PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

On the Refractive Index of Gaseous Fluorine

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IX. *On the Refractive Index of Gaseous Fluorine.*

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Though fluorine was isolated by M. Moissan as long ago as 1886, no attempt has hitherto been recorded, so far as we are aware, to measure its refractive index in the gaseous state. This omission is the more to be regretted since great interest attaches to the determination. Not only is fluorine the first member of an important group of elements, but its power to retard light, calculated from the refractivities of its compounds, appears to vary within unusually wide limits, so that the estimates of its refraction equivalent are singularly discordant, and agree only in showing that it must be remarkably low.

Thus, Dr. J. H. Gladstone* originally gave the refraction equivalents of fluorine and chlorine as 1·4 and 9·9 respectively, figures which correspond to a refractive index for fluorine of 1·000108, or considerably less than that of hydrogen (1·000139). In 1885† he placed it at 1·6. In 1886 G. Gladstone‡ put down the refraction equivalent at between 0·3 and 0·8, and in 1891 the same observer, with Dr. J. H. Gladstone,§ estimated it as "extremely small, in fact, less than 1·0." More recently Moissan and Dewar,‖ judging from the appearance of liquid fluorine, recorded their belief that the index would be found to be higher than had previously been supposed, though still low in relation to its atomic weight.

In these circumstances it seemed desirable to attempt to measure the index of the element in the gaseous state, and with this object Mr. Cuthbertson visited Paris in January, 1904, and, by the kindness of M. Moissan, was enabled to observe the index of a current of fluorine passing through a small hollow prism of copper, the apertures of which were covered by plates of fluor spar. A summary of this work has already

* 'Phil. Trans.,' vol. 160, p. 26, 1870.

† 'American Journal of Science' [3], XXIX., p. 57, 1885.

‡ 'Phil. Mag.' [5], XX., p. 483, 1885.

§ J. H. Gladstone and G. Gladstone. 'Phil. Mag.' [5], XXXI., p. 9, 1891.

‖ Moissan and Dewar, 'Proc. Chem. Soc.,' XXXI., p. 175, 1897.

been published,* but the following details are added in order that the value of the experiment may be criticised.

Table I. exhibits the results obtained in five experiments, performed on two occasions.

TABLE I.

Number.	Date.	Refractivity $(\mu - 1)\ 10^6$.	Time of flow of gas.
1	January 13, 1904	232	25 minutes.
2	,, 13, ,,	228 and 226	Not recorded. About half-an-hour additional.
3	,, 20, ,,	243	About half-an-hour.
4	,, 20, ,,	241	An additional quarter of an hour.
5	,, 20, ,,	227	An additional half-hour, with another electrolytic tube.

These figures require some explanation and comment. The refractivity of fluorine is certainly much lower than those of oxygen and nitrogen, while that of all other elements (except hydrogen, helium and neon, the presence of which need not be suspected) and, *à fortiori*, of all compounds,† is higher. Consequently, when air is displaced from a prism by fluorine, the lower the index observed the nearer do we approach to that of the latter.

The first experiment recorded in Table I. may be discarded. During its progress an unaccountable change of zeros took place, which makes it doubtful whether the reading given above, or a lower one (215), should be accepted. The balance of probability is in favour of the higher value.

When the prism had been swept out with dry air the second experiment was performed, and gave two trustworthy readings of 228 and 226 for the refractivity of the contents of the prism.

After making some improvements in the stability of the apparatus and substituting tubes of finer bore (about 2 millims.) for the old leads, a second attempt was made on the 20th January.

On this occasion a very trustworthy experiment gave a refractivity of 243, or 16 points worse than that of the second experiment of the 13th January; while a second trial, made after recovering the zero by sweeping out the prism with air, gave an almost identical result, 241.

It was then suspected that the electrolytic tube had developed a leak, and a new one was substituted.

The fifth experiment, performed with this apparatus, at once gave a refractivity of 227, which is nearly identical with the best experiment of the 13th January.

* 'Phil. Trans.,' A, vol. 204, 1905, p. 323.

† A molecule of HF probably retards light less than a molecule of fluorine, but since the molecule of this vapour, under normal conditions, is at least as complex as H_2F_2, its presence in an atmosphere of fluorine would probably raise the refractivity of the mixture.

