

would result in an almost normal behavior of the velocity of propagation of sound waves in a B-E fluid around the quantum-condensation temperature, if one leaves out of account the transport properties of the fluid. However, the comparison of this result with the experimental data<sup>3</sup> on liquid He seems to be difficult in view of the strange transport properties of liquid He II.<sup>4</sup> It seems rather that the experimental results on the scattering of light by liquid He around the transition temperature admit a far more direct interpretation in terms of the properties of elasticity of this fluid than those relative to the velocity of propagation of sound waves.

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<sup>1</sup> F. London, Phys. Rev. **54**, 947 (1938).

<sup>2</sup> A. Einstein, Ber. Berl. Akad. 261 (1924) and 3 (1925).

<sup>3</sup> E. F. Burton, Nature **141**, 970 (1938); J. O. Wilhelm, Phys. Rev. **54**, 506 (1938).

<sup>4</sup> Cf. J. E. Groenewold, Physica **6**, 303 (1939).

#### Thermal Separation Ratios Calculated from Viscosity Data

In the design of the apparatus and the choice of a suitable gas for the separation of isotopes by the thermal diffusion-thermal syphoning method, the ratio of the coefficient of thermal diffusion  $D_T$  to the coefficient of self-diffusion  $D$  plays a very important role.<sup>1</sup> For the case of isotopes

$$D_T/D = K_T = \alpha c_1 c_2, \quad (1)$$

where  $c_1$  and  $c_2$  are the relative particle densities of our two species and

$$\alpha = \frac{105}{118} \frac{(m_2 - m_1)}{(m_2 + m_1)}$$

for elastic spheres, the  $m$ 's being the relative masses of the two types of particles.

The variation of viscosity with temperature being now known with a considerable degree of accuracy for a great many gases, it is of interest to calculate the thermal separation ratios (ratio of  $K_T$  for the actual gas to  $K_T$  for elastic

spheres) from Chapman's limiting equations relating  $\alpha$  to the repulsive force index.<sup>2</sup> According to Chapman<sup>3</sup>

$$R_T = K_T / (K_T)_{e.s.} = \alpha / \alpha_{e.s.} = (s-5)/(s-1), \quad (2)$$

where  $s$  is the repulsive force index of the molecules, and the subscript e.s. denotes rigid elastic spheres.

For the variation of viscosity with temperature we have

$$\eta = aT^n, \quad (3)$$

where  $\eta$  is the coefficient of viscosity at the absolute temperature  $T$ ,  $a$  is a constant, and  $n$  is related to the repulsive force index by

$$n = \frac{1}{2} [(s+3)/(s-1)]. \quad (4)$$

In general,  $n$  varies with the temperature.

From the above expressions, the values of  $s$  and  $R_T$  for the various gases given in Table I were calculated. The  $n$  values used were taken at  $T=450^\circ\text{K}$ , which is a likely average temperature for a thermal diffusion column.

It has been found that thermal diffusion data for mixtures of the monatomic rare gases give values of  $R_T$  that are in quite good agreement with values calculated in the above approximate manner.<sup>4</sup> However, the recent work of Nier<sup>5</sup> with methane indicates that Eq. (2) is perhaps none too reliable for complex polyatomic molecules. Nier obtains a value of  $R_T$  for methane of 0.3 which is about  $\frac{2}{3}$  of the value calculated here. Nevertheless, calculations of this type are of interest, because they do give the order of magnitude of the value of  $R_T$  to be expected experimentally, and the relative values of  $R_T$  to be expected for different molecules. Consequently such preliminary calculations can be used as a guide in choosing a suitable molecular species for isotope separation by the thermal method.

For example, one can see from Table I that  $\text{N}_2$  would be a far more suitable gas to use than either  $\text{NH}_3$ ,  $\text{NO}$ , or  $\text{N}_2\text{O}$  for the separation of the nitrogen isotopes. Similarly the hydrogen halides should be much more satisfactory than the halogen gases. For the separation of the oxygen isotopes,  $\text{CO}$  is the most satisfactory gas listed. It has the advantage over  $\text{O}_2$  in both its value of  $R_T$  and the mass of the molecule. It is interesting that in spite of the fact that the molecular weight of  $\text{CO}$  is greater than that of methane, because of its larger  $R_T$  it should yield an  $\alpha$ -value almost as large as that of methane. Of the rare gases, neon and argon

TABLE I. Values of  $n$ ,  $s$  and  $R_T$  for various gases at  $T=450^\circ\text{K}$ .

