

A Mass Spectrometric Method for the Determination of Permeability Coefficients

F. E. SAALFELD AND M. V. McDOWELL

*Physical Chemistry Branch
Chemistry Division*

December 30, 1964



U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

Copies available from Office of Technical Services
Department of Commerce — \$.50

A Mass Spectrometric Method for the Determination of Permeability Coefficients

F. E. SAALFELD AND M. V. MCDOWELL

*Physical Chemistry Branch
Chemistry Division*

A method for the determination of permeability coefficients from mass spectral data has been described in detail. The method has been illustrated by the determination of permeability coefficients for the systems N₂-neoprene, O₂-neoprene, and CO₂-neoprene at room temperature.

The value for the permeability coefficient Q for CO₂ through neoprene has been shown to be independent of membrane thickness with diaphragms of 0.081 and 0.200 cm thickness ($Q = 13.1 \pm 0.3 \times 10^{-11}$ and $13.3 \pm 0.2 \times 10^{-11}$ cm² sec⁻¹ torr⁻¹, respectively). The data presented shows that Q increases with a decrease in the pressure of 1.0 to 0.5 atmosphere across the membrane. For the CO₂-neoprene system, the values of Q for pressure differentials of 1.0, 0.75, and 0.50 atmosphere are $13.3 \pm 0.02 \times 10^{-11}$, $16.2 \pm 0.2 \times 10^{-11}$, and $19.2 \pm 0.1 \times 10^{-11}$ cm² sec⁻¹ torr⁻¹, respectively. For the same three pressure differentials with N₂-neoprene, the values of Q were found to be $2.87 \pm 0.04 \times 10^{-11}$, $5.80 \pm 0.03 \times 10^{-11}$, and $7.00 \pm 0.03 \times 10^{-11}$ cm² sec⁻¹ torr⁻¹, respectively. This trend was not checked for the O₂-neoprene system due to experimental difficulties. The values for Q at a pressure differential of 1 atmosphere agree with with previously published values.

INTRODUCTION

Modern technology requires the extensive use of nonmetallic components as gaskets, diaphragms, and seals to restrict the movement of liquid or volatile materials from a confined space. In many applications the intent is to preserve the confined substance; in others, the object is to prevent its appearance in places where it will be detrimental to equipment or to personnel. This is of particular importance in nuclear submarines and in spacecraft where prolonged residence in a closed system is required.

Transfer of mobile substances can occur through leakage around the barriers or through the body of the nonmetallic sealing components by various diffusive processes. The rates of these latter transfer processes are inherent characteristics of the barrier materials and the confined substances; their effect can be controlled to some extent by engineering design, which requires information on the characteristics of the system.

The rate of transfer of one material through another is commonly given by a permeability coefficient which expresses the mass of material transferred in unit time across a unit area of

surface under standard conditions. Barrer (1) has defined the permeability coefficient Q as:

$$Q = \frac{dn}{dt} \frac{d}{A \Delta P} \quad (1)$$

where dn/dt is the quantity of material penetrating the barrier in unit time, d is the thickness of the barrier or membrane, A is the exposed area of the membrane, and ΔP is the pressure drop across the barrier. This expression implies that the permeability coefficient is a constant. Since Q actually represents a numerical value for the sum of a series of processes involving adsorption, diffusion (with or without physical dissolution of the diffusing substance in the membrane), and desorption, it would be surprising if it were a true constant.

The unique ability of the mass spectrometer to identify and quantitatively measure extremely small quantities of gases or vapors suggests that the use of such instrumentation in permeability studies would greatly extend the pressure range over which such measurements could be made (2), and give additional details on the overall diffusion process. Norton (3) has demonstrated the general applicability of mass spectrometry to permeability studies. The procedural steps required to collect the necessary mass spectral data and to

NRL Problem C07-02; Project RR 001-01-43-4804. This is an interim report; work on this problem is continuing. Manuscript submitted September 24, 1964.

relate it to permeability determinations in some simple systems, the diffusion of CO₂, N₂, and O₂ through neoprene, are given here.