In all these trials a singular fact was observed. The index slowly decreased to a minimum, and, after remaining steady for a few minutes, retrograded by several points, indicating the presence of an increased proportion of some gas of higher refractivity. This effect was observed in nearly every subsequent experiment performed with the prism, and its significance will be referred to hereafter.

But, in spite of the concordance between the lowest values obtained on the first and second days, these experiments could not, for several reasons, be regarded as satisfactory. All previous estimates of the refractivity of fluorine, based on the refraction equivalent, point to a much lower value than 227; and, though this expression cannot be relied upon to give a very close approximation, its agreement with the refractivity is usually fair, and there is no other instance of so wide a discrepancy between the two as these figures would show.

In the second place, it was not certain that the current of gas employed, which was at the rate of $1\frac{1}{2}$ to 2 litres per hour, would completely displace, from the train of purifiers, a volume of 100 cub. centims. of air, whose density is not far removed from its own. And, thirdly, the retrograde motion of the index after reaching a minimum, and subsequent slight variations, definitely proved that the contents of the prism were not homogeneous.

For these reasons the authors determined to undertake a further investigation of the subject, using the apparatus with which Mr. PRIDEAUX had, by this date, succeeded in obtaining fluorine, by the method of M. MOISSAN. The form of the electrolytic tube employed may be seen in fig. 1. It was kept cool by means of a

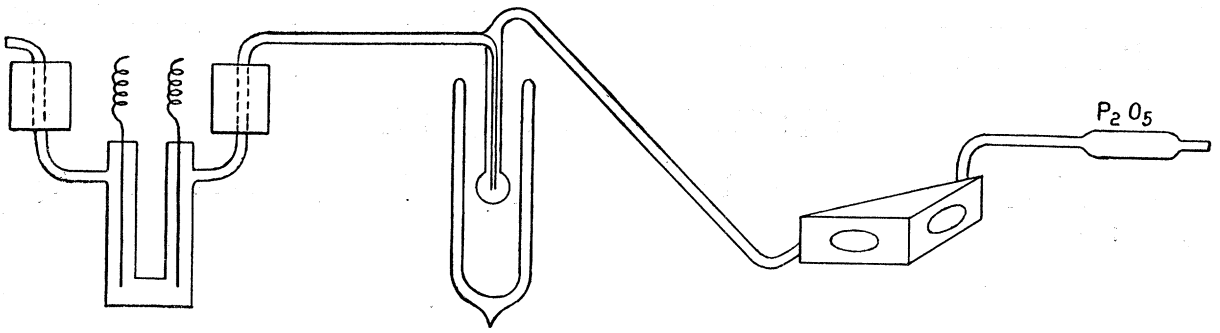

Fig. 1.

mixture of alcohol and solid carbonic acid, in such proportions as to form a paste. The current ranged from one to two ampères. In two or three minutes the voltage usually ran up to its steady value, and, soon after this, a piece of blotting paper, wetted with alcohol, when held near the exit tube gave abundant fumes of HF and then burst into flame. When this was observed the U-tube was connected to the train of purifiers and prism or refractometer tube by means of a well-fitting platinum junction.

Many experiments were made with this apparatus, but the results were not more

concordant than those obtained in Paris, and suggested, as in that case, that the current of fluorine was not sufficiently rapid to displace completely the air in the coolers and tubes.

It was, therefore, decided to liquefy the gas as it was produced, and, when sufficient had been collected, to allow it to boil off rapidly through the prism. This was done with the arrangement shown in fig. 1, but the results showed no improvement, and it seemed probable that some oxygen, either from the air or some other source, was condensing with the fluorine, the boiling-points of the two elements being very nearly identical.

These experiments led to the conviction that it was practically impossible to obtain fluorine in a state of absolute purity.* And since no means could be devised for removing the gases by which it was accompanied without affecting the fluorine, it was decided to have recourse to an analysis of the mixture of gases whose refractivity was observed, and to correct for the impurities detected. For this purpose the prism method was found unsuitable and JAMIN'S refractometer was substituted for it.

