

13. *Behaviour at Low Temperatures.*

A single experiment was made with an early sample of gas, of density 19·1, which certainly contained a considerable amount of nitrogen. On compressing it in a pressure apparatus to between 80 and 100 atmospheres pressure, and cooling to -90° by means of boiling nitrous oxide, no appearance of liquefaction could be observed. As the critical pressure was not likely to be so high as the pressure to which it had been exposed, the non-liquefaction was ascribed to insufficient cooling.

This supposition turned out to be correct. For, on sending a sample to Professor OLSZEWSKI, the author of most of the accurate measurements of the constants of gases at low temperatures, he was kind enough to submit it to examination. His results are published elsewhere; but, for convenience of reference, his tables, showing vapour-pressures, and giving a comparison between the constants of argon and those of other gases, are here reproduced.

VAPOUR-PRESSURES.

Temperature.	Pressure.	Temperature.	Pressure.	Temperature.	Pressure.
$-186^{\circ}9$	740·5 millims.	$-136^{\circ}2$	27·3 atms.	$-129^{\circ}4$	35·8 atms.
$-139\cdot1$	23·7 atms.	$-135\cdot1$	29·0 "	$-128\cdot6$	38·0 "
$-138\cdot3$	25·3 "	$-134\cdot4$	29·8 "	$-121\cdot0$	50·6 "

Gas.	Critical temperature.	Critical pressure.	Boiling-point.	Freezing-point.	Freezing pressure.	Density of gas.	Density of liquid at boiling-point.	Colour of liquid.
Hydrogen, H_2 . . .	Below $-220\cdot0^{\circ}$	atms. 20·0	? °	? °	millims. ?	1	?	Colourless
Nitrogen, N_2 . . .	$-146\cdot0$	35·0	$-194\cdot4$	$-214\cdot0$	60	14	0·885	"
Carbon monoxide, CO	$-139\cdot5$	35·5	$-190\cdot0$	$-207\cdot0$	100	14	?	"
Argon, A_1	$-121\cdot0$	50·6	$-186\cdot9$	$-189\cdot6$?	19·9	About 1·5	"
Oxygen, O_2	$-118\cdot8$	50·8	$-182\cdot7$?	?	16	1·124	Bluish
Nitric oxide, NO . . .	$-93\cdot5$	71·2	$-153\cdot6$	$-167\cdot0$	138	15	?	Colourless
Methane, CH_4	$-81\cdot8$	54·9	$-164\cdot0$	$-185\cdot8$	80	8	0·415	"

14. *The ratio of the Specific Heats of Argon.**

In order to decide regarding the elementary or compound nature of argon, experiments were made on the velocity of sound in it. It will be remembered that from the velocity of sound, the ratio of the specific heat at constant pressure to that at constant volume can be deduced by means of the equation

* See Addendum, p. 239.

$$n\lambda = v = \sqrt{\left\{ \frac{e}{d}(1 + \alpha t) \frac{C_p}{C_v} \right\}},$$

where n is the frequency, λ is the wave-length of sound, v its velocity, e the isothermal elasticity, d the density, $(1 + \alpha t)$ the temperature-correction, C_p the specific heat at constant pressure, and C_v that at constant volume. In comparing two gases at the same temperature, each of which obeys BOYLE'S law with sufficient approximation and in using the same sound, many of these factors disappear, and the ratio of specific heats of one gas may be deduced from that of the other, if known, by the simple proportion

$$\lambda^2 d : \lambda'^2 d' :: 1.408 : x,$$

where for example λ and d refer to air, of which the ratio is 1.408, according to the mean of observations by RÖNTGEN (1.4053), WÜLLNER (1.4053), KAYSER (1.4106), and JAMIN and RICHARD (1.41).

