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SOLUBILITY OF NITROGEN IN DISTILLED WATER

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The concentration of nitrogen in distilled water was measured using a dynamic, turbulently mixed saturation chamber. Concentrations at three temperatures (12.3, 19.6, and 25.5°C) and three pressures (760, 1520, and 2280 mm Hg) were investigated. Results are presented as mole fractions, X_{N_2} , and Bunsen coefficients, α . A comparison of concentrations obtained by turbulent mixing is made to concentrations obtained by only surface absorption with no mixing. Concentrations are reported on the fifth day after turbulent bubbling ceases.

It is shown that there is a significant difference in nitrogen concentrations between the turbulently mixed system and the unmixed system. Values taken from the turbulently mixed system are approximately 130 percent higher than literature values. Values taken from the unmixed system are 7 to 9 percent higher than literature

values. The turbulently mixed system's concentrations closely approximate Henry's Law.

The Pressure and Temperature Effects on the Solubility
of Nitrogen in Distilled Water

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THE PRESSURE AND TEMPERATURE EFFECTS ON THE SOLUBILITY OF NITROGEN IN DISTILLED WATER

INTRODUCTION

In the Pacific Northwest there is a great interest in the solubility of atmospheric gases in water. A disease known as the gas bubble disease may be harming the migrating fishes of the Columbia River system and other locations (6, 11). This disease has been reported to cause blindness and a subsequent loss of proper spawning capabilities (31). Occurrence of this disease has been noted in hatcheries (15, 25) resulting in mortality even in young fish. Investigators generally indicate that the gas responsible for this disease is nitrogen (11, 24). Concentrations of nitrogen are reported as percent saturation. Values associated with toxicity are usually greater than 100 percent, thus generating the term "nitrogen supersaturation."

Supersaturated levels of atmospheric gases were observed and first reported by Jarnefelt in 1928 (15). In 1948, Jarnefelt (15) summarized his earlier work and implicated rapids and hydroelectric installations as the principle cause of variations in the nitrogen saturation of water. A stream study by Harvey and Cooper (15) showed that the amount of supersaturation was affected by the type of stream flow. Water plunging into a deep basin increased the gas concentration in the water while water plunging off rocks into shallow areas

appeared to decrease in gas concentration. Ebel (11) correlated the degree of supersaturation to the amount of water flowing over spillways on the Columbia River hydroelectric system. At high flow over spillways high levels of nitrogen occurred.

Since supersaturated water is toxic to fish, various means have been devised to eliminate supersaturated gas from the water (15, 25). These devices are meant to operate on small scale such as the water supply to a hatchery. The problem takes on much greater proportions when dealing with a water system such as the Columbia River.

The supersaturation of nitrogen in water is a difficult phenomena to accept. A possible explanation of supersaturation is that incorrect values of absolute saturation are used to calculate percent saturation. Values up to 110 percent can be explained by the variations in absolute values. However saturation values greater than 110 percent cannot be explained by variation in absolute values.

This study was initiated to build a laboratory apparatus that would explore the nitrogen-water system. The apparatus was designed to mix turbulently nitrogen and water and then to analyze the mixture as the system approached equilibrium. It was hoped that the phenomena of supersaturation could be observed and solubility data could be generated for varying temperatures and pressures.

BACKGROUND

The subject of gas solubility in liquids has been investigated at great length since early in the nineteenth century. Much work has been done in recent times to update the knowledge of gas solubility in liquids. Markham and Kobe (18) reviewed the literature up to 1941, and Battino and Clever (2) have gathered together a very comprehensive review up to 1965. These two reports are quite comprehensive, including such areas as methods of measuring solubility, definitions of terms used in expressing gas solubilities, and over 1000 references on solubility experiments.

Three important areas will be discussed in this text. The topics include definitions used in expressing gas solubility, methods and results in determining nitrogen solubilities, and surface tension effects.

Definitions

The Bunsen coefficient, α , is defined as the volume of gas reduced to 0°C and 760 mm Hg which is absorbed by a unit volume of solvent (at the temperature of the measurement) when under a gas pressure of 760 mm Hg. When the partial pressure of the gas above the solvent differs from 760 mm Hg, it is corrected to this pressure by Henry's Law. One equation used to calculate the Bunsen coefficient

is

$$\alpha = \left[\left(V_g \frac{273.15}{T} \frac{P_g}{760} \right) \left(\frac{1}{V_s} \right) \right] \frac{760}{P_g} . \quad (1)$$

Equation 1 obviously reduces to

$$\alpha = \frac{V_g}{V_s} \frac{273.15}{T} . \quad (2)$$

The units of α are usually expressed as milliliters per milliliter.

In dealing with slightly soluble gases the units lend easily to interpretation as parts per million.

Equation 2 shows no explicit pressure dependence. To show a pressure dependence a modified form of the Bunsen coefficient is used. The same calculations are applied to this coefficient, α' , as to α , except that α' is not corrected to 760 mm Hg by Henry's Law. In this report two values, α and α' , will be reported at 1520 mm Hg and at 2280 mm Hg. Henry's Law can be recognized in the reported data with the modified form of the Bunsen coefficient.