The plan at first adopted was to displace the air in the refractometer tube by a current of fluorine, counting the interference bands as they passed across the field, owing to the change of refractivity. When a steady state was reached the tube was disconnected from the source of fluorine and its contents collected over dry mercury, by filling it with mercury from a reservoir.† It was anticipated that the fluorine, on being bubbled through mercury, would instantly be absorbed as fluoride, and that the residual gases could be measured and analysed. In a second set of experiments glass tubes were used, and the residuals were collected over a standard solution of soda. Here the reaction expected was the absorption of fluorine and production of half its volume of oxygen, according to the equation

$$2F_2 + 4NaOH = 4NaF + 2H_2O + O_2.$$

The principal figures connected with these experiments are given in the following table :—

* Even in his most recent density experiment M. MOISSAN, after a prolonged trial with a current of 5 ampères, found 5·78 cub. centims. of nitrogen still left in a density bulb of volume 159·2 cub. centims., or $3\frac{1}{2}$ per cent. of impurity. 'C. R.,' 138, p. 731, 1904.

† A new refractometer tube was made for each experiment, when copper tubes were used.

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TABLE II.—Preliminary Experiments (Unsuccessful).

Measurements with Refractometer. Absorption of Fluorine by Liquids.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Number.	Date.	Form of apparatus.	Refractivity of mixed gases.	Refractivity of residual gases.		Proportion of gases present, from analysis.			Refractivity of fluorine (calculated.)
				Observed.	Calculated from columns 8 and 9.	Fluorine.	Air.	Oxygen.*	
						per cent.	per cent.	per cent.	
1	November 3, 1904	Copper tube, glass ends secured with paraffin; absorption by mercury	262	282	283	33	29·8	37·2	223
2	„ 3, „	Copper tube, glass ends secured with paraffin; absorption by mercury	246	282	275	54·5	8·8	36·7	217
3	„ 29, „	Glass tube, ends secured with shellac; absorption by mercury	240	292	282	68	17·3	14·7	215
4	„ 29, „	Glass tube, ends secured with shellac; absorption by mercury	237	289·5	274	74	4·8	21·2	218
5	December 13, „	Glass tube; absorption over NaOH solution; ozone destroyer.	235	277†	298‡	89	9·4	1·6	226
6	„ 13, „	Glass tube; absorption over NaOH solution; ozone destroyer.	236	278†	322‡	82·9	9·5	8·6	227
7	January 2, 1905	Glass tube; absorption over mercury; ozone destroyer .	238·5	274†	281‡	79·5	15·2	5·3	230
8	„ 2, „	Copper tube; the rest as before	247·6	292·5	285·5	50·3	34·6	15·1	203
9	„ 2, „	Copper tube; the rest as before	232	278	274·5	77·5	4·9	17·6	218

* Exclusive of that contained in the air.

† Including the oxygen produced by the reaction.

‡ Excluding the oxygen produced by the reaction. Calculated from Columns 5, 8 and 9

These results are not concordant, and the causes of the discrepancies were not completely disentangled. It will be sufficient, therefore, to indicate, briefly, their probable nature, without attempting detailed criticism which the figures will not bear. The first four experiments are rendered nugatory by the absence of any means for destroying the ozone produced with the oxygen, which, as will be shown later, invariably accompanied the fluorine (see Column 9).

No correction can be introduced into the figures for this source of error; for the proportion of ozone to oxygen, produced under the conditions of the experiment, is not known, and the quantity of oxygen present is itself doubtful, since the nature of the reaction between ozone and mercury is not beyond dispute.*

Any correction for ozone would reduce the value found for the index of fluorine.

In the fifth and sixth experiments the measurements of the volumes of residual gases proved insufficiently accurate, and were complicated by the presence of ozone produced by the action of the fluorine on the solution of soda.

In the last three experiments these sources of error had been eliminated, and we are forced to suppose that the method of absorbing the fluorine over mercury is open to some grave objection, possibly the formation of an oxyfluoride of mercury. It is certain that some source of error is to be sought in the process of absorption over mercury, since, in these experiments, the calculated values for the index of fluorine given in Column 10 are more discordant than those given in Column 4 for the observed refractivity of the mixture of gases.