MASS SPECTRAL DATA REQUIREMENTS

Determination of the permeability coefficient Q requires information on the rate of transfer of material through the membrane under equilibrium conditions. Since the diffusing gases or vapors enter directly into the inlet of the mass spectrometer, the equilibrium pressure existing in the inlet is directly related to the pumping speed of the mass spectrometer vacuum system. To determine dn/dt , then, information as to the pumping rate of the system for the particular gas in question must be obtained, as well as the mass spectrometer response (sensitivity) to ion fragments produced from the gas by ionization in the ion source.

According to Dushman (4), the rate M at which a gas flows through the system is defined by the product of the volumetric flow rate dV/dt and the pressure p :

$$M = p \frac{dV}{dt} \quad (2)$$

From the ideal gas law relationship, $pV = nRT$, the change in volume with pressure under conditions of constant temperature can be found by differentiation with respect to p to give

$$dV = \frac{-nRT}{p^2} \frac{dp}{dt} \quad (3)$$

Substitution of this relation into that of Eq. (2) gives

$$M = \frac{-nRT}{p} \frac{dp}{dt} \quad (4)$$

where R is the molar gas constant and dp/dt is the change in pressure with time.

Separating the variables and defining a new parameter K as M/nRT transforms Eq. (4) to the form

$$-Kdt = \frac{dp}{p} \quad (5)$$

which on integration between the limits p_1 and p_2 and the respective times t_1 and t_2 gives

$$\ln \frac{p_1}{p_2} = K (t_2 - t_1) \quad (6)$$

Expressing Eq. (6) in exponential form for the condition $p_1 = p_0$ when $t_1 = 0$ results in

$$p = p_0 e^{-Kt} \quad (7)$$

where K represents the rate at which a particular gas is removed from the system by pumping.

Since in a mass spectrometer the ion current associated with the mass peak of any ion fragment is directly proportional to the pressure of the parent compound in the system, ion current ratios may be substituted for pressure ratios in Eqs. (6) or (7). Hence, K can be determined experimentally for any gas by exhausting a sample of known size (known pressure in a fixed volume, for example) through the mass spectrometer and measuring the ion current for a characteristic mass fragment as a function of time. The sensitivity (ion current per micron pressure) of the mass spectrometer toward a characteristic mass fragment from the gas under study is also obtained from this calibration.

Under steady state conditions the rate of removal of gas ($-dn/dt$) by the pumping system of the mass spectrometer is equal to the rate of diffusion through the membrane under evaluation. The term, $-dn/dt$, can be found from the gas equation, $pV = nRT$, by differentiating with respect to time while holding constant the system volume V and temperature T :

$$-\frac{dn}{dt} = \frac{V}{RT} \frac{dp}{dt} \quad (8)$$

The minus sign is used to indicate removal of gas from the system.

Substituting Eq. (5) into Eq. (8) gives

$$\begin{aligned} \frac{dn}{dt} &= \frac{V}{RT} pK \text{ moles/sec} \\ &= 22,414 \frac{V}{RT} \cdot pK \text{ cm}^3/\text{sec.} \end{aligned} \quad (9)$$

The sensitivity S of the instrument is given by the expression, $S = I/p$, where I is the ion

current of a characteristic mass fragment and p is the pressure existing in the mass spectrometer inlet system. Substitution in Eq. (9) gives

$$\frac{dn}{dt} = 22414 \frac{V}{RT} \cdot K \cdot \frac{I}{S} \text{ cc/sec,}$$

hence

$$Q = \frac{\left(22414 \cdot \frac{V}{RT} \cdot K \cdot \frac{I}{S}\right) d}{A \Delta P}. \quad (10)$$

The permeability coefficient Q is expressed in conventional units when the thickness d is in cm, the area A is in cm^2 , and the pressure differential ΔP is in torr (mm Hg). For the mass spectrometer data, V is in cc, R in cc microns/degree mole (6.237×10^7), T in degrees absolute ($^\circ\text{K}$), K in sec^{-1} , and I/S in microns pressure.

