tronen bei der Ionisierung der Neutralteilchen auf die gebildeten Sekundärelektronen Energie übertragen, die diese befähigt, den Molekularstrahlbereich gegen ein positives Raumladungspotential zu verlassen. Der Aufbau des positiven Raumladungspotentials wird dadurch begünstigt, daß die gebildeten cluster-Ionen wegen ihres kleinen Verhältnisses von Ladung zu Masse aus dem Gebiet mit positiver Raumladung wesentlich langsamer abwandern, als normale Molekül- oder Atomionen. Es ist daher anzunehmen, daß bei der koaxialen Durchdringung von Elektronenstrahl und kondensiertem Molekularstrahl eine Art Fadenstrahleneffekt [10] auftritt, durch den die Elektronen in der Achse des Molekularstrahls konzentriert werden.

[10] E. Brüche u. W. Ende, Z. Phys. **64**, 186 [1930].

Separation of Binary Gas Mixtures by Thermal Diffusion Columns

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Two hot-wire type of glass thermal diffusion columns (approximately 3 m long, 8 mm internal diameter and fitted with an axial platinum wire 0.5 mm diameter) have been used to study the characteristics of gas mixture separation. In particular, the mixtures of Ne-Ar and He-Ar are examined, and the dependence of the separation factor, q, on the pressure and composition of the gas mixture and the temperature of the hot-wire is investigated. The variation of q with pressure and temperature for nonisotopic mixtures is in qualitative agreement with the predictions of the theory for isotopic mixtures. Further q is found to increase as the proportion of the lighter component in the mixture is decreased. These conclusions are of special relevance for the purification of gas mixtures viz., the removal of the lighter gas impurity from the mixture.

The theory of thermal diffusion columns, as applied to isotopic gas mixtures, is well known [1], but very little is understood for nonisotopic gas mixtures because of their involved nature, in spite of their great relevance in the separation and purification processes. Consequently, efforts have been made to experimentally investigate the dependence of the separation factor for nonisotopic gas mixtures as a function of different variables. Recently, we [2] analysed the available data concerning the pressure dependence of the separation factor and found that, even for nonisotopic gas mixtures, the theory derived for isotopic gas mixtures holds qualitatively.[2] Here we report results on two binary gas systems, Ne-Ar and He-Ar, as obtained from hot-wire type of glass thermal diffusion columns. The investigations include the dependence of the separation factor on (a) the pressure of the gas mixture, (b) the temperature of the hot-wire, and (c) the composition of the mixture.

Experimental

The general design of our thermal diffusion columns is similar to that used by us [3] earlier in connection with isotopic separation. Our columns consist of a pyrex glass tube of uniform bore of 7.8 mm internal diameter and are surrounded by a jacket of 40 mm outer diameter through which water is circulated at a proper rate to maintain it at a constant temperature. A platinum wire of 0.5 mm diameter is installed along the tube axis with the help of 20 mil nickel spacers, spot welded 50 cm apart. The platinum wire is 99.99% pure and is supplied by M/S Ravindra Heraeus Co., Bombay. The other details of the columns and associated units are given elsewhere [4]. The experiments reported here were performed on two

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[1] See for example S. C. Saxena and S. Raman, Rev. Mod. Phys. **34**, 252 [1962].

[2] V. K. Saxena and S. C. Saxena, Z. Naturforsch. **23** a, 471 [1968].

[3] V. K. Saxena and S. C. Saxena, Indian J. Technol. **4**, 227 [1966].

[4] V. K. Saxena, Studies on the Transport Properties of Gases, Ph. D. Thesis, Physics Department, Rajasthan University, Jaipur, India, 1967.

identical columns except for their lengths. These will be referred to as: column A, length 333.5 cm, and column B, length 299.2 cm.