The apparatus employed, although in principle the same as that usually employed, differed somewhat from the ordinary pattern, inasmuch as the tube was a narrow one, of 2 millims. bore, and the vibrator consisted of a glass rod, sealed into one end of the tube, so that about 15 centims. projected outside the tube, while 15 centims. was contained in the tube. By rubbing the projecting part longitudinally with a rag wet with alcohol, vibrations of exceedingly high pitch of the gas contained in the tube took place, causing waves which registered their nodes by the usual device of lycopodium powder. The temperature was that of the atmosphere and varied little from 17.5° ; the pressure was also atmospheric, and varied only one millim. during the experiments. Much of the success of these experiments depends on so adjusting the length of the tube as to secure a good echo, else the wave-heaps are indistinct. But this is easily secured by attaching to its open end a piece of thick-walled india-rubber tubing, which can be closed by a clip at a spot which is found experimentally to produce good heaps at the nodes.

The accuracy of this instrument has frequently been tested; but fresh experiments were made with air, carbon dioxide, and hydrogen, so as to make certain that reasonably reliable results were obtainable. Of these an account is here given.

Gas in tube.	Number of observations.		Half-wave-length.		Ratio $\frac{C_p}{C_v}$.	
	I.	II.	I.	II.		
Air	3	2	19.60	19.59	1.408	Assumed
CO ₂	3	..	15.11	..	1.276	Found
H ₂	3	..	73.6	..	1.376	Found

To compare these results with those of previous observers, the following numbers

were obtained for carbon dioxide :—CAZIN, 1.291; RÖNTGEN, 1.305; DE LUCCHI, 1.292; MÜLLER, 1.265; WÜLLNER, 1.311; DULONG, 1.339; MASSON, 1.274; REGNAULT, 1.268; AMAGAT, 1.299; and JAMIN and RICHARD, 1.29. It appears just to reject DULONG's number, which deviates so markedly from the rest; the mean of those remaining is 1.288, which is in sufficient agreement with that given above. For the ratio of the specific heats of hydrogen, we have :—CAZIN, 1.410; RÖNTGEN, 1.385; DULONG, 1.407; MASSON, 1.401; REGNAULT, 1.400; and JAMIN and RICHARD, 1.410. The mean of these numbers is 1.402. This number appears to differ considerably from the one given above. But it must be noted, first, that the wave-length which should have been found is 74.5, a number differing but little from that actually found; second, that the waves were long and that the nodes were somewhat difficult to place exactly; and third, that the atomic weight of hydrogen has been taken as unity, whereas it is more likely to be 1.01, if oxygen, as was done, be taken as 16. The atomic weight 1.01 raises the found value of the ratio to 1.399, a number differing but little from the mean value found by other observers.

Having thus established the trustworthiness of the method, we proceed to describe our experiments with argon.

Five series of measurements were made with the sample of gas of density 19.82. It will be remembered that a previous determination with the same gas gave as its density 19.90. The mean of these two numbers was therefore taken as correct, viz., 19.86.

The individual measurements are :—

I.	II.	III.	IV.	V.	Mean.
18.16	18.14	18.02	18.04	18.03	millims. 18.08

for the half-wave-length. Calculating the ratio of the specific heats, the number 1.644 is obtained.

The narrowness of the tube employed in these experiments might perhaps raise a doubt regarding the accuracy of the measurements, for it is conceivable that in so narrow a tube the viscosity of the gas might affect the results. We therefore repeated the experiments, using a tube of 8 millims. internal diameter.

The mean of eleven readings with air, at 18°, gave a half-wave-length of 34.62 millims. With argon in the same tube, and at the same temperature, the half-wave-length was, as a mean of six concordant readings, 31.64 millims. The density of this sample of argon, which had been transferred from a water gas-holder to a mercury gas-holder, was 19.82; and there is some reason to suspect the presence of a trace of air, for it had been standing for some time.

The result, however, substantially proves that the ratio previously found was

correct. In the wide tube, $C_p : C_v :: 1.61 : 1$. Hence the conclusion must be accepted that the ratio of specific heats is practically $1.66 : 1$.

It will be noticed that this is the theoretical ratio for a monatomic gas, that is, a gas in which all energy imparted to it at constant volume is expended in effecting translational motion. The only other gas of which the ratio of specific heats has been found to fulfil this condition is mercury at a high temperature.* The extreme importance of these observations will be discussed later.