EXPERIMENTAL APPARATUS

Mass Spectrometer

The mass spectrometer used in this study was a Bendix Time-of-Flight Model 12-101 with a 12-107 ion source. The spectrometer was operated under the following conditions: ionizing current, pulsed and regulated at $0.125 \mu\text{amp}$; ionization energy, 70 volts; the ion lens on; time constant set at 0.5 seconds. The instrument has been modified (5) to scan the characteristic peaks of the permeating gases automatically at pre-selected times. In this manner the approach and attainment of the steady state condition may be observed. The spectrum was continuously monitored on a broadband oscilloscope for any foreign gas which might enter the system through a vacuum leak or as an impurity in the diffusing gas. The mass spectra were recorded on a Leeds and Northrup Speedomax Model G AZAR strip chart recorder with a one-second full-scale response time.

The inlet system was similar to the metal sampling system provided with a Consolidated Electrodynamic Corporation Model 21-620 mass spectrometer, except the expansion volume could be isolated from the system, and a valve connecting the diffusion cell to the inlet block was installed on a side port. The ability to bypass the

expansion volume provided greater instrument response for a given quantity of gas. The time required to determine the permeability constant was also reduced since there was less volume to be evacuated.

The gas from the inlet system was introduced into the ion source of the mass spectrometer through a Granville-Phillips variable leak opened to the position of greatest gas flow. This arrangement was quite versatile for the study of a series of membranes varying in thicknesses. The open leak enabled the system to accommodate the large flow rates occurring with the thinner membranes while the high sensitivity of the mass spectrometer permitted the small ion currents due to small flow rates through the thicker samples to be monitored.

Diffusion Cell

A diffusion cell similar to that described by Norton (3) was constructed to hold a membrane having any thickness from 0.02 to 0.7 cm. The cell exposed a 10.0 cm^2 area of the membrane to the diffusing gas; it could withstand a pressure differential of several atmospheres. A sectional view of the cell is given in Fig. 1 with Fig. 2 showing the design specifications.

One side of the cell was connected through a high vacuum valve to the mass spectrometer inlet block while the other side, the high pressure side, connected through a large bore stopcock to a 5-liter ballast volume. This volume was evacuated and then filled to the desired pressure with the gas being studied. Variation in pressure during the approximately 6-hour period required for a complete experiment was less than 0.5 percent, as measured with a Dubrovin gauge.

Materials

These preliminary studies were carried out on samples of neoprene rubber compounded and fabricated in the Elastomers Laboratory of the Chemistry Division. A relatively simple curing system was employed to keep the number of components at a minimum. Data on physical characteristics of the rubber were obtained from tensile specimens prepared in the conventional manner; data on sample composition and properties are given in Table 1. Uniform samples of the desired thickness were formed and cured in a compression