The spectroscopically pure grade gases helium, neon, and argon used here are supplied by British Oxygen Co., England. A typical run consists in evacuating the column to 10^{-6} cm of Hg pressure and then loading it with the test mixture at the desired pressure. The wire is energized by a d.c. power pack to heat it to different temperatures, while the cold wall is maintained at a constant temperature (T_1) of 303.5 °K. The steady state samples are analysed on a sensitive differential thermal conductivity analyser[5,6] within a percent. A few runs are also made on the natural isotopic mixture of neon, the enriched samples being analysed on a mass spectrometer model MS-GP(O2) at the Bhabha Atomic Research Center, Bombay. We estimate the accuracy of this analysis within two percent.

The separation in a column is expressed in terms of the separation factor, q, defined as

$$q = x_1^t(1 - x_1^b)/[x_1^b(1 - x_1^t)]. \quad (1)$$

Here x_1^t and x_1^b are the mole fractions of the lighter component in the mixture at the top and bottom ends of the column respectively. The theory[1] of isotopic mixtures gives the following form for the pressure dependence of q:

$$\ln q = (a/p^2)/[1 + (b/p^4)]. \quad (2)$$

Here a and b are complicated functions of the column geometry, the temperatures of the hot and cold walls, properties of the gas mixture and intermolecular force law only, and p is the pressure of the gas. The separation factor exhibits a maximum at a particular pressure. We refer to these values by q_{opt} and p_{opt} respectively. Both these quantities can be written in terms of the constants a and b of Eq. (2) as,

$$p_{\text{opt}} = (b)^{1/4} \quad (3)$$

and

$$q_{\text{opt}} = \exp(a/2\sqrt{b}). \quad (4)$$

A detailed account of thermal diffusion column work covering constructional features, theories, separation of gas mixtures, etc. has recently appeared in a monography by VASARU, MÜLLER, REINHOLD, and FODOR[7].

Results

The experiments were started with column A and a mixture of neon-argon containing 17% neon. The experimentally determined separation factors at two pressures are reported in Table 1. A careful check revealed that the column is not perfectly vertical and some parasitic remixing is limiting the overall separation. As a further check we performed a few experiments with isotopic mixtures of neon. These results are also listed in Table 1. The separation factors are again found to be smaller than the previously obtained values on a somewhat similar column[3] and those predicted by theory[1,3] for the inverse power potential (values designated with superscript [a] in Table 1) and for the Lennard-Jones (12—6) potential (with superscript [b] in Table 1). We have therefore deferred further use of this column and erected a similar column referred to as column B and performed a series of measurements reported below.

(a) Pressure Dependence of q

A neon-argon mixture, again containing 17% neon, was filled into column B and steady state separation factors were determined at four different gas pressures. These results are recorded in Table 1 and graphically shown in Fig. 1. A similar set of experiments was made on a different mixture of neon-argon (83% neon) with results listed in Table 1 and graphically displayed in Fig. 2. Both

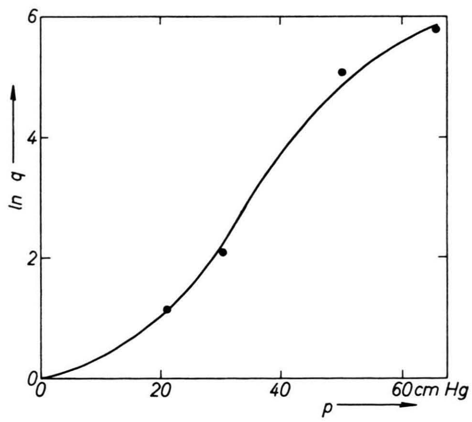

Fig. 1. $\ln q$ versus p for a Ne-Ar mixture (17% Ne). Solid circles represent experimental points. The curve is a least square fit through the experimental points on the basis of Eq. (2). The electrical power fed to the axial hot wire was 340 watt.

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[7] G. VASARU, G. MÜLLER, G. REINHOLD and T. FODOR, The Thermal Diffusion Column, VEB Deutscher Verlag der Wissenschaften, Berlin 1969.

