of black rubber LM, terminating in the reservoir N. When the supply of mercury to the manometer is a little short of what is needed, the connexion with the reservoir is cut off by a pinch-cock at O, and the fine adjustment is continued by squeezing the tube at P between a pair of hinged boards, gradually approximated by a screw. This plan, though apparently rough, worked perfectly, leaving nothing to be desired.

It remains to explain the object of the vessel shown at Q. In the early trials, when the rubber tube was connected directly to R, the gradual fouling of the mercury surface, which it seems impossible to avoid, threatened to interfere with the setting at B. By means of Q, the mercury can be discharged from the measuring chambers, and a fresh surface constituted at B as well as at C.

Connexions with Pump and Manometer.

Some of the details of the process of filling the globe with gas under standard conditions will be best described later under the head of the particular gas; but the general arrangement and



the connexions with the pump and the manometer are common to all. They are sketched in Fig. 2, in which S represents the globe, T the inverted bell-glass employed to contain the enveloping ice. The connexion with the rest of the apparatus is by a short tube U of thick rubber, carefully wired on. The tightness of these joints was always tested with the aid of the Töppler X, the tap V leading to the gas generating apparatus being closed. The side tube at D leads to the vacuum chamber of the manometer, while that at E leads to the pressure chamber B. The wash out of the tubes, and in some cases of the generator, was aided by the Töppler. When this operation was judged to be complete, V was again closed, and a good vacuum made in the parts still connected to the pump. W would then be closed, and the actual filling commenced by opening V, and finally the tap of the globe. The lower chamber of the manometer was now in connexion with the globe, and through a regulating tap (not shown) with the gas-generating apparatus. By means of the Töppler, the vacuum in the manometer could be carried to any desired point. But with respect to this a remark must be made. It is a feature of the method employed¹ that the exhaustions of

¹ Due to von Jolly.

the globe are carried to such a point that the weight of the residual gas may be neglected, thus eliminating errors due to a second manometer reading. There is no difficulty in attaining this result, but the delicacy of the Töppler employed as a gauge is so great that the residual gas still admits of tolerably accurate measurement. Now in exhausting the head of the manometer it would be easy to carry the process to a point much in excess of what is necessary in the case of the globe, but there is evidently no advantage in so doing. The best results will be obtained by carrying both exhaustions to the same degree of perfection.

The Water Contents of the Globe.

The globe being packed in finely-divided ice, was filled with boiled distilled water up to the level of the top of the channel through the plug of the tap, that is, being itself at 0°, was filled with water also at 0°. Thus charged the globe had now to be weighed; but this was a matter of some difficulty, owing to the very small capacity available above the tap. At about 9° there would be a risk of overflow. Of course the water could be retained by the addition of extra tubing, but this was a complication that it was desired to avoid. In February, 1882, during a frost, an opportunity was found to effect the weighing in a cold cellar at a temperature ranging from 4° to 7°. The weights required (on the same side of the balance as the globe and its supports) amounted to 0.1822 gram. On the other side were other weights whose values did not require to be known so long as they remained unmoved during the whole series of operations. Barometer (corrected) 758.9 mm.; temperature 6°.3.

A few days later the globe was discharged, dried, and replaced in the balance with tap open. 1834.1701 grams had now to be associated with it in order to obtain equilibrium. The difference,

$$1834.170 - 0.182 = 1833.988,$$

represents the weight of the water less that of the air displaced by it.

It remains to estimate the actual weight of the air displaced by the water under the above mentioned atmospheric conditions. It appears that, on this account, we are to add 2.314, thus obtaining

$$1836.30$$

as the weight of the water at 0° which fills the globe at 0°.

A further small correction is required to take account of the fact that the usual standard density is that of water at 4° and not at 0°. According to Broch (Everett's "C.G.S. System of Units"), the factor required is 0.99988, so that we have

$$\frac{1836.30}{0.99988} = 1836.52$$

as the weight of water at 4° which would fill the globe at 0°.

Air.

Air drawn from outside (in the country) was passed through a solution of potash. On leaving the regulating tap it traversed tubes filled with fragments of potash, and a long length of phosphoric anhydride, followed by a filter of glass wool. The arrangements beyond the regulating tap were the same for all the gases experimented upon.

In deducing the weight of the gas we compare each weighing "full" with the mean of the preceding and following weights "empty," except in the case of October 15, when there was no subsequent weighing empty. The results are

September 27	...	...	...	2.37686
" 29	...	...	...	2.37651
October 3	...	...	...	2.37653
" 8	...	...	...	2.37646
" 11	...	...	...	2.37668
" 13	...	...	...	2.37679
" 15	...	...	...	2.37647
Mean	...	...	...	2.37661

There is here no evidence of the variation in the density of air suspected by Regnault and v. Jolly.

To allow for the contraction of the globe (No. 14) when weighed empty, discussed in my former papers, we are to

add 0.00056 to the apparent weight, so that the result for air becomes

$$2.37717.$$

This is the weight of the contents at 0° and under the pressure defined by the manometer gauge at 15° of the thermometer. The reduction to standard conditions is, for the present, postponed.