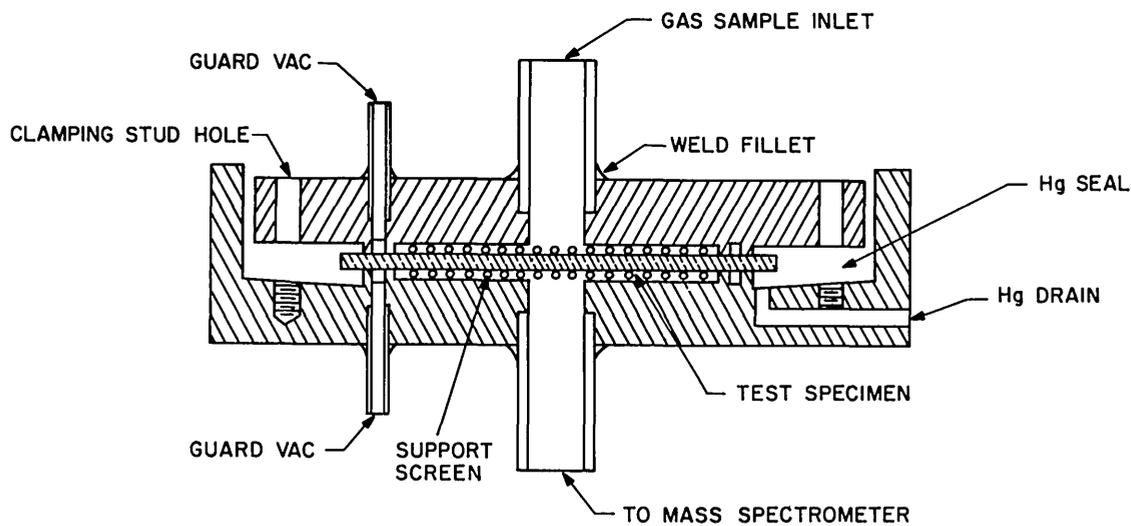


Fig. 1 — Sectional view of the diffusion cell

mold with highly polished faces. No mold release agent or talc was used the rubber specimens. The specimens were stored between high-rag-content bond paper until used in the diffusion experiments. The actual sample thickness was determined by averaging a series of micrometer readings of each sample. The samples were reasonably uniform as evidenced by the small deviation of the thickness measurements. All membrane samples of the same thickness were obtained from a single tensile slab of rubber; different samples were used form each of the gases measured.

The O_2 , N_2 , and CO_2 used in these diffusion studies were research grade and were used without further purification. It should be noted that the mass spectrometric method is not sensitive to the gas quality since it scans only those ion peaks characteristic of the gas under study.

EXPERIMENTAL PROCEDURE

The previously described rubber diaphragm was inserted in the diffusion cell, the guard vacuum turned on to prevent leakage around the edges of the sample, and then the entire system including both sides of the sample were evacuated by means of an oil diffusion pump to remove any occluded or dissolved gases. After degassing overnight, this supplemental vacuum system was isolated from the diffusion system. The valve connecting the diffusion cell to the mass spectrometer was

then opened and a mass spectrum of the residual gases obtained. If there was no background ion current at the mass-to-charge ratios of interest, a measured pressure of gas was quickly introduced on the upstream side of the sample coincident with the starting of cyclic scans by the mass spectrometer. Scanning of the ion currents at the mass fragments of interest was continued until a steady state condition was reached whereby diffusion through the diaphragm was balanced by removal through the mass spectrometer by its vacuum system.

The mass transfer through the system was obtained from the steady state ion current value, the calibration information on the pumping rate of the particular gas in the system, and the spectrometer sensitivity toward the gas. The pumping rate K was obtained (as explained earlier) by connecting a known pressure and volume of gas through a leak to the mass spectrometer and observing the change in ion current with time as the sample was exhausted through the spectrometer by its vacuum system. From a plot of this information, the decrease in ion current during a one-minute interval was determined and used for the evaluation of K . Since K is not a linear function of the pressure or ion current, errors were minimized by taking the first time reading to correspond to the steady state ion current and reading from the graph the ion current after one minute. The initial ion current reading in this