GAS	$n$	$s$	$R_T$	REF.	GAS	$n$	$s$	$R_T$	REF.
He	0.667	13.1	0.67	<i>a</i>	$\text{N}_2$	0.687	11.8	0.63	<i>d</i>
Ne	0.644	14.7	0.71	<i>a</i>	$\text{NH}_3$	1.05	4.6	-0.10	<i>d</i>
A	0.76	8.7	0.48	<i>a</i>	$\text{NO}$	0.975	5.2	0.05	<i>g</i>
Xe	0.994	5.05	0.01	<i>b</i>	$\text{N}_2\text{O}$	0.90	6.0	0.20	<i>f</i>
$\text{Cl}_2$	0.989	5.1	0.02	<i>c</i>	$\text{CH}_4$	0.769	8.4	0.46	<i>e</i>
$\text{Br}_2$	0.985	5.1	0.03	<i>c</i>	$\text{C}_2\text{H}_6$	0.867	6.5	0.27	<i>e</i>
$\text{I}_2$	1.04	4.7	-0.08	<i>c</i>	$\text{C}_2\text{H}_8$	0.909	5.9	0.18	<i>e</i>
HCl	0.94	5.5	0.12	<i>a</i>	$\text{C}_2\text{H}_4$	0.840	6.9	0.32	<i>d</i>
HI	0.94	5.5	0.12	<i>c</i>	$\text{CO}_2$	0.90	6.0	0.20	<i>f</i>
$\text{O}_2$	0.731	9.7	0.54	<i>d</i>	$\text{CO}$	0.68	11.8	0.63	<i>h</i>
$\text{H}_2$	0.667	13.1	0.67	<i>d</i>	$\text{SO}_2$	1.05	4.6	-0.10	<i>i</i>

<sup>a</sup> M. Trautz and H. Binkele, Ann. d. Physik **20**, 118 (1934).

<sup>b</sup> M. Trautz and R. Heberling, Ann. d. Physik **20**, 118 (1934).

<sup>c</sup> M. Trautz and H. Winterkorn, Ann. d. Physik **10**, 511 (1931).

<sup>d</sup> M. Trautz and R. Heberling, Ann. d. Physik **10**, 155 (1931).

<sup>e</sup> M. Trautz and K. Sorg, Ann. d. Physik **10**, 81 (1931).

<sup>f</sup> M. Trautz and F. Kurtz, Ann. d. Physik **9**, 981 (1931).

<sup>g</sup> M. Trautz and E. Gabriel, Ann. d. Physik **11**, 606 (1931).

<sup>h</sup> M. Trautz and A. Melster, Ann. d. Physik **7**, 409 (1930).

<sup>i</sup> M. Trautz and W. Weizel, Ann. d. Physik **78**, 305 (1925).

should be quite easily resolved. Xenon should be more difficult because of its close approach to the Maxwellian state.

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<sup>1</sup> W. Furry, R. Jones and L. Onsager, Phys. Rev. **55**, 1083 (1939).

<sup>2</sup> S. Chapman, Phil. Mag. **7**, 1 (1929).

<sup>3</sup> Combination of Eqs. (23') and (23'') of reference 2.

<sup>4</sup> B. Atkins, R. Bastick and T. Ibbs, Proc. Roy. Soc. **172**, 142 (1939).

<sup>5</sup> A. Nier, Phys. Rev. **56**, 1009 (1939).

### New Energy Levels in the Silver Atom

With an ordinary arc between electrodes of pure silver a number of new weak lines were observed, by means of which a few new levels in the silver atom were discovered, especially the important  $d^9s^2 2D$  term, which has been looked for by several investigators.<sup>1</sup>

A preliminary list of the classified wave-lengths and the estimated relative intensities is given in Table I, while Table II contains the calculated new terms. It will be seen from the tables that two more members of the  $2P$  series have been found by means of pairs of infra-red lines forming the second and the third members of the combination series  $6^2S-m^2P$ . With these new  $2P$  terms the wave-lengths of the third and the fourth members of the principal series can be calculated to be  $\lambda\lambda 1850.5$ ,  $1847.7$  and  $1766.2$ ,  $1764.9\text{\AA}$ , which are in sufficient agreement with some of the wave-lengths of unclassified lines given in *Kaysers Handbook*. The  $2P$  series is quite regular as well in regard to the effective quantum numbers as to the size of the doublet splitting.