15. *Attempts to induce Chemical Combination.*

A great number of attempts were made to induce chemical combination with the argon obtained by use of magnesium, but without any positive result. In such a case as this, however, it is necessary to chronicle negative results, if for no other reason but that of justifying its name, "argon." These will be detailed in order.

(a) *Oxygen in Presence of Caustic Alkali.*—This need not be further discussed here; the method of preparing argon is based on its inactivity under such conditions.

(b) *Hydrogen.*—It has been mentioned that, in order to free argon from excess of oxygen, hydrogen was admitted, and sparks passed to cause combination of hydrogen and oxygen. Here again caustic alkali was present, and argon appeared to be unaffected.

A separate experiment was, however, made in absence of water, though no special pains was taken to dry the mixture of gases. The argon was admitted up to half an atmosphere pressure into a bulb, through whose sides passed platinum wires, carrying pointed poles of gas-carbon. Hydrogen was then admitted until atmospheric pressure had been attained. Sparks were then passed for four hours by means of a large induction coil, actuated by four storage cells. The gas was confined in a bulb closed by two stop-cocks, and a small V-tube with bulbs was interposed, to act as a gauge, so that if expansion or contraction had taken place, the escape or entry of gas would be observable. The apparatus, after the passage of sparks, was allowed to cool to the temperature of the atmosphere, and, on opening the stop-cock, the level of water in the V-tube remained unaltered. It may therefore be concluded that, in all probability, no combination has occurred; or, that if it has, it was attended with no change of volume.

(c) *Chlorine.*—Exactly similar experiments were performed with dry, and afterwards with moist, chlorine. The chlorine had been stored over strong sulphuric acid for the first experiment, and came in contact with dry argon. Three hours sparking produced no change of volume. A drop of water was admitted into the bulb. After four hours sparking, the volume of the gas, after cooling, was diminished by about

* KUNDT and WARBURG, 'Pogg. Ann.,' 157, p. 353, 1876.

$\frac{1}{10}$ cub. centim., due probably to the solution of a little chlorine in the small quantity of water present.

(d) *Phosphorus*.—A piece of combustion-tubing, closed at one end, containing at the closed end a small piece of phosphorus, was sealed to the mercury reservoir containing argon; connected to the same reservoir was a mercury gauge and a SPRENGEL'S pump. After removing all air from the tubes, argon was admitted to a pressure of 600 millims. The middle portion of the combustion-tube was then heated to bright redness, and the phosphorus was distilled slowly from back to front, so that its vapour should come into contact with argon at a red heat. When the gas was hot, the level of the gauge altered; but, on cooling, it returned to its original level, showing that no contraction had taken place. The experiment was repeated several times, the phosphorus being distilled through the red-hot tube from open to closed end, and *vice versa*. In each case, on cooling, no change of pressure was remarked. Hence it may be concluded that phosphorus at a red-heat is without action on argon. It may be remarked parenthetically that no gaseous compound of phosphorus is known, which does not possess a volume different from the sum of those of its constituents. That no solid compound was formed is sufficiently proved by the absence of contraction. The phosphorus was largely converted into the red modification during the experiment.

(e) *Sulphur*.—An exactly similar experiment was performed with sulphur, again with negative results. It may therefore be concluded that sulphur and argon are without action on each other at a red heat. And again, no gaseous compound of sulphur is known in which the volume of the compound is equal to the sum of those of its constituents.

(f) *Tellurium*.—As this element has a great tendency to unite with heavy metals, it was thought worth while to try its action. In this, and in the experiments to be described, a different form was given to the apparatus. The gas was circulated over the reagent employed, a tube containing it being placed in the circuit. The gas was dried by passage over soda-lime and phosphoric anhydride; it then passed over the tellurium or other reagent, then through drying tubes, and then back to the gas-holder. That combination did not occur was shown by the unchanged volume of gas in the gas-holder; and it was possible, by means of the graduated cylinder which admitted water to the gas-holder, to judge of as small an absorption as half a cubic centimeter. The tellurium distilled readily in the gas, giving the usual yellow vapours; and it condensed, quite unchanged, as a black sublimate. The volume of the gas, when all was cold, was unaltered.