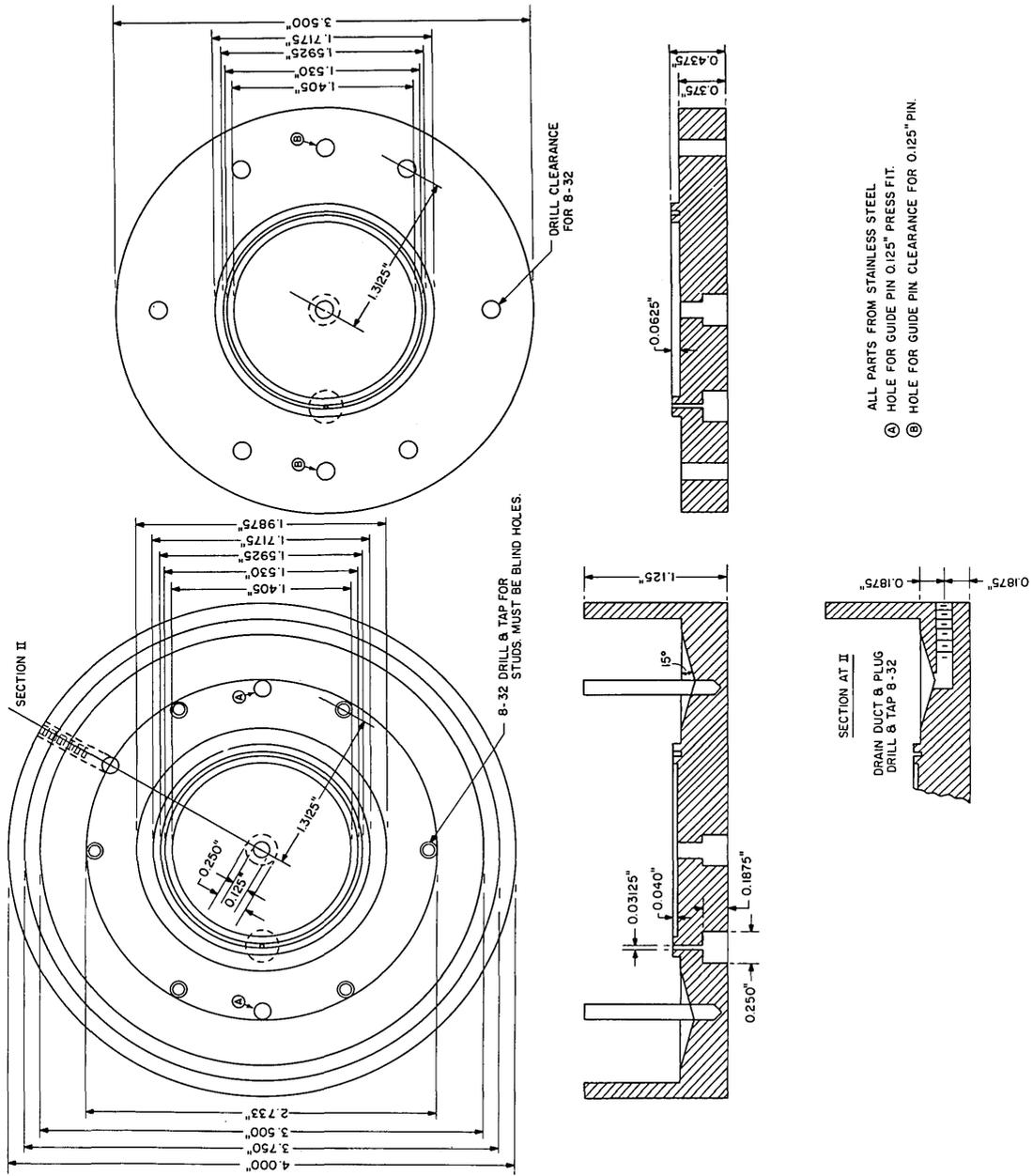


Fig. 2 — Design specifications for the diffusion cell.

TABLE I
Neoprene GN Diaphragm Material
Composition (35-minute cure at 307°F)

Formulation (phr)		
Neoprene GN	100.0	
Stearic Acid	0.5	
Neozone A	2.0	
Philblack O	14.9	
MgO	4.0	
ZnO	5.0	
Physical Properties		
	Sample Thickness	
	0.075 - 0.079 in.	0.030 - 0.032 in.
Modulus (300% elongation)	1270 psi	1294 psi
Tensile strength at break	4160 psi	4410 psi
Elongation at break	600 %	600 %
Hardness (Shore A)	60	60

determination of K was taken at a known pressure of the gas in the system and served to define the sensitivity (ion current/micron) of the mass spectrometer toward the gas under study.

RESULTS AND DISCUSSION

Permeability coefficients have been determined for the diffusion of three gases, nitrogen, oxygen, and carbon dioxide, through neoprene at room temperature ($75 \pm 2^\circ\text{F}$) (Table 2). The average values of the permeability coefficients Q obtained for the three systems at a pressure differential of one atmosphere agree reasonably well with the results reported by Barrer (1) and Roger (2) for neoprene of unreported composition. The observed order of permeability, $\text{CO}_2 > \text{O}_2 > \text{N}_2$, through neoprene is in accordance with the trends reported in the literature for the diffusion of these gases through elastomeric materials (1,2,6,7).