But, though this series did not give values sufficiently concordant to warrant the belief that the true index of fluorine was being measured, some important inferences could be drawn from the results. The number of values which ranged below the lowest figure obtained in Paris confirmed the opinion that, on that occasion, some other gas or gases were present. On the other hand, the absence of any very low value, in spite of the variety of methods employed, indicated that the refractivity of fluorine was to be sought in the neighbourhood of the figure 200, and was by no means so low as students of the refraction equivalents have surmised.

But the most interesting point observed was the presence, in the residuals, of a larger proportion of oxygen than could be accounted for by the amount of air present. This was observed to be the case in all the experiments shown in Tables II. and III., as well as in others specially designed to test the point;† and it was ultimately proved, beyond reasonable doubt, that the oxygen was produced by the intermittent electrolysis of traces of water in the electrolytic tube, and not by subsequent reactions. Our experience was that the proportions of oxygen and fluorine liberated were not sensibly altered by prolonging the experiment for two or three hours.

Having established this fact, we were enabled to make dispositions for the series of

* Andrews and Tait, 'Phil. Trans.,' 1860, p. 114; Shenstone and Cundall, 'C. J.,' 51, p. 623; E. C. C. Baly, 'B.A. Reports,' 1897, p. 613.

† It is hoped that the details of these experiments may be published on another occasion.

experiments by which the index has, we believe, been measured with some approach to accuracy.

Fig. 2 shows, in a diagrammatic form, the arrangement of the apparatus. A is the copper electrolytic tube, from the right side of which issues the fluorine. In order to prevent the escape of the vapour of hydrofluoric acid the exit tubes were

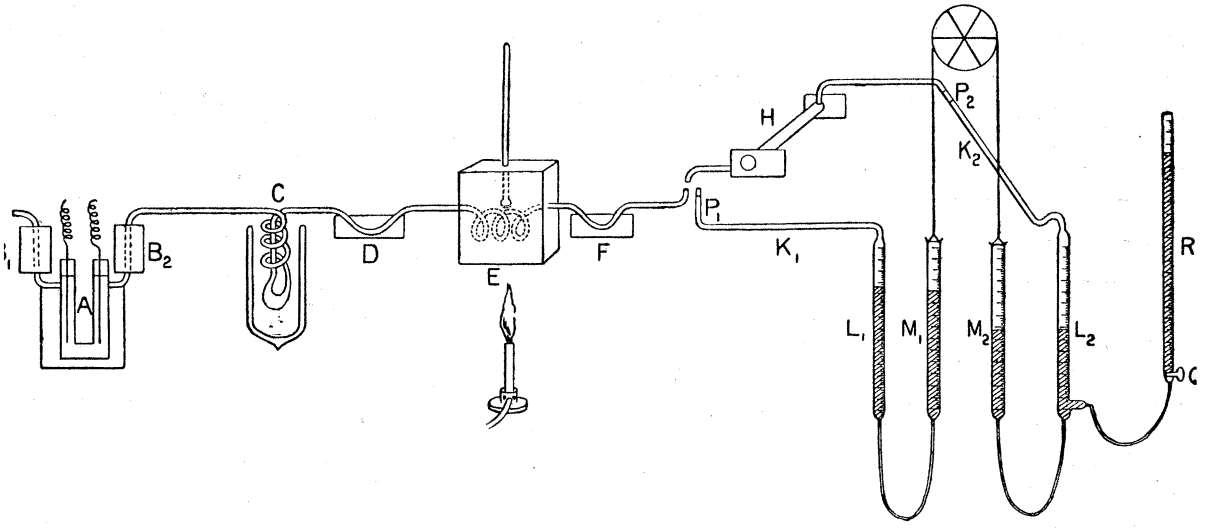

Fig. 2.

carried upwards, and surrounded by vessels, B_1, B_2, containing alcohol, cooled to $-78°$ C. As a further precaution, the gas next passed through a length of 73 centims. of platinum tube immersed in a solution at the same temperature (C), and in many of the experiments a guard tube, filled with NaF, as recommended by M. Moissan, was added at the point F. The fact that the presence or absence of this salt did not appear to affect the refractivity of the mixture of gases is evidence that the other precautions were effectual.