(g) *Sodium*.—A piece of sodium, weighing about half a gramme, was heated in argon. It attacked the glass of the combustion tube, which it blackened, owing to liberation of silicon; but it distilled over in drops into the cold part of the tube. Again no change of volume occurred, nor was the surface of the distilled sodium tarnished; it was brilliant, as it is when sodium is distilled *in vacuo*. It may probably also be

concluded from this experiment that silicon, even while being liberated, is without action on argon.

The action of compounds was then tried; those chosen were such as lead to oxides or sulphides. Inasmuch as the platinum-metals, which are among the most inert of elements, are attacked by fused caustic soda, its action was investigated.

(*h*) *Fused and Red-hot Caustic Soda*.—The soda was prepared from sodium, in an iron boat, by adding drops of water cautiously to a lump of the metal. When action had ceased, the soda was melted, and the boat introduced into a piece of combustion-tube placed in the circuit. After three hours circulation no contraction had occurred. Hence caustic soda has no action on argon.

(*i*) *Soda-lime at a red-heat*.—Thinking that the want of porosity of fused caustic soda might have hindered absorption, a precisely similar experiment was carried out with soda-lime, a mixture which can be heated to bright redness without fusion. Again no result took place after three hours heating.

(*j*) *Fused Potassium Nitrate* was tried under the impression that oxygen plus a base might act where oxygen alone failed. The nitrate was fused, and kept at a bright red heat for two hours, but again without any diminution in volume of the argon.

(*k*) *Sodium Peroxide*.—Yet another attempt was made to induce combination with oxygen and a base, by heating sodium peroxide to redness in a current of argon for over an hour, but also without effect. It is to be noticed that metals of the platinum group would have entered into combination under such treatment.

(*l*) *Persulphides of Sodium and Calcium*.—Soda-lime was heated to redness in an open crucible, and some sulphur was added to the red-hot mass, the lid of the crucible being then put on. Combination ensued, with formation of polysulphides of sodium and calcium. This product was heated to redness for three hours in a brisk current of argon, again with negative result. Again, metals of the platinum group would have combined under such treatment.

(*m*) Some argon was shaken in a tube with nitro-hydrochloric acid. On addition of potash, so as to neutralise the acid, and to absorb the free chlorine and nitrosyl chloride, the volume of the gas was barely altered. The slight alteration was evidently due to solubility in the aqueous liquid, and it may be concluded that no chemical action took place.

(*n*) Bromine-water was also without effect. The bromine vapour was removed with potash.

(*o*) A mixture of potassium permanganate and hydrochloric acid, involving the presence of nascent chlorine, had no action, for on absorbing chlorine by means of potash, no alteration in volume had occurred.

(*p*) Argon is not absorbed by platinum black. A current was passed over a pure specimen of this substance; as usual, however, it contained occluded oxygen. There was no absorption in the cold. At 100°, no action took place; and on heating to

redness, by which the black was changed to sponge, still no evidence of absorption was noticed. In all these experiments, absorption of half a cubic centimetre of argon could have at once been detected.

We do not claim to have exhausted the possible reagents. But this much is certain, that the gas deserves the name "argon," for it is a most astonishingly indifferent body, inasmuch as it is unattacked by elements of very opposite character, ranging from sodium and magnesium on the one hand, to oxygen, chlorine, and sulphur on the other. It will be interesting to see if fluorine also is without action, but for the present that experiment must be postponed, on account of difficulties of manipulation.

It will also be necessary to try whether the inability of argon to combine at ordinary or at high temperatures is due to the instability of its possible compounds, except when cold. Mercury vapour at 800° would present a similar instance of passive behaviour.

16. *General Conclusions.*

It remains, finally, to discuss the probable nature of the gas or gases which we have succeeded in separating from atmospheric air, and which has been provisionally named *argon*.