Several experiments were run to determine the effect of sample thickness on the permeability

coefficient. As is evident from the data presented in Table 3, the permeability coefficient Q is essentially independent of membrane thickness, as is implied in Barrer's equation.

The data included in Table 2 for measurements of Q over the pressure range (ΔP) of 0.5 to 1.0 atmosphere for the N_2 -neoprene and CO_2 -neoprene systems indicates an increase in Q with a decrease in the pressure. If this trend continues to lower pressures, it would indicate that diffusion coefficients determined by conventional procedures (*i.e.*, at atmospheric pressure or greater) could greatly underestimate the rate of diffusion of gases through barriers between systems at reduced pressures. More rapid than anticipated losses of gases from a space capsule to the vacuum of outer space might occur with possibly serious consequences on long flights. No determinations were made of this effect in the O_2 -neoprene system because of the detrimental effect of oxygen on the mass spectrometer system; namely, accelerated filament burnout.

TABLE 2
Permeability Coefficients Q for the N_2 -Neoprene,
 O_2 -Neoprene and CO_2 -Neoprene Systems at Room
Temperature ($75 \pm 2^\circ F$)

System*	Pressure (torr)	Permeability Coefficient ($cm^2 \text{ sec}^{-1} \text{ torr}^{-1}$)	
		Q_{avg}^\dagger	Q_{lit}^\ddagger
N_2 -neoprene GN	760	$2.87 \pm 0.04 \times 10^{-11}$ (6)	1.18×10^{-11}
	570	$5.80 \pm 0.03 \times 10^{-11}$ (5)	
	380	$7.00 \pm 0.03 \times 10^{-11}$ (5)	
O_2 -neoprene GN	760	$4.12 \pm 0.07 \times 10^{-11}$ (5)	4.0×10^{-11}
CO_2 -neoprene GN	760	$13.3 \pm 0.2 \times 10^{-11}$ (15)	$25. \times 10^{-11}$
	570	$16.2 \pm 0.2 \times 10^{-11}$ (15)	
	380	$19.2 \pm 0.1 \times 10^{-11}$ (15)	

*Neoprene membrane was 0.200-cm thick in the N_2 and CO_2 experiment and 0.203-cm thick in the O_2 diffusion experiment.

† Uncertainty shown is the standard deviation of the mean; the number of measurements is noted in parentheses.

‡ C.E. Roger "Permeability and Chemical Resistance," Chap. 9 in "Engineering Design for Plastics," Eric Baer, Editor, New York:Reinhold, 1964.

TABLE 3
Effect of Membrane Thickness on the Permeability
Coefficient Q for the CO_2 -Neoprene System
($\Delta P = 760$ torr, $T = 75 \pm 2^\circ F$)

Membrane Thickness (cm)	Permeability Coefficient [Q_{avg}] ($cm^2 \text{ sec}^{-1} \text{ torr}^{-1}$)*
0.081	$13.1 \pm 0.3 \times 10^{-11}$ (7)
0.200	$13.3 \pm 0.02 \times 10^{-11}$ (15)

*Uncertainty shown is the standard deviation of the mean; the number of measurements is noted in parentheses.

CONCLUSIONS

It is entirely feasible to adapt a mass spectrometer to the determination of the rates of diffusion of gases or vapors through membranes. Due to the extreme sensitivity of the mass spectrometer and its unique ability to identify materials by their characteristic mass spectra, the method is useful under conditions where normal methods are useless; *i.e.*, with substances of low volatility, with barriers of low permeability, or relatively great thickness; and in the simultaneous determination of the rate of diffusion of components of a mixture of volatile materials.

A study of the steps preceding the establishment of a steady state diffusion condition may lead to better insight on the overall mechanism of the diffusion process involving adsorption, solution, transport, and desorption phases. In multi-component diffusion studies, the possible interaction or interference of the various components with one another would be of interest.