Another term used extensively to report gas solubilities is mole fraction. All three forms of expressing gas solubility are used in this text.

Methods and Results of Nitrogen Solubility in Water

A great variety of approaches have been used to determine the solubility of gases in liquids. The methods range from the purely qualitative to the highly precise. The methods discussed in this section are directly related to the solubility of nitrogen in water.

There are four general methods used to study the solubility of gases in liquids, manometric-volumetric methods (sometimes called gasometric methods), mass spectrometric methods, gas chromatographic methods, and chemical methods. Since chemical methods are not usually applicable to dissolved nitrogen they will not be considered.

Manometric-volumetric methods are probably the most extensively used and undoubtedly have the longest history. There are two general types of apparatus, those that measure gas as it is absorbed into a degassed solvent, and those that extract and measure gas from a saturated solvent. The Ostwald apparatus is an example of the first type and the second type is typified by the Van Slyke method (18).

Mass spectrometric methods require that the sample be stripped of gas, the gas trapped and then analyzed by mass spectrometry. This method is very useful for the study of mixed gas solubilities but depends heavily on the extraction method used (such as a Van Slyke method). Cantone and Gurrier (7) described a mass spectrometric method to analyze water samples for CH_4 , O_2 , N_2 , and Ar. Benson

and Parker (4) used a similar technique to determine the ratios of atmospheric gases dissolved in sea water.

The major use of gas chromatography in gas solubility determinations has been to separate and quantify gases extracted from saturated solvents. As in the mass spectrometric method a means of extraction is inherent in the method.

Swinnerton, Linnerbom, and Cheek (26, 27) determined the amount of dissolved gases in aqueous solutions by using a chromatograph. The dissolved gases were extracted from solution in a glass sample chamber divided into two parts by a coarse fritted disk. A known quantity of saturated liquid was admitted to the sample chamber through a rubber septum. The carrier gas was directed up through the fritted disk thus forming small bubbles and stripping the sample of any dissolved gas. The gases were then separated and detected in the chromatograph. Since the extraction procedure is very important to the chromatographic method, various types of extraction equipment have been investigated (2).

Table 1 lists several experimenters who have obtained results for nitrogen solubility in water. The following discussion attempts to give some background for each experimenter listed in Table 1.

Fox (13) used a modification of the Ostwald method to determine nitrogen solubility. Fox devised a method to completely fill the saturation chamber with degassed water without contamination. The

Table 1. Literature values of nitrogen solubility in water ($\alpha \times 10^3$).

	Temperature ($^{\circ}\text{C}$)				
	10	15	20	25	30
Fox	18.54	16.84	15.54	14.43	13.55
Winkler	18.29		15.18		13.20
Bohr and Bock	19.25		16.13		13.58
Adeney and Becker	18.70 ⁺	16.96	15.55	14.35	13.27
Morrison and Billett	19.25 ⁺	17.36	15.86	14.63	13.64
Douglas	18.75	17.05	15.57	14.41	13.45
Klots and Benson	18.99	17.24	15.84	14.66	13.45
Murray, Riley, and Wilson	18.82	17.06	15.63	14.46	13.49
Farhi, Edwards, and Homma ^x				(14.30) ^{26.8}	(14.25) ^{27.15} (13.37) ^{32.0}
Weiss	18.81	17.02	15.59	14.41	13.45

⁺Smoothed data taken from Battino and Clever (2)

^xNumbers in superscript designated the temperature ($^{\circ}\text{C}$) of measurement.

saturation chamber was shaken to allow absorption of nitrogen and then placed in a constant temperature bath. At appropriate times, volume measurements were taken. Winkler's apparatus (32) was theoretically analogous to Fox's. However, argon was discovered after Winkler's work so corrections for this gas must be made. Bohr and Bock (5) bubbled a stream of atmospheric nitrogen through water to attain saturation. The absorbed gas was then extracted and measured. Fox (13) has corrected the values of Winkler and Bohr and Bock for the presence of argon. The corrected values given by Fox appear in Table 1.

Adeney and Becker (1) experimented by enclosing a large gas bubble, of known volume, in a narrow tube containing degassed water. They allowed the bubble to pass up through the water repeatedly until saturation was reached. The pressure in the bubble was measured after each double passage up the tube by means of a water manometer. The pressure measurement gave data for calculating the absorption which took place step by step to saturation.

An apparatus described by Morrison and Billett (19, 20) was based on the flow of a liquid film through a gas. This method compared favorably with the normal Ostwald technique.

Douglas (10) determined the solubility of nitrogen in distilled water microgasometrically. Gas free water was brought into contact with pure gas and after equilibration the amount of gas absorbed by the

water was measured volumetrically with a micrometer buret. Shaking of the saturation chamber was done to saturate the liquid but avoidance of bubbles was required.