It was probable that some part of previously observed discrepancies arose from the presence of ozone produced when the oxygen was liberated; and, in order to destroy this, the gases next passed through a spiral of platinum tube, 49 centims. in length, heated to from 250° to 300° C. (E). The bends, D and F, were immersed in iced water to prevent conduction of heat from the spirals to the condenser on one side and the refractometer tube on the other.

The refractometer tube, H, was of platinum-iridium, 45·78 centims. long and 0·65 centim. in diameter. Its volume, with the leads, was 15·01 cub. centims. Each end was furnished with a collar of platinum 0·25 centim. broad. The plates with which the ends were closed were of fluor spar, and were secured to the tube by a shoulder of shellac, melted round the outside of the circumference of the collar, so as to be as far as possible from the fluorine within. Thus, after leaving the electrolytic tube, the fluorine was never in contact with anything but platinum and fluor spar.

The plan adopted for measuring the volume of fluorine present was to allow it to

combine with an element whose fluoride was a solid (lead was chosen), measuring the contraction of volume so produced by means of mercury manometers which were, however, kept as far as possible from the fluorine by a column of air.

In the figure, L_1 and L_2 are graduated glass tubes of the same bore, having, at their upper extremities, narrow tubes filled with dry lead filings, K_1, K_2, and terminating in platinum tubes, P_1, P_2, which fitted the leads of the refractometer tube. These closed burettes were connected with open movable burettes, M_1, M_2, also of equal bore, which were joined by a wire passing over a pulley. One of the burettes (L_2) was in connection with a graduated reservoir of mercury, R, provided with a tap, and all were filled, to the proper point, with dry mercury.

When the air in the refractometer tube had been displaced by the gaseous products of electrolysis as completely as possible, and the number of bands which had crossed the field had been noted, the entry tube was disconnected, and the two tubes P_1, P_2 rapidly connected with the system of burettes, the junctions being made air-tight by immersing them in mercury. The burette M_2 was then raised slowly, while M_1, being connected by a pulley, fell by an equal amount. The mercury in L_1, L_2 followed the motion of that in their respective companions, and the effect was to push the contents of the refractometer tube into the glass tube at K_1, which was filled with lead filings, without appreciably altering the pressure, so as to avoid errors due to possible leaks. As the fluorine combined with the lead, there took place a diminution of the volume of gases in the closed space K_1, H, K_2, which was indicated by a difference of level between the mercury in the closed and open burettes. As fast as this was observed, pressure was equalised by opening the tap Q and letting in mercury. By continuing and reversing this process the gases in the refractometer tube were pushed back and forward for about an hour. When no further change of levels could be detected it was assumed that all the fluorine present had been absorbed, and that the residual gases consisted of oxygen and nitrogen. The volume of fluorine was measured by observing the change of levels of the mercury in the two closed burettes, and the measurement checked by reading the change of level in the reservoir R.

The amount of oxygen present was found by taking a sample of the total residual gases in the closed system and burning it with phosphorus. The residue was also tested for SiF_4, and, finally, was shown by its index and spectrum to be nitrogen.

From these *data* the index of fluorine could be found. But as the calculation is rather long, a specimen is given below, the figures being those actually observed in the third experiment given in Table III.

Barometer 741·5 millims.
Thermometer (mean) 13° C.

Length of the refractometer tube	45·78	centims.
Number of bands which would cross the field for one atmosphere of air at normal temperature and pressure introduced into this tube	227·6	
[$N\lambda = (\mu - 1) \times$ length of tube]		
Number of bands which would cross the field for one atmosphere of air at the temperature and pressure observed	212	
Number of bands observed to cross the field as air was displaced by gases produced by electrolysis	47	
Hence, by difference, number of bands which would cross the field for one atmosphere of these gases at the temperature and pressure of the day	165	
Therefore the refractivity of the mixture of gases in the tube (air = 293) is		
$\frac{165}{212} \times 293 =$	228	
Volume of the refractometer tube and leads containing this mixture of gases	15·01	cub. centims.
Volume of the gas absorbed by the lead filings	9·04	,,
Hence, by difference, the volume of gases in the refractometer tube and leads which are not fluorine (tube residuals) is	5·97	,,

Determination of the proportion of oxygen in the tube residuals from analysis of the contents of the burettes and refractometer tube (K_1, HK_2) after the experiment (total residuals):—

Volume of total residuals	43·62	cub. centims.
Volume of tube residuals	5·97	,,
Hence, by difference, volume of air was	37·65	,,

A sample of the total residuals contained 25 per cent. of oxygen.