Oxygen.

This gas has been prepared by three distinct methods: (a) from chlorates, (b) from permanganate of potash, (c) by electrolysis.

In the first method mixed chlorates of potash and soda were employed, as recommended by Shenstone, the advantage lying in the readier fusibility. Two sets of five fillings were effected with this oxygen. In the first set (May, 1892) the highest result was 2.6272, and the lowest 2.6266, mean 2.62691. In the second set (June, July, 1892) the highest result was 2.6273 and the lowest 2.6267, mean 2.62693.

The second method (b) proved very convenient, the evolution of gas being under much better control than in the case of chlorates. The recrystallised salt was heated in a Florence flask, the wash-out, in this case also, being facilitated by a vacuum. Three fillings gave satisfactory results, the highest being 2.6273, the lowest 2.6270, and the mean 2.62714. The gas was quite free from smell.

By the third method I have not as many results as I could have wished, operations having been interrupted by the breakage of the electrolytic generator. This was, however, of less importance, as I had evidence from former work that there is no material difference between the oxygen from chlorates and that obtained by electrolysis. The gas was passed over hot copper, as detailed in previous papers. The result of one filling, with the apparatus as here described, was 2.6271. To this may be added the result of two fillings obtained at an earlier stage of the work, when the head of the manometer was exhausted by an independent Sprengel pump, instead of by the Töppler. The value then obtained was 2.6272. The results stand thus:—

Electrolysis (2), May, 1892	...	...	2.6272
" (1), "	...	...	2.6271
Chlorates (5), May, 1892	...	...	2.6269
" (5), June, 1892	...	...	2.6269
Permanganate (3), January, 1893	...	...	2.6271
Mean	...	...	2.62704
Correction for contraction	...	...	0.00056
			2.62760

It will be seen that the agreement between the different methods is very good, the differences, such as they are, having all the appearance of being accidental. Oxygen prepared by electrolysis is perhaps most in danger of being light (from contamination with hydrogen), and that from chlorates of being abnormally heavy.

Nitrogen.

This gas was prepared, in the usual manner, from air by removal of oxygen with heated copper. Precautions are required, in the first place, to secure a sufficient action of the reduced copper, and secondly, as was shown by v. Jolly, and later by Leduc, to avoid contamination with hydrogen which may be liberated from the copper. I have followed the plan, recommended by v. Jolly, of causing the gas to pass finally over a length of unreduced copper. The arrangements were as follows:—

Air drawn through solution of potash was deprived of its oxygen by reduced copper, contained in a tube of hard glass heated by a large flame. It then traversed a U tube, in which was deposited most of the water of combustion. The gas, practically free, as the event proved, from oxygen, was passed, as a further precaution, over a length of copper heated in a combustion furnace, then through strong sulphuric acid,¹ and afterwards back through the furnace over a length of oxide of copper. It then passed on to the regulating tap, and thence through the remainder of the apparatus, as already described. In no case

¹ There was no need for this, but the acid was in position for another purpose.

did the copper in the furnace, even at the end where the gas entered, show any sign of losing its metallic appearance.

Three results, obtained in August, 1892, were :—

August 8.....	2'31035
„ 10.....	2'31026
„ 15.....	2'31024
Mean	2'31028

To these may be added the results of two special experiments made to test the removal of hydrogen by the copper oxide. For this purpose a small hydrogen generator, which could be set in action by closing an external contact, was included between the two tubes of reduced copper, the gas being caused to bubble through the electrolytic liquid. The quantity of hydrogen liberated was calculated from the deflection of a galvanometer included in the circuit, and was sufficient, if retained, to alter the density very materially. Care was taken that the small stream of hydrogen should be uniform during the whole time (about 2½ hours) occupied by the filling, but, as will be seen, the impurity was effectually removed by the copper oxide.¹ Two experiments gave—

September 17	2'31012
„ 20	2'31027
Mean	2'31020

We may take as the number for nitrogen—

	2'31026
Correction for contraction ...	56
	2'31082

Although the subject is not yet ripe for discussion, I cannot omit to notice here that nitrogen prepared from ammonia, and expected to be pure, turned out to be decidedly lighter than the above. When the oxygen of air is burned by excess of ammonia, the deficiency is about 1/1000th part.² When oxygen is substituted for air, so that all (instead of about one-seventh part) of the nitrogen is derived from ammonia, the deficiency of weight may amount to ½ per cent. It seems certain that the abnormal lightness cannot be explained by contamination with hydrogen, or with ammonia, or with water, and everything suggests that the explanation is to be sought in a dissociated state of the nitrogen itself. Until the questions arising out of these observations are thoroughly cleared up, the above number for nitrogen must be received with a certain reserve. But it has not been thought necessary, on this account, to delay the presentation of the present paper, more especially as the method employed in preparing the nitrogen for which the results are recorded is that used by previous experimenters.