The method is perhaps sensitive enough for use in determining the degree of crystallinity of polymers under different conditions of temperature, compression, or tension; it suggests itself to the determination of the glass transition temperature of polymers where a radical

change in the rate of gaseous diffusion with temperature is postulated.

REFERENCES

1. Barrer, R.M., "Diffusion in and through Solids," Cambridge: University Press, 1951
2. Roger, C.E., "Permeability and Chemical Resistance," Chap. 9 in "Engineering Design for Plastics," Eric Baer, editor, New York:Reinhold, 1964
3. Norton, F.J., "Diffusion of Helium and Zenon Through Polymer," Knolls Atomic Power Laboratory (General Electric Co.) Report KAPL 737, Apr. 1952
4. Dushman, S., "Scientific Foundations of Vacuum Technique," 2nd ed., J.M. Lafferty, editor, New York:John Wiley, 1962
5. McDowell, M.V., Olfky, R.S., and Saalfeld, F.E., *Anal. Chem.* **36**:959 (1964)
6. Major, C.J., and Kammermeyer, K., *Modern Plastics* **39** (July):135 (1962)
7. Jost, W., "Diffusion in Solids, Liquids, Gases," New York: Academic Press, 1960

DOCUMENT CONTROL DATA - R&D		
<small>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</small>		
1. ORIGINATING ACTIVITY (Corporate author) U.S. Naval Research Laboratory Washington, D.C. 20390		2 a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2 b. GROUP
3. REPORT TITLE "A Mass Spectrometric Method for the Determination of Permeability Coefficients"		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) An interim report on one phase of the problem.		
5. AUTHOR(S) (Last name, first name, initial) Saalfeld, Fred E., and McDowell, Michael V.		
6. REPORT DATE December 30, 1964	7 a. TOTAL NO. OF PAGES 10	7 b. NO. OF REFS 7
8 a. CONTRACT OR GRANT NO. NRL Problem C07-02	9 a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6182	
b. PROJECT NO. RR 001-01-43-4804	9 b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES Unlimited availability		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy (Office of Naval Research)	
13. ABSTRACT <p>A method for the determination of permeability coefficients from mass spectral data has been described in detail. The method has been illustrated by the determination of permeability coefficients for the systems N₂-neoprene, O₂-neoprene, and CO₂-neoprene at room temperature.</p> <p>The value for the permeability coefficient Q for CO₂ through neoprene has been shown to be independent of membrane thickness with diaphragms of 0.081 and 0.200 cm thickness ($Q = 13.1 \pm 0.3 \times 10^{-11}$ and $13.3 \pm 0.2 \times 10^{-11}$ cm² sec⁻¹ torr⁻¹, respectively). The data presented shows that Q increases with a decrease in the pressure of 1.0 to 0.5 atmosphere across the membrane. For the CO₂-neoprene system, the values of Q for pressure differentials of 1.0, 0.75, and 0.50 atmosphere are $13.3 \pm 0.02 \times 10^{-11}$, $16.2 \pm 0.2 \times 10^{-11}$, and $19.2 \pm 0.1 \times 10^{-11}$ cm² sec⁻¹ torr⁻¹, respectively. For the same three pressure differentials with N₂-neoprene, the values of Q were found to be $2.87 \pm 0.04 \times 10^{-11}$, $5.80 \pm 0.03 \times 10^{-11}$, and $7.00 \pm 0.03 \times 10^{-11}$ cm² sec⁻¹ torr⁻¹, respectively. This trend was not checked for the O₂-neoprene system due to experimental difficulties. The values for Q at a pressure differential of 1 atmosphere agree with previously published values.</p>		

14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	Mass spectrometry Permeability Neoprene rubber Membranes Nuclear Submarine Atmospheres Gases and vapors Ion currents Diffusion cell Mass-to-charge Diffusion rate						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.
- 2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.
- 2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.
3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.
4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.
5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.
6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.
- 7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.
- 7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.
- 8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.
- 8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.
- 9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.
- 9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).
10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.
12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.
13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.