System	T_2 °K	p cm Hg	ln q (exptl)	ln q Eq. (2)	Column
$Ne^{20}-Ne^{22}$	1119	22.1	0.13	0.48[a] 0.40[b]	A
		37.5	0.31	0.95[a] 0.90[b]	A
Ne-Ar (17% Ne)	1302	41.4	3.30	—	A
		52.4	3.93	—	A
Ne-Ar (17% Ne)	1313	21.2	1.14	1.11	B
		30.3	2.06	2.20	B
		50.1	5.11	4.88	B
		65.8	5.83	5.88	B
	1130	21.2	0.77	—	B
	1577	21.2	1.31	—	B
Ne-Ar (83% Ne)	1003	28.1	0.50	0.38	B
		40.4	0.78	0.88	B
		50.1	1.26	1.27	B
		61.7	1.73	1.69	B
He-Ar (22% He)	881	20.6	1.65	1.81	B
		30.7	4.09	3.70	B
		39.8	5.25	5.27	B
		60.3	6.01	6.02	B
	996	20.6	1.68	—	B
	1039	20.6	1.71	—	B
He-Ar (46% He)	949	10.0	0.38	0.36	B
		15.4	0.78	0.82	B
		21.9	1.44	1.42	B

[a] Theoretically calculated values for the inverse power potential.
[b] Theoretically calculated values for the Lennard-Jones (12—6) potential.

Table 1. Values of the separation factor (q) as a function of pressure (p), temperature of the hot wire (T_2), for the two thermal diffusion columns (A and B) and for isotopic and nonisotopic binary gas systems. The temperature of the cold wall (T_1) is 303.5°K.

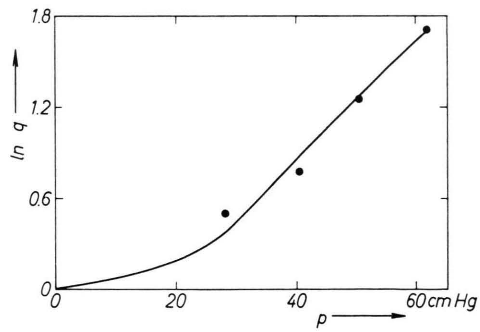

Fig. 2. The legend is the same as in Fig. 1. except for the mixture composition (83% Ne).

figures indicate that the general trend of variation of ln q with p is the same as found for isotopic gas mixtures. Consequently, Eq. (2) fitted through the experimental points in each case and the constants a and b were determined by the method of least squares. These values are given in Table 2 along with p_{opt} and q_{opt} as obtained from Eqs. (3) and (4) respectively.

Similarly, two mixtures of different compositions of helium and argon were examined. These results are recorded again in Table 1 and plotted in Figs. 3 and 4. These measurements again confirm the pressure dependence of ln q for nonisotopic mixtures to be of the same form as for isotopic mixtures.

System	T_2 °K	a atm²	b atm⁴	p_{opt} cm Hg	q_{opt}	Column
Ne-Ar (17% Ne)	1302	4.44	0.311	56.8	53.8	A
Ne-Ar (17% Ne)	1313	9.71	0.676	68.9	367	B
Ne-Ar (83% Ne)	1003	5.19	1.58	85.2	7.87	B
He-Ar (22% He)	881	6.12	0.343	53.4	490	B
He-Ar (46% He)	949	0.627	0.030	31.6	6.20	B

Table 2. Values of the constants a and b of Eq. (2), and of p_{opt} and q_{opt} from Eqs. (3) and (4) respectively.