Reduction to Standard Pressure.

The pressure to which the numbers so far given relate is that due to 762·511 mm. of mercury at a temperature of 14°·85,³ and under the gravity operative in my laboratory in latitude 51° 47'. In order to compare the results with those of other experimenters, it will be convenient to reduce them not only to 760 mm. of mercury pressure at 0°, but also to the value of gravity at Paris.

The product of the three factors, corrective for length, for temperature, and for gravity, is 0·99914. Thus multiplied, the numbers are as follows :—

Air.	Oxygen.	Nitrogen.
2'37512	2'62534	2'30883

and these may now be compared with the water contents of the globe, viz. 1836·52.

The densities of the various gases under standard conditions, referred to that of distilled water at 4°, are thus :—

Air.	Oxygen.	Nitrogen.
0'00129327	0'00142952	0'00125718

With regard to hydrogen, we may calculate its density by

¹ Much larger quantities of hydrogen, sufficient to reduce the oxide over several centimetres, have been introduced without appreciably altering the weight of the gas.

² NATURE, vol. xlvii. p. 512.

³ The thermometer employed with the manometer read 0°·15 too high.

means of the ratio of densities of oxygen and hydrogen formerly given by me, viz. 15'882. Hence

Hydrogen.
0'00090009.

The following table shows the results arrived at by various experimenters. Von Jolly did not examine hydrogen. The numbers are multiplied by 1000 so as to exhibit the weights in grams per litre :—

	Air.	Oxygen.	Nitrogen.	Hydrogen.
Regnault, 1847	1'29319	1'42980	1'25617	0'08938
Corrected by Crafts ..	1'29349	1'43011	1'25647	0'08988
Von Jolly, 1880	1'29351	1'42939	1'25787	—
Ditto corrected.....	1'29383	1'42971	1'25819	—
Leduc, 1891.....	1'29330	1'42910	1'25709	0'08985
Rayleigh, 1893	1'29327	1'42952	1'25718	0'09001

The correction of Regnault by Crafts (*Comptes Rendus*, vol. civ., p. 1664) represents allowance for the contraction of Regnault's globe when exhausted, but the data were not obtained from the identical globe used by Regnault. In the fourth row I have introduced a similar correction to the results of von Jolly. This is merely an estimate founded upon the probability that the proportional contraction would be about the same as in my own case and in that of M. Leduc.

In taking a mean we may omit the uncorrected numbers, and also that obtained by Regnault for nitrogen, as there is reason to suppose that his gas was contaminated with hydrogen. Thus

	Mean Numbers.		
Air.	Oxygen.	Nitrogen.	Hydrogen.
1'29347	1'42961	1'25749	0'08991

The evaluation of the densities as compared with water is exposed to many sources of error which do not affect the comparison of one gas with another. It may, therefore, be instructive to exhibit the results of various workers referred to air as unity.

	Oxygen.	Nitrogen.	Hydrogen.
Regnault (corrected)	1'10562	0'97138	0'06949
v. Jolly (corrected)	1'10502	0'97245	—
Leduc.....	1'1050	0'9723	0'06947
Rayleigh	1'10535	0'97209	0'06960
Mean.....	1'10525	0'97218	0'06952

As usually happens in such cases, the concordance of the numbers obtained by various experimenters is not so good as might be expected from the work of each taken separately. The most serious discrepancy is in the difficult case of hydrogen. M. Leduc suggests (*Comptes Rendus*, July, 1892) that my number is too high on account of penetration of air through the blow-off tube (used to establish equilibrium of pressure with the atmosphere), which he reckons at 1 m. long and 1 cm. in diameter. In reality the length was about double, and the diameter one-half of these estimates; and the explanation is difficult to maintain, in view of the fact, recorded in my paper, that a prolongation of the time of contact from 4^m to 30^m had no appreciable ill effect. It must be admitted, however, that there is a certain presumption in favour of a lower number, unless it can be explained as due to an insufficient estimate for the correction for contraction. On account of the doubt as to the appropriate value of this correction, no great weight can be assigned to Regnault's number for hydrogen. If the atomic weight of oxygen be indeed 15'88, and the ratio of densities of oxygen and hydrogen be 15·90, as M. Leduc makes them, we should have to accept a much higher number for the ratio of volumes than that (2'0002) resulting from the very elaborate measurements of Morley. But while I write the information reaches me that Mr. A. Scott's recent work upon the volume ratio leads him to just such a higher ratio, viz. 2'00245, a number *a priori* more probable than 2'0002. Under the circumstances both the volume ratio and the density of hydrogen must be regarded as still uncertain to the 1/1000th part.

ELECTRICAL RAILWAYS.¹

ONE of the most striking of the many new departures in the practical application of electrical science, which made the Paris Exhibition of 1881 memorable, was a short tramway laid

¹ *Bulletin des Séances de la Société de Physique.*

² Friday evening discourse delivered at the Royal Institution by Dr. Edward Hopkinson on February 24.