THE DENSITY, COMPRESSIBILITY AND ATOMIC WEIGHT OF NEON

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The density of neon at different pressures and at 0° has been determined by the method described in recent papers.[1]

Crude neon, containing approximately sixty per cent of helium and nitrogen, was generously supplied by the Air Reduction Company through the courtesy of Professor H. N. Davis. The gas was first subjected to chemical purification in the train shown in figure 1, by being passed successively over solid potassium hydroxide in A, hot calcium in B_1, hot copper in C_1, hot copper oxide in D_1 and D_2, potassium hydroxide solution in E, solid potassium hydroxide in A_2, phosphorus pentoxide in F, hot copper in C_2 and hot calcium in B_2 and B_3. The product, which composed less than half the volume of the original gas, was stored in the seven, 750 ml., mercury gasometers H. During the subsequent purification it was found to contain approximately 15 per cent of helium and a small proportion of nitrogen.

In common with earlier investigators[2] we found fractional adsorption to be a satisfactory method for further purification. We used chilled dehydrated chabazite as adsorbent.

Spectroscopic examination of the gas during the course of the purification under certain conditions showed the first order hydrogen lines. While it seemed probable that this was due wholly or largely to traces of moisture, to vapor from the stopcock grease, or to gases held in the tungsten electrodes of the discharge tube, the possibility remained that hydrogen had been evolved in the tubes B_2 and B_3 containing calcium. Therefore, a secondary chemical train was added to the system, through which the gas could be circulated as desired. This train consisted of hot copper oxide in D_3, phosphorus pentoxide in F_2 and hot nickel in G. Before use this train was thoroughly exhausted while the copper oxide and nickel were not. Since after the gas had been passed through this train several times the hydrogen spectrum still appeared under the same conditions as before, it is doubtful whether the neon actually contained hydrogen at any time after the chemical purification.

Owing to the limited capacity of the storage system the gas was subjected to the chemical purification in three portions. The first two portions were combined as soon as their volumes had been sufficiently reduced by physical fractionation and were further purified. Later, a third portion was brought to the same stage of purification as the first two and

added to the combination.   All the final determinations were made with the mixture of all three.

For the fractional adsorption the chabazite (150 grams) was contained in the tube K, which could be connected at will with a mercury vapor pump, the gasometers H, the pump L, the spectrum tube or the density globes (shown in Fig. 3).   Preparatory to each adsorption the chabazite was outgassed at 550° in a high vacuum.   Ordinarily during use it was chilled with liquid nitrogen, although occasionally liquid oxygen was employed, through lack of nitrogen.   When the chabazite was used to adsorb about 5 liters of pure neon at the lower temperature the residual
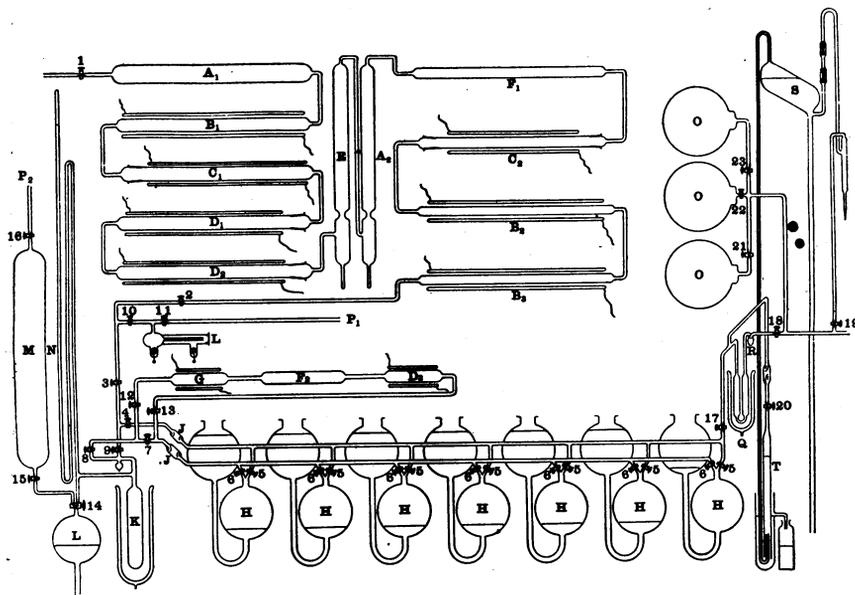