Therefore the whole contains, of oxygen,

$\frac{25}{100} \times 43·62 =$	10·90	,,

Of this amount the 37·66 cub. centims. of air contain, of oxygen,

$\frac{20·9}{100} \times 37·66 =$	7·90	,,
And the difference between this and the whole quantity of oxygen found (10·9) is	3·00	,,

Hence the refractometer tube, at the moment when its contents gave a refractivity of 228, held—

Fluorine	9·04	cub. centims.
Oxygen	3·00	,,
Nitrogen	2·97	,,
	15·01	,,

Now, the refractivity of the mixture, multiplied by its volume, is equal to the sum of the refractivities of its constituents multiplied respectively by their volumes.

Taking the refractivity of oxygen as 270 and that of nitrogen as 297, the refractivity of fluorine is given by the equation

$$15·01 \times 228 = 9·04\,(\mu - 1)\,F_2 + 3·0 \times 270 + 2·97 \times 297,$$

whence

$$(\mu - 1)\,F_2 = 192.$$

The following table shows the results obtained by this method. With the exception of the second experiment, which was discordant, probably owing to the presence of a slight leak afterwards detected, the coincidence is as close as we can hope to attain, having regard to the difficulties of the inquiry.

We believe that the refractivity of fluorine for the D line lies in the neighbourhood of 195, most probably within 2 per cent. of that number.

TABLE III.—Refractive Index of Gaseous Fluorine.

1.	2.	3.	4.	5.	6.	7.	8.	9.
Number.	Date.	Refractivity of mixed gases.	Volume of tube.	Volume of fluorine present.	Volume of oxygen present.	Volume of nitrogen present.	Refractivity of fluorine.	Remarks.
			cub. centims.	cub. centims.	cub. centims.	cub. centims.		
1	February 9, 1905	237	15·01	7·45	5·32	2·24	195	
2	„ 18, „	225	15·01	8·40	2·43	4·17	177	A slight leak was detected, after the experiment.
3	„ 28, „	228	15·01	9·04	3·02	2·95	192	
4	„ 28, „	227	15·01	9·62	2·25	3·14	194	
5	March 10, „	236	15·01	8·4	3·37	3·24	$198\frac{1}{2}$	The glass tube K_1 (fig. 2) holding lead filings was replaced by a copper tube, to diminish the chance of obtaining SiF_4.
						Mean of 1, 3, 4, and 5 . . .	195	
						Index of gaseous fluorine 1·000195.		

The principal difficulties and sources of error involved in the method are as follows:—

(1) In disconnecting the refractometer tube and connecting with the measuring apparatus a few seconds are spent, and a small proportion of the contents of the tube may be lost by diffusion. To minimise this the leads were made about 20 centims. long, of platinum tube of less than 2 millims. bore.

(2) The volume of fluorine present is measured by contraction during the combination of the fluorine with the lead filings. The success of the method, therefore, depends absolutely on the assumption that no gaseous compounds are formed, or that if formed (*e.g.*, SiF_4) they are allowed for: and, secondly, on the absence of leaks.

These dangers were met by reducing the quantity of glass used as far as possible, bringing the lead filings into immediate contact with the exits of the refractometer tube, drying the whole with scrupulous care, and, finally, by testing the residuals for silicon fluoride. This test was carried out in three cases and only in one of these was a minute quantity of SiF_4 found (0·3 cub. centim.), which did not affect the index by more than one or two units.

(3) The presence of ozone in the refractometer tube, especially if afterwards disintegrated, would introduce a serious error. The device employed to obviate this is described above.

(4) Owing to the form of the apparatus it was not possible to isolate the tube residuals and measure their index directly, and their volume was so small, in comparison with that of the total residuals, that it would have been unsafe to calculate the refractivity of the former from that of the latter, even after the most careful measurements. It was necessary, therefore, to calculate the value of the refractivity of the tube residuals from their composition, ascertained by the analysis given above. But the calculation was confirmed by comparison with the figures given in the preceding series of experiments when the residuals were collected undiluted with air. Table II. shows that, in that series, the index lay, in nearly every case, between those of oxygen and nitrogen.