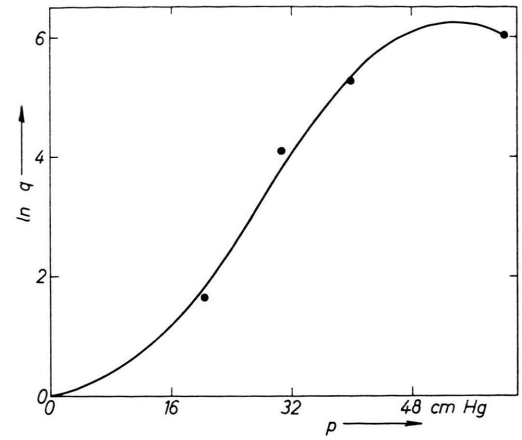

Fig. 3. ln$q$ versus p for a He-Ar mixture (22% He). Solid circles represent experimental points and the curve is a least square fit through the experimental points on the basis of Eq. (2). The electrical power fed to the axial wire was 204 watt.

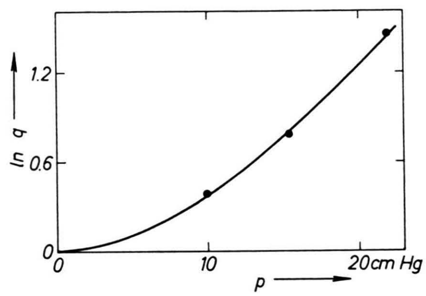

Fig. 4. The legend is the same as in Fig. 3 except for the mixture composition (46% He) and electrical power (310 watt).

Particularly interesting are the data of Fig. 3 where the observed points do establish a maximum. Eq. (2) when fitted through these data leads to the values of a and b given in Table 2. Also recorded in this table are the values of p_{opt} and q_{opt} from Eqs. (3) and (4) respectively.

These studies along with similar conclusions drawn by us[2] from the experimental data on a number of nonisotopic gas mixtures of different groups of workers establish that Eq. (2) is successful and reliable in representing the pressure dependence of q. This inference is of particular value because, given a few points, one can calculate p_{opt} and q_{opt}.

(b) Temperature Dependence of q

The separation factor depends sensitively and in a complicated way on the temperature of the hot wire[1,8], and this becomes more involved for nonisotopic mixtures. The composition profile along the legnth of the column creates appreciable temperature nonuniformity of the hot wire. The values of Table 1 refer to the average temperature (T_2) as determined by the net linear expansion of the wire.

We performed two sets of measurements, one on each system, and varied the average temperature of the hot wire keeping the gas pressure constant and determining in each case the corresponding q values. The physical and material properties of the wire dictate very strongly the choice of the temperature. We consequently operated the column in this range and the results are given in Table 1 and plotted in Figs. 5 and 6. In these figures the electri-

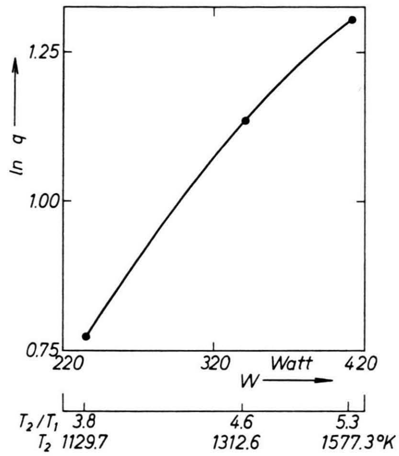

Fig. 5. Dependence of ln$q$ on the electrical power (w) fed to the axial wire for a Ne-Ar mixture (17% Ne) at a pressure of 21.2 cm Hg. Solid circles represent experimental points. The curve is a smooth plot through the experimental points. The temperature of the hot wire (T_2) and the temperature ratio (T_2/T_1) are also shown along the abscissa.

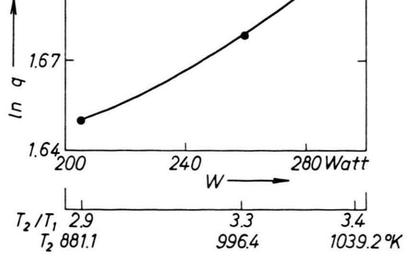

Fig. 6. The legend is the same as in Fig. 5 with the exception that it refers to a He-Ar mixture (22% He) at a pressure of 20.6 cm Hg.