FIGURE 1

pressure of the neon was not over 15 cm., while at the higher temperature the residual pressure was 40 cm. or more.   The advantage of the lower temperature is, therefore, considerable.   Even at the lower temperature helium is far less adsorbed than neon, and may be rapidly though not sharply separated from neon by lowering the pressure over the chabazite. Nitrogen, on the other hand, is far more tenaciously retained by the chabazite than neon and may be eliminated by rejection of the fraction of gas remaining after the evaporation of the greater part of the neon.   The proportion of nitrogen was so small that only in the first few treatments with chabazite was it evolved in detectable amounts even at room temperature.   Repeated adsorption, with rejection of the least and most adsorbed fractions, was, therefore, employed for the progressive purification of the

neon. This method may be depended upon to eliminate other denser gases as well, although we found no evidence of their presence at any stage of the purification.

The progress of the purification was followed at first with a spectroscope, then by density determinations. The main portion of gas after only two adsorptions reached the stage where no impurities could be detected spectroscopically, but for several subsequent adsorptions the rejected more and less adsorbed fractions proved to contain nitrogen and helium, respectively.

The method of conducting an adsorption was as follows: The exhausted tube K containing chabazite was chilled with liquid nitrogen and put into communication with the receptacles containing neon. In the case of the storage reservoirs O, or the density globes, as soon as the pressure has reached a minimum, connection with the tube K was closed and by means of the Töpler pump S the residual gas was pumped into one of the gasometers H. Any gas in the gasometers was then transferred to the chabazite tube by filling them with mercury. After standing for some time the unabsorbed gas was allowed to expand into the pump L and then was either discarded, or transferred to the reservoir M. The middle fraction, usually the bulk of the gas, was next allowed to evaporate into the gasometers, or, in the case of a density determination, directly into the density bulbs through the chilled chabazite tube Q. The greater part of the residual gas in the chabazite was collected in the gasometers and the residue was either discarded or collected in the reservoir M.

The course of the purification by adsorption for the three portions of neon is shown in figure 2. The initial volumes refer to chemically purified gas. The course of each main sample is indicated by the vertical lines below the circle, each crossing by a horizontal line representing a separate adsorption. Circles to the right of the main line represent less volatile, those to the left more volatile fractions, the approximate volumes of which appear in the circles. If light or heavy fractions were preserved for further treatment the corresponding circles are connected by lines and arrows to others with which they were combined.

For instance, the first sample was adsorbed twice in succession, 300 ml. light fractions and 50 ml. heavy fractions being separated. The heavy fractions were rejected. The light fractions were combined and adsorbed separately. A 25 ml. middle fraction was added to the main portion. A 25 ml. heavy fraction was rejected and a 550 ml. light fraction was combined with a later one of the same size for further fractionation.

After five adsorptions the purified portions of the first two lots of neon were combined for further treatment. As soon as the mixture had been subjected to two adsorptions the first density determination was made. The result of this experiment was essentially that ultimately found as the

average of all.   Four more adsorptions reduced the volume of gas so far
that a third portion was brought to the same stage of purity.   Owing to
less liberality in the size of the light fractions rejected and to the fact that
a considerable volume of helium-containing neon, resulting from the puri-
fication of the first two samples, was added to the third at an early stage,
a larger number of adsorptions was necessary than with the first two

FIGURE 2

samples before the density reached the constant value already found with
the earlier material.   In series 6, 7 and 8 the density was gradually rising
to a maximum reached in series 9 and 10.   At this point all the purified
material was combined for the final series (11 to 26).

   The low results of series 6–8 led to the suspicion that the gas might still
contain hydrogen as well as helium and caused the addition of the system

D_3, F_2, G, containing copper oxide, phosphorus pentoxide and nickel, through which all the gas was circulated several times. As stated before this produced no apparent alteration in the intensity of the hydrogen spectrum.