That argon is present in the atmosphere, and is not manufactured during the process of separation is amply proved by many lines of evidence. First, atmospheric nitrogen has a high density, while chemical nitrogen is lighter. That chemical nitrogen is a uniform substance is proved by the identity of properties of samples prepared by several different processes, and from several different compounds. It follows, therefore, that the cause of the high density of atmospheric nitrogen is due to the admixture with heavier gas. If that gas possesses the density of 20 compared with hydrogen as unity, atmospheric nitrogen should contain of it approximately 1 per cent. This is found to be the case, for on causing the nitrogen of the atmosphere to combine with oxygen in presence of alkali, the residue amounted to about 1 per cent.; and on removing nitrogen with magnesium the result is similar.

Second: This gas has been concentrated in the atmosphere by diffusion. It is true that it cannot be freed from oxygen and nitrogen by diffusion, but the process of diffusion increases relatively to nitrogen the amount of argon in that portion which does not pass through the porous walls. That this is the case is proved by the increase of density of that mixture of argon and nitrogen.

Third: On removing nitrogen from "atmospheric nitrogen" by means of magnesium, the density of the residue increases proportionately to the concentration of the heavier constituent.

Fourth: As the solubility of argon in water is relatively high, it is to be expected that the density of the mixture of argon and nitrogen, pumped out of water along with oxygen should, after removal of the oxygen, exceed that of "atmospheric nitrogen." Experiment has shown that the density is considerably increased.

Fifth: It is in the highest degree improbable that two processes, so different from each other, should each manufacture the same product. The explanation is simple if it be granted that these processes merely eliminate nitrogen from "atmospheric nitrogen."

Sixth: If the newly discovered gas were not in the atmosphere, the discrepancies in the density of "chemical" and "atmospheric" nitrogen would remain unexplained.

Seventh: It has been shown that pure nitrogen, prepared from its compounds, leaves a negligible residue when caused to enter into combination with oxygen or with magnesium.

There are other lines of argument which suggest themselves; but we think that it will be acknowledged that those given above are sufficient to establish the existence of argon in the atmosphere.

It is practically certain that the argon prepared by means of electric sparking with oxygen is identical with argon prepared by means of magnesium. The samples have in common:—

First: Spectra which have been found by Mr. CROOKES, Professor SCHUSTER, and ourselves to be practically identical.

Second: They have approximately the same density. The density of argon, prepared by means of magnesium, was 19.9; that of argon, from sparking with oxygen, about 19.7; these numbers are practically identical.

Third: Their solubility in water is the same.

That argon is an element, or a mixture of elements, may be inferred from the observations of § 14. For CLAUSIUS has shown that if K be the energy of translatory motion of the molecules of a gas, and H their whole kinetic energy, then

$$\frac{K}{H} = \frac{3(C_p - C_v)}{2C_v},$$

C_p and C_v denoting as usual the specific heat at constant pressure and at constant volume respectively. Hence, if, as for mercury vapour and for argon (§ 14), the ratio of specific heats $C_p : C_v$ be $1\frac{2}{3}$, it follows that $K = H$, or that the whole kinetic energy of the gas is accounted for by the translatory motion of its molecules. In the case of mercury the absence of interatomic energy is regarded as proof of the monatomic character of the vapour, and the conclusion holds equally good for argon.

The only alternative is to suppose that if argon molecules are di- or polyatomic, the atoms acquire no relative motion, even of rotation, a conclusion improbable in itself and one postulating the sphericity of such complex groups of atoms.

Now a monatomic gas can be only an element, or a mixture of elements; and hence it follows that argon is not of a compound nature.

According to AVOGADRO, equal volumes of gases at the same temperature and pressure, contain equal numbers of molecules. The molecule of hydrogen gas, the density of which is taken as unity, is supposed to consist of two atoms. Its mole-

cular weight is therefore 2. Argon is approximately 20 times as heavy as hydrogen, that is, its molecular weight is 20 times as great as that of hydrogen, or 40. But its molecule is monatomic, hence its atomic weight, or, if it be a mixture, the mean of the atomic weights of the elements in that mixture, taken for the proportion in which they are present, must be 40.