The  $d^9s^2 2D$  term was found by the combinations with the  $2P$  terms forming a series of inverted doublets with the  $d^9s^2 2D$  term as limit term, and further, in analogy with the copper spectrum, combinations with  $2F$  terms were found. The correctness of the deep  $d^9s^2 2D$  term is confirmed by its splitting,  $4472\text{ cm}^{-1}$ , which corresponds to the value estimated by McLennan and McLay. The three pairs of lines with this difference found by them may therefore give the values  $-4532$ ,  $-5867$  and  $-12,421\text{ cm}^{-1}$  of three higher terms belonging to the displaced system.

TABLE I. Wave-lengths and relative intensities in arc spectrum of silver.

F	$\lambda$	$\nu$	COMBINATION
5	8704.9	11484.6	$6^2S_{1/2}-7^2P_{1/2}$
10	8644.7	11564.6	$6^2S_{1/2}-7^2P_{3/2}$
8	7360.0	13583.2	$d^9s^2 2D_{3/2}-6^2P_{1/2}$
2	7251.5	13786.5	$d^9s^2 2D_{3/2}-6^2P_{3/2}$
3	7108.5	14063.8	$6^2S_{1/2}-8^2P_{1/2}$
6	7088.4	14103.7	$6^2S_{1/2}-8^2P_{3/2}$
10	5475.4	18258.4	$d^9s^2 2D_{5/2}-6^2P_{3/2}$
7	5172.8	19326.5	$d^9s^2 2D_{3/2}-7^2P_{1/2}$
1	5151.4	19406.8	$d^9s^2 2D_{3/2}-7^2P_{3/2}$
5	5129.2	19490.8	$d^9s^2 2D_{3/2}-4^2F_{5/2}$
3	4563.8	21905.4	$d^9s^2 2D_{3/2}-8^2P_{1/2}$
8	4186.6	23879.0	$d^9s^2 2D_{5/2}-7^2P_{3/2}$
4	4172.0	23962.6	$d^9s^2 2D_{5/2}-4^2F_{7/2}$
2	3784.1	26418.9	$d^9s^2 2D_{5/2}-8^2P_{3/2}$

TABLE II. Calculated new terms in silver.

TERM	VALUE	$\Delta\nu$	$n^*$
$d^9s^2 2D_{5/2}$	30863.2	4472.2	
$d^9s^2 2D_{3/2}$	26391.0		
$7^2P_{1/2}$	7063.9	80.0	3.9414
$7^2P_{3/2}$	6983.9		
$8^2P_{1/2}$	4484.7	39.9	4.9466
$8^2P_{3/2}$	4444.8		

Although the deep metastable  $d^9s^2 2D$  term is only represented very weakly in the silver arc spectrum (probably because of its nearness to the deep  $2P$  term), it is very probable that it plays an important role for the chemical behavior of the silver atom. Especially it seems promising to take the existence of this level into account in the theoretical discussion of the photochemical properties of the silver halides. The fact that the excitation potentials for the lowest levels in the silver atom (3.65 and 3.76 volts for the  $2P$  term; 3.73 and 4.28 volts for the  $2D$  term) nearly coincide with the values of electron affinities for the halogen atoms seems to be connected with the exceptional behavior of the silver halides and to suggest an explanation of the atomic mechanism of the photographic process.

A detailed report of the silver arc spectrum involving higher levels of the quartet system is under preparation and will be published in the *Proceedings of the Royal Society, Denmark*. I wish to express my thanks to Professor Niels Bohr for his kind interest in this work.

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### New Vacuum Tube Scaling Circuits of Arbitrary Integral or Fractional Scaling Ratio

It is the purpose of this note to give a brief report on new scaling circuits having scaling ratios equal to any integer or the ratio of any two integers. In particular, a scale-of-10 or decade counter has been constructed according to these principles and tested satisfactorily up to 100,000 pulses per second. The essential idea behind these new circuits is that some of the  $N$  states of a scale-of- $N$  circuit are thrown away in order to obtain arbitrary scaling ratios less than  $N$ .

The basic component of the method is the usual vacuum tube scale-of-2.<sup>1</sup> A series of  $n$  stages of scale-of-2 has a scaling ratio of  $2^n = N$ . Each scale-of-2 has two states of electrical equilibrium. Similarly, a scale-of- $N$  has  $N$  states, indicated in Table I for  $N=16$ .

In a scale-of-16 the four stages have associated numbers of 1, 2, 4, and 8, respectively. If we designate the two tubes in each stage by  $A$  and  $B$ , then all tubes  $A$  are nonconducting in the zeroth state. Starting in the zeroth state, or zero reset condition, the circuit goes through its 16 states in succession as input pulses are applied. To obtain a scale-of-10 circuit, we may (1) start at the zeroth state and go up