Aston[2] has already found that in a prolonged series of 3000 fractional adsorptions no perceptible isotopic separation of neon takes place. The
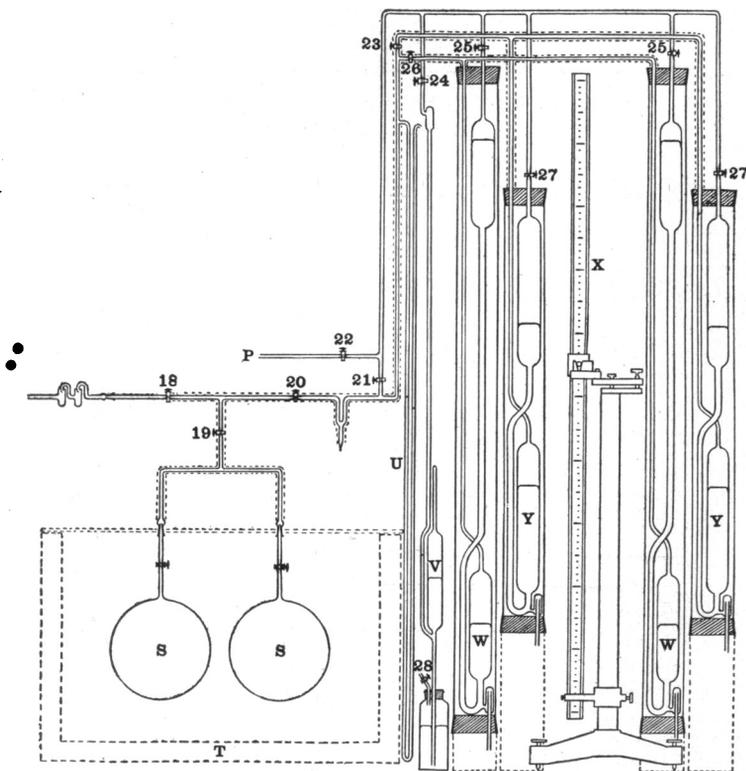

FIGURE 3

P—Lead to mercury vapor pump. *S, S*—Density Globes. *T*—Ice bath for density globes. *U*—Open arm manometer. *V*—McLeod gauge. *W, W*—High-pressure barometers. *X*—Invar meter bar. *Y, Y*—Low-pressure barometers.

essentially constant density reached by our material after a few adsorptions bears out this conclusion.

Although the apparatus for filling the globes and measuring the pressure has already been described,[3] a diagram is reproduced here.

The weights used for weighing the gas and for determining the volumes of the globes at 0° were referred by the Richards substitution method[4] to the same standard.

Corrections for the compressibilities of the globes were applied both to the weights of gas and to the volumes of the globes when filled at the lower pressure.

Pressure corrections were applied for small differences in level between the centers of the globes and the lower levels of the barometers. Since the actual pressures at which the globes were filled were always very near the reference pressures no corrections for deviations from Boyle's Law were necessary.

Since the temperature of the ice bath was usually a few thousandths of a degree below the freezing point corrections for this fact were made on the assumption that the temperature coefficient of neon is 0.003663 at 0°.

The readings of the invar meter bar were corrected for errors in the scale as determined by the Bureau of Standards, and for its coefficient of expansion.

In calculating the density of neon the following constants were employed:

Density of water at 0°	0.999868
Cubical coefficient of expansion of mercury	0.0001818
Acceleration of gravity at Lat. 45° and sea level	980.616
Acceleration of gravity at Coolidge Laboratory	980.399

No experiments have been omitted from table 1.

Earlier values found by other experimenters at one atmosphere are as follows:

Ramsay and Travers[5]	0.891
Watson[6] (determinations at 0°)	0.9000
(determinations at 16–18°)	0.9004
LeDuc[7]	0.8985
Aston[8]	0.9016

In table 2 are given the values of PV at different pressures calculated by the method of Guye[9] from the corresponding densities, on the basis of unit value for the product at one atmosphere.

If the change in PV is assumed to be proportional to the change in pressure, and equal weight is given to the values at the two lower pressures the value calculated for zero pressure is 0.99942. This value is considerably higher than that found experimentally by Burt, 0.99895.[10]

The atomic weight of neon calculated from the above values of density and deviation from Boyle's Law, as well as the corresponding values for oxygen found by us,[11] 1.42897 and 1.00092, is 20.182.

At the end of the following paper are given the results of calculating the deviation from Boyle's Law and atomic weight of neon by a more rational method.