This conclusion rests on the assumption that all the molecules of argon are monatomic. The result of the first experiment is, however, so nearly that required by theory, that there is room for only a small number of molecules of a different character. A study of the expansion of argon by heat is proposed, and would doubtless throw light upon this question.

There is evidence both for and against the hypothesis that argon is a mixture: for, owing to Mr. CROOKES'S observations of the dual character of its spectrum; against, because of Professor OLSZEWSKI'S statement that it has a definite melting-point, a definite boiling-point, and a definite critical temperature and pressure; and because on compressing the gas in presence of its liquid, pressure remains sensibly constant until all gas has condensed to liquid. The latter experiments are the well-known criteria of a pure substance; the former is not known with certainty to be characteristic of a mixture. The conclusions which follow are, however, so startling, that in our future experimental work we shall endeavour to decide the question by other means.

For the present, however, the balance of evidence seems to point to simplicity. We have, therefore, to discuss the relations to other elements of an element of atomic weight 40. We inclined for long to the view that argon was possibly one, or more than one, of the elements which might be expected to follow fluorine in the periodic classification of the elements—elements which should have an atomic weight between 19, that of fluorine, and 23, that of sodium. But this view is apparently put out of court by the discovery of the monatomic nature of its molecules.

The series of elements possessing atomic weights near 40 are:—

Chlorine	35·5
Potassium	39·1
Calcium	40·0
Scandium	44·0.

There can be no doubt that potassium, calcium, and scandium follow legitimately their predecessors in the vertical columns, lithium, beryllium, and boron, and that they are in almost certain relation with rubidium, strontium, and (but not so certainly) yttrium. If argon be a single element, then there is reason to doubt whether the periodic classification of the elements is complete; whether, in fact, elements may not exist which cannot be fitted among those of which it is composed. On the other hand, if argon be a mixture of two elements, they might find place in the eighth group, one after chlorine and one after bromine. Assuming 37 (the

approximate mean between the atomic weights of chlorine and potassium) to be the atomic weight of the lighter element, and 40 the mean atomic weight found, and supposing that the second element has an atomic weight between those of bromine, 80, and rubidium, 85.5, viz., 82, the mixture should consist of 93.3 per cent. of the lighter, and 6.7 per cent. of the heavier element. But it appears improbable that such a high percentage as 6.7 of a heavier element should have escaped detection during liquefaction.

If the atomic weight of the lighter element were 38, instead of 37, however, the proportion of heavier element would be considerably reduced. Still, it is difficult to account for its not having been detected, if present.

If it be supposed that argon belongs to the eighth group, then its properties would fit fairly well with what might be anticipated. For the series, which contains



might be expected to end with an element of monatomic molecules, of no valency, *i.e.*, incapable of forming a compound, or if forming one, being an octad; and it would form a possible transition to potassium, with its monovalence, on the other hand. Such conceptions are, however, of a speculative nature; yet they may be perhaps excused, if they in any way lead to experiments which tend to throw more light on the anomalies of this curious element.

In conclusion, it need excite no astonishment that argon is so indifferent to reagents. For mercury, although a monatomic element, forms compounds which are by no means stable at a high temperature in the gaseous state; and attempts to produce compounds of argon may be likened to attempts to cause combination between mercury gas at 800° and other elements. As for the physical condition of argon, that of a gas, we possess no knowledge why carbon, with its low atomic weight, should be a solid, while nitrogen is a gas, except in so far as we ascribe molecular complexity to the former and comparative molecular simplicity to the latter. Argon, with its comparatively low density and its molecular simplicity, might well be expected to rank among the gases. And its inertness, which has suggested its name, sufficiently explains why it has not previously been discovered as a constituent of compound bodies.

We would suggest for this element, assuming provisionally that it is not a mixture, the symbol A.

We have to record our thanks to Messrs. GORDON, KELLAS, and MATTHEWS, and especially to Mr. PERCY WILLIAMS, for their assistance in the prosecution of this research.

ADDENDUM (by Professor W. RAMSAY).

March 20, 1895.