It will be observed that the result given here rests on the assumption that the density of gaseous fluorine is 1·319 (air = 1); *i.e.*, that the molecule is diatomic under normal conditions. M. Moissan has twice measured this important constant. On the first occasion, in 1889, he obtained four concordant values,* 1·264, 1·262, 1·265, 1·270, the mean of which was 1·265, and he thence inferred that the gas contained a small proportion of molecules of F_1.†

In 1904 a second series of experiments, in glass bulbs, gave values of 1·298, 1·319, 1·313, 1·312, of which the mean is 1·310, a figure very nearly identical with the value assumed. We have accepted this later determination, which was made with the precautions dictated by many additional years of experience, and is supported by *à priori* probability.

In a recent paper by Mr. Cuthbertson,‡ it was shown that, in four groups of elements, the refractivities of the different members of the same group are related in the ratios of small integers, and it was pointed out that, if this coincidence were not due to chance, the refractivity of fluorine should bear to that of chlorine the ratio of one to four, as those of nitrogen, oxygen, and neon do to phosphorus, sulphur, and argon respectively.

* 'Le Fluor,' p. 87; 'Ann. de Chimie et de Physique,' vol. 25, 1892, p. 131; 'C. R.,' vol. 109, 1889, p. 863.

† 'C. R.,' vol. 138, p. 729 (1904).

‡ 'Phil. Trans.,' A, vol. 204, p. 323, 1905.

This prediction has been verified. The refractivity of chlorine for sodium light is generally accepted to be 768, or 4×192. That which is now found for fluorine is 195.

Table IV. shows the exact ratios experimentally obtained in all cases. The indices were determined, in the case of the inert gases for white light, in that of iodine for the red and the violet. In all other cases the measurements are for sodium light.

It will be seen that, except in the case of the anomalous red rays in iodine, the discrepancies between the ratios actually found and those of integers do not exceed 3·2 per cent. A discussion of the possible causes of these discrepancies will be found in Mr. CUTHBERTSON's paper.

The element chosen as standard in each group is indicated by an asterisk, and, to avoid doubling all the other figures, the ratio of helium is taken as one half.

TABLE IV.

Elements.	Refractivities observed.	Ratios in each group.	Observers.
Helium	72·6	0·511	RAMSAY and TRAVERS.
Neon	137·4	0·968	,, ,,
*Argon	568	4	,, ,,
Krypton	850	5·986	,, ,,
Xenon	1378	9·704	,, ,,
Fluorine	195	1·015	CUTHBERTSON and PRIDEAUX.
*Chlorine	768	4	MASCART.
Bromine	1125	5·859	,,
Iodine	1920 V.	10	HURION.
	2050 R.	10·68	
Nitrogen	297	0·992	MASCART.
*Phosphorus	1197	4	CUTHBERTSON.
Oxygen	270	0·981	MASCART.
*Sulphur	1101	4	CUTHBERTSON.

With the addition of fluorine the table given in the paper quoted above, showing the refractivities of all the elements whose index has been measured in the gaseous state, now stands as follows. A few additional elements are put down to suggest the framework of the periodic system, and the refractivities are rounded off.

TABLE V.—Relative Refractivities of some of the Elements.

H 139	—	—	—	—	—	—	He $139 \times \frac{1}{2}$
Li	Be	B	C	N 297×1	O 270×1	F 192×1	Ne 139×1
Na	—	—	—	P 297×4	S 270×4	Cl 192×4	A 139×4
K	—	—	—	—	—	Br 192×6	Kr 139×6
Rb	—	—	—	—	—	I 192×10	X 139×10
Cs	—	—	—	—	—	—	—
—	Hg 1857	—	—	—	—	—	—

We have pleasure in expressing our thanks to Sir WILLIAM RAMSAY and to Professor TROUTON for assistance throughout the research, to M. MOISSAN for his kindness in supplying the fluorine used in the first series of experiments, and to the Royal Society for grants in aid of the expense incurred in the research.