[8] S. C. Saxena and W. W. Watson, Phys. Fluids **3**, 105 [1960].

cal power (W) fed to the wire, and the corresponding temperature ratio (T_2/T_1) and temperatures T_2 are also shown. It will be noted that the separation factor increases with T_2 for both systems and, consequently, here again for nonisotopic mixtures we find that the operation at a high hot wire temperature is preferable, though under certain conditions [9] this simple conclusion may be invalidated.

(c) Composition Dependence of q

In the separation of nonisotopic mixtures the composition of the mixture is another important variant to be considered in contrast with isotopic mixtures. Not enough guidance is available at the moment from previously published results[7]. Our results in Table 1 throw some light on this point. A careful relative evaluation reveals that the separation factor increases as the proportion of the lighter component in the mixture is decreased. This result is of great importance and of considerable help in the extraction of the light gas impurity from the mixture.

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Thermische Resonatoreffekte bei YAG : Nd^{3+}-Dauerstrichlasern

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Anhand eines Resonatormodells von BYKOV und VAINSHTEIN wurden an YAG:Nd^{3+}-Stäben thermische Resonatoreffekte im Laserbetrieb untersucht.

Die YAG:Nd^{3+}-Stäbe mit 25 mm bzw. 75 mm Länge und 3 mm Durchmesser wurden jeweils in einem angepaßten, exfokalen, rotationssymmetrischen Pumpsystem kontinuierlich bzw. im 100 Hz Halbwellenbetrieb gepumpt. Die Laserstäbe waren an den Enden mit dielektrischen Vielfachschichten belegt. Es ergaben sich thermische Krümmungsradien von 1—4 m bei einer Emission von 20—60 transversalen Moden. Die durch das optische Pumpen hervorgerufene Temperaturerhöhung im Kristall wurde mit $\Delta T = 0{,}57\,°\mathrm{C}/100\ \mathrm{W}$ bestimmt. Die Kenntnis der effektiven Resonatorkrümmung ist wichtig für eine Korrektur dieses störenden Effektes.

Festkörperlaser zeigen eine starke Abhängigkeit ihrer Funktion von der Temperatur des Lasermaterials. Eine Temperaturerhöhung wirkt sich in der Strahldivergenz sowie in der Anzahl und Ordnung der schwingenden transversalen Moden aus. Benützt man Stäbe mit direkt auf die Endfläche aufgedampften Spiegeln, so bewirkt eine Erwärmung des Kristalls die Ausbildung effektiv gekrümmter Endflächen; ein zunächst ebener Resonator geht so während des Betriebes in einen allgemeinen konfokalen Resonator über. In früheren Arbeiten [1–4] wurden thermische Effekte an Rubinlasern studiert. Wir haben die Effekte an YAG : Nd^{3+}-Stäben untersucht, bei denen wegen des Vier-Niveaucharakters dieses Materials ein wesentlich geringerer Temperatureinfluß als bei dem Drei-Niveau-Material Rubin zu erwarten war. Die experimentell ermittelten Werte der thermisch bedingten Krümmungsradien und die Temperaturerhöhung in YAG : Nd^{3+}-Lasern unterscheiden sich von den entsprechenden Rubinstäben um etwa eine Größenordnung.

Bei den durchgeführten Experimenten wurden YAG: Nd^{3+}-Stäben verschiedener Länge, jedoch gleichen Durchmessers (30 mm bzw. 75 mm lang, 3 mm ∅) in einem jeweils angepaßten exfokalen, rotationssymmetrischen Pumpsystem nach [5] gepumpt. Als Pumplichtquelle wurden zwei verschiedene Lampentypen verwendet: eine Quarz-Jod-

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