Further determinations of the density of argon prepared by means of magnesium have been made. In each case the argon was circulated over magnesium for at least

two hours after all absorption of nitrogen had stopped, as well as over red-hot copper, copper oxide, soda-lime, and phosphoric anhydride. The gas also passed out of the mercury gas-holder through phosphoric anhydride into the weighing globe. The results are in complete accordance with previous determinations of density; and for convenience of reference the former numbers are included in the table which follows.

DENSITY of Argon.

Date.	Volume.	Temperature.	Pressure.	Weight.	Weight of 1 litre at 0° and 760 millims.	Density (0 = 16).
	cub. centims.	°	millims.	gram.		
(1) Nov. 26 . . .	162·843	15·00	767·7	0·2773	1·7784	19·904
(2) „ 27 . . .	162·843	16·00	769·0	0·2757	1·7717	19·823
(3) Dec. 22 . . .	162·843	15·62	750·1	0·26915	1·7704	19·816
(4) Feb. 16 . . .	162·843	13·45	771·1	0·2818	1·7834	19·959
(5) „ 19 . . .	162·843	14·47	768·2	0·2789	1·7842	19·969
(6) „ 24 . . .	162·843	17·85	764·4	0·2738	1·7810	19·932

The general mean is 19·900; or if Nos. (2) and (3) be rejected as suspiciously low, the mean of the remaining four determinations is 19·941. The molecular weight may therefore be taken as 39·9 without appreciable error.

The value of R in the gas-equation $R = pv/T$ has also been determined between -89° and $+248^\circ$. For this purpose, a gas-thermometer was filled with argon, and a direct comparison was made with a similar thermometer filled with hydrogen.

The method of using such a hydrogen-thermometer has already been described by RAMSAY and SHIELDS.* For the lowest temperature, the thermometer bulbs were immersed in boiling nitrous oxide; for atmospheric temperature, in running water; for temperatures near 100° in steam, and for the remaining temperatures, in the vapours of chlorobenzene, aniline, and quinolene.

The results are collected in the following tables:—

HYDROGEN Thermometer.

Temperature.	Pressure.	Volume (corr.).	R.
° C.	millims.		
13·04	763·6	1·00036	2·6705
99·84	992·6	1·00280	2·6697
130·62	1073·8	1·00364	2·6701
185·46	1218·5	1·00518	2·6716
248·66	1385·1	1·00703	2·6737
- 87·92	497·3	0·99756	2·6804

* 'Trans. Chem. Soc.,' vol. 63, pp. 835, 836. It is to be noticed that the value of R is not involved in using the hydrogen-thermometer; its constancy alone is postulated.

The value of R is thus practically constant, and this affords a proof that the four last temperatures have been estimated with considerable accuracy.

ARGON Thermometer.

	Temperature.	Pressure.	Volume (corr.).	R.
	° C.	millims.		
Series I.	14·15	701·7	1·000396	2·4446
	14·27	699·7	1·000401	2·4366
	14·40	702·6	1·000404	2·4462
	99·96	906·5	1·00280	2·4379
	100·06	904·8	1·00280	2·4322
	−87·92	455·6	0·99756	2·4556
By mischance, air leaked into the bulb; it was therefore refilled.				
Series II.	130·58	1060·0	1·0037	2·6363
	185·46	1200·3	1·0052	2·6317
A bubble of argon leaked into the bulb, and the value of R increased.				
Series III.	12·05	760·9	1·00034	2·6698
	12·61	761·3	1·00034	2·6728
	248·66	1384·0	1·0070	2·6717
	248·66	1376·9	1·0070	2·6580
	−87·92	495·7	0·99756	2·6718

It may be concluded from these numbers, that argon undergoes no molecular change between -88° and $+250^{\circ}$.

Further determinations of the wave-length of sound in argon have been made, the wider tube having been used. In every case the argon was as carefully purified as possible. In experiment (3) too much lycopodium dust was present in the tube; that is perhaps the cause of the low result. For completeness' sake, the original result in the narrow tube has also been given.

Date.	Density.	Half-wave-length.		Temperature.		Ratio.
		In air.	In argon.	Air.	Argon.	
Dec. 6	19·92	19·59	18·08	17 ^o ·5	17 ^o ·5	1·644
Feb. 15	19·96	33·73	31·00	6·7	6·5	1·641
„ 20	19·97	34·10	31·31	7·22	8·64	1·629
Mar. 19	19·94	34·23	31·68	11·20	11·49	1·659

The general mean of these numbers is 1·643; if (3) be rejected, it is 1·648. In the last experiment every precaution was taken. The half-wave-length in air is the mean of 11 readings, the highest of which was 34·67 and the lowest 34·00. They run :—

34·67 ; 34·06 ; 34·27 ; 34·39 ; 34·00 ; 34·00 ; 34·13 ; 34·20 ; 34·20 ; 34·33 ; 34·33.
 11·25° ; 11·00° ; 10·80° ; 10·8° ; 10·0° ; 11·0° ; 11·3° ; 11·4° ; 11·4° ; 11·6° ; 11·6°.

With argon the mean is also that of 11 readings, of which the highest is 31·83, and the lowest, 31·5. They are :—

31·5 ; 31·5 ; 31·66 ; 31·55 ; 31·83 ; 31·77 ; 31·81 ; 31·83 ; 31·83 ; 31·50 ; 31·66.
 11·8° ; 11·8° ; 11·20° ; 11·40° ; 11·60° ; 11·40° ; 11·40° ; 11·4° ; 11·5° ; 11·5° ; 11·4°.

If the atomic weight of argon is identical with its molecular weight, it must closely approximate to 39·9. But if there were some molecules of A_2 present, mixed with a much larger number of molecules of A_1 , then the atomic weight would be correspondingly reduced. Taking an imaginary case, the question may be put :—What percentage of molecules of A_2 would raise the density of A_1 from 19·0 to 19·9? A density of 19·0 would imply an atomic weight of 38·0, and argon would fall into the gap between chlorine and potassium. Calculation shows that in 10,000 molecules, 474 molecules of A_2 would have this result, the remaining 9526 molecules being those of A_1 .

Now if molecules of A_2 be present, it is reasonable to suppose that their number would be increased by lowering the temperature, and diminished by heating the gas. A larger change of density should ensue on lowering than on raising the temperature, however, as on the above supposition, there is not a large proportion of molecules of A_2 present.

But it must be acknowledged that the constancy of the found value of R is not favourable to this supposition.

A similar calculation is possible for the ratio of specific heats. Assuming the gas to contain 5 per cent. of molecules of A_2 , and 95 per cent. of molecules of A_1 the value of γ , the ratio of specific heats, would be 1·648. All that can be said on this point is, that the found ratio approximates to this number ; but whether the results are to be trusted to indicate a unit in the second decimal appears to me doubtful.

The question must therefore for the present remain open.

ADDENDUM.

April 9.

It appears worth while to chronicle an experiment of which an accident prevented the completion. It may be legitimately asked, Does magnesium not absorb any argon, or any part of what we term argon? To decide this question, about 500 grms. of magnesium nitride, mixed with metallic magnesium which had remained unacted on, during extraction of nitrogen from "air-nitrogen," was placed in a flask, to which a reservoir full of dilute hydrochloric acid was connected. The

flask was coupled with a tube full of red-hot copper oxide, intended to oxidise the hydrogen which would be evolved by the action of the hydrochloric acid on the metallic magnesium. To the end of the copper-oxide tube a gas-holder was attached, so as to collect any evolved gas; and the system was attached to a vacuum-pump, in order to exhaust the apparatus before commencing the experiment, as well as to collect all gas which should be evolved, and remain in the flask.

On admitting hydrochloric acid to the flask of magnesium nitride a violent reaction took place, and fumes of ammonium chloride passed into the tube of copper oxide. These gave, of course, free nitrogen. This had not been foreseen; it would have been well to retain these fumes by plugs of glass-wool. The result of the experiment was that about 200 cub. centims. of gas were collected. After sparking with oxygen in presence of caustic soda, the volume was reduced to 3 cub. centims. of a gas which appeared to be argon.