Klots and Benson (17) devised a method to measure the amount of gas absorbed into a water sample and then extracted the gas from the same sample to obtain a comparison. Excellent comparisons were obtained. The method allowed nitrogen to absorb through a stopcock into degassed water. The apparatus was gently rocked while absorption was taking place.

Murray, Riley, and Wilson (22) described an improved version of the apparatus first described by Ben Naim and Baer (3). This apparatus involved a gasometric technique which took advantage of a swirling motion which forced liquid up a capillary tube into a region where the gas to be absorbed existed. The liquid then returned to the vortex. Saturation occurred in five to seven hours in this system.

Farhi, Edwards, and Homma (12) combined vacuum extraction in a Van Slyke chamber and detection of the gases in a gas chromatograph to determine nitrogen content in blood and distilled water. A tonometer was used to saturate the water with nitrogen. Approximately 30 milliliters of water were entered into the 200 milliliter tonometer. Nitrogen was flushed through the tonometer without bubbling for 30 minutes. The tonometer was then swirled so that a liquid film crept half-way up the sides. Samples were withdrawn and injected into

the Van Slyke apparatus for analysis on the chromatograph. Ikels (16) used a similar devise to study the solubility of nitrogen in human fat and in water. An interesting apparatus, using a gas chromatograph, was explained by Tolk, Lingerak, Kout, and Borger (28) for measuring trace quantities of nitrogen in aqueous solutions. Unfortunately no results were given.

Weiss (30) has taken recent data on the solubility of nitrogen in distilled water and fitted it to thermodynamically consistent equations by the method of least squares.

Table 2 gives a concise review of literature reported at 12.3°C, 19.6°C, and 25.5°C. This table will be used to compare literature values with values reported in the current study.

Table 2. Literature values of nitrogen solubility at the experimental temperatures of this study ($\alpha \times 10^3$).

	Temperature (°C)		
	12.3	19.6	25.5
Fox	17.70	15.64	14.33
Klots and Benson	18.15	15.94	14.56
Murray, <u>et al.</u>	17.96	15.73	14.35
Douglas	17.95	15.68	14.31
Weiss	17.95	15.70	14.32

Surface Tension

Since the current study involves the violent mixing of nitrogen

bubbles with distilled water, a consideration of surface tension effect on gas bubbles was performed. The following development is described by Vanderslice, Schamp, and Mason (29). Calculations described by Vanderslice et al. were intended for small liquid droplets but can be extended to small vapor bubbles in a liquid phase. The physical basis for the calculation is that the surface acts as a tight skin, so that the environment inside the bubble or droplet is at a slightly higher pressure than the surroundings with which it is in equilibrium.

Using the concept of virtual work it can be seen that the work done to decrease the volume of a small sphere by dV is $\Delta p dV$ where Δp is the excess pressure on the sphere due to surface tension. This work term is equated to σdA , where σ is the surface tension and dA is the decrease in surface area accompanying the decrease in volume.

$$(\Delta p)dV = \sigma dA \quad (3)$$

For a sphere of radius r the following relations hold.

$$V = 4/3\pi r^3 \quad dV = 4\pi r^2 \quad (4)$$

$$A = 4\pi r^2 \quad dA = 8\pi r \quad (5)$$

Substituting Equations 4 and 5 into Equation 3 it can be shown that

$$\Delta p = \frac{2\sigma}{r} \quad (6)$$

Thus the pressure inside the sphere increases as the radius of the sphere decreases. Using σ values from the Handbook of Chemistry and Physics (8) Table 3 compares sphere radius and the pressure differences of small bubbles.

Table 3. Pressure difference due to surface tension.

Sphere Radius (cm)	Pressure Difference (mm Hg)
0.1	0.546
0.01	5.46
0.001	54.6
0.0001	546.0

Thus with very small bubbles a significant pressure difference is generated. Since the surrounding liquid environment is subject to Henry's Law, a corresponding increase in liquid concentration of the gas should be observed.

EQUIPMENT

The equipment used in the experimental investigation can best be described by subdividing it into three sections. The first section deals with the saturation chamber and the associated sampling device. The second section discusses the temperature and pressure measuring equipment. The third section explains the chromatographic equipment and a discussion of the chemicals used. Together these sections give a description of the solubility measuring apparatus. A schematic of the system is given in Figure 1.

Saturation Chamber and Sampling Device

The design criteria for a saturation chamber required the chamber have a cell in which water could become saturated when nitrogen gas was bubbled into the liquid, be small enough to place in a constant temperature bath, and have a sampling port which would transfer a representative sample to a chromatograph. A comprehensive diagram of this piece of equipment and a photograph are given in Figures 2 and 3, respectively.

The saturation chamber was a six inch piece of pyrex glass pipe, four inches in diameter. The ends were flanged and sealed with teflon seals. Each flange was tapped to accommodate two 1/4-inch swagelok adaptors and one 1/8-inch adaptor. The 1/8-inch adaptors