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TABLE 1
THE DENSITY OF NEON

0° $g = 980.616$

SERIES	SAMPLE	NUMBER OF ADSORPTIONS	GLOBE IV 2110.95 ML.	GLOBE VII 2117.77 ML.	AVERAGE
			$P = 760$ mm.		
1	1	7		0.89991	
2	1	9		0.89988	
4	1	11		0.89987	
			Average	0.89989	
6	2	11		(0.89785)	
7	2	15		(0.89892)	
8	2	19		(0.89948)	
9	2	23		0.89992	
10	2	27		0.89990	
			Average	0.89991	
11	1 + 2	13 and 29	0.89991	0.89994	0.89993
13	1 + 2	15 and 31	0.89987	0.89996	0.89992
15	1 + 2	17 and 33	0.89988	0.89991	0.89990
17	1 + 2	18 and 34	0.89981	0.89990	0.89986
19	1 + 2	19 and 35	0.89993	0.89992	0.89993
21	1 + 2	20 and 36	0.89984	0.89997	0.89992
		Average	0.89987	0.89993	0.89991
Average of all except series 6, 7 and 8					0.89990
			$P = 506.667$ mm.		
3	1	9		0.60000	0.60000
12	1 + 2	13 and 29	0.60000	0.60007	0.60004
16	1 + 2	17 and 33	0.60007	0.60010	0.60009
18	1 + 2	18 and 34	0.60002	0.60014	0.60008
23	1 + 2	21 and 37	0.59999	0.60006	0.60003
25	1 + 2	22 and 38	0.59998	0.60006	0.60002
		Average	0.60001	0.60007	0.60004
			$P = 253.333$ mm.		
5	1	11	0.30000	0.30007	0.30004
14	1 + 2	15 and 31	0.30007	0.30009	0.30008
20	1 + 2	19 and 35	0.30003	0.30010	0.30007
22	1 + 2	20 and 36	0.30009	0.30018	0.30014
24	1 + 2	21 and 37	0.30012	0.30010	0.30011
26	1 + 2	22 and 38	0.30011	0.30012	0.30012
		Average	0.30007	0.30011	0.30009

TABLE 2

PRESSURES ATMOSPHERES	Pv
1	1.00000
2/3	0.99982
1/3	0.99959

the American Academy of Arts and Sciences for generous assistance, without which this work would not have been possible.

[1] Baxter and Starkweather, these PROCEEDINGS, **10**, 479 (1924); **11**, 231 (1925); **12**, 20, 699, 703 (1926).

[2] Watson, *J. Chem. Soc.*, **97**, 810 (1910); Aston, *Phil. Mag.*, **37**, 523 (1919).

[3] See Baxter and Starkweather, these PROCEEDINGS, **12**, 701 (1926).

[4] Richards, *J. Amer. Chem. Soc.*, **22**, 144 (1900).

[5] Ramsay and Travers, *Trans. Roy. Soc.*, **197**, 47 (1901).

[6] Watson, *J. Chem. Soc.*, **97**, 810 (1910).

[7] LeDuc, *Compt. Rend.*, **158**, 864 (1914); *Ann. Physique* [9] **9**, 24 (1918).

[8] Aston, *Proc. Roy. Soc.*, **A89**, 439 (1914); *Phil. Mag.*, **37**, 523 (1919).   This result is corrected by us for deviation of neon from Boyle's law.

[9] Guye, *J. chim. phys.*, **17**, 171 (1919).

[10] Burt, *Trans. Far. Soc.*, **6**, 19 (1910).

[11] Baxter and Starkweather, these PROCEEDINGS, **12**, 699 (1926).

THE DENSITY, COMPRESSIBILITY AND ATOMIC WEIGHT OF ARGON

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In two recent discussions of earlier work upon the density of argon, by Blanchard and Pickering,[1] and Moles,[2] the more probable values 1.7825 and 1.7833, respectively, are deduced.   Since both these figures involve corrections of somewhat dubious validity, the atomic weight of argon derived from them is uncertain in the second decimal place.

We have applied to argon the methods utilized in determining the densities and compressibilities of oxygen, nitrogen, helium and neon,[3] and find the normal density 1.78364 and the limiting density 1.78204. The atomic weight of argon computed from these figures is 39.943.

Argon was very generously provided by the Air Reduction Co., through the courtesy of Mr. C. C. Van Nuys.   The gas as furnished was stated to be nearly 99 per cent pure, the impurity being chiefly nitrogen with a trace of oxygen.   In the course of the purification which we employed we were unable to detect any of the less abundant rare gases.   The chemical purification train consisted of solid potassium hydroxide in A (Fig. 1), hot copper in B, hot copper oxide in C_1 and C_2, aqueous potassium hydroxide in D, solid potassium hydroxide in E, phosphorus pentoxide in F_1, hot calcium in G_1 and G_2, hot copper oxide in C_3, phosphorus pentoxide in F_2 and hot nickel in H.   The U-tube J contained chabazite chilled with ice, and the tube K contained chabazite chilled with liquid air.   In L the first portion of chemically purified argon was liquefied, and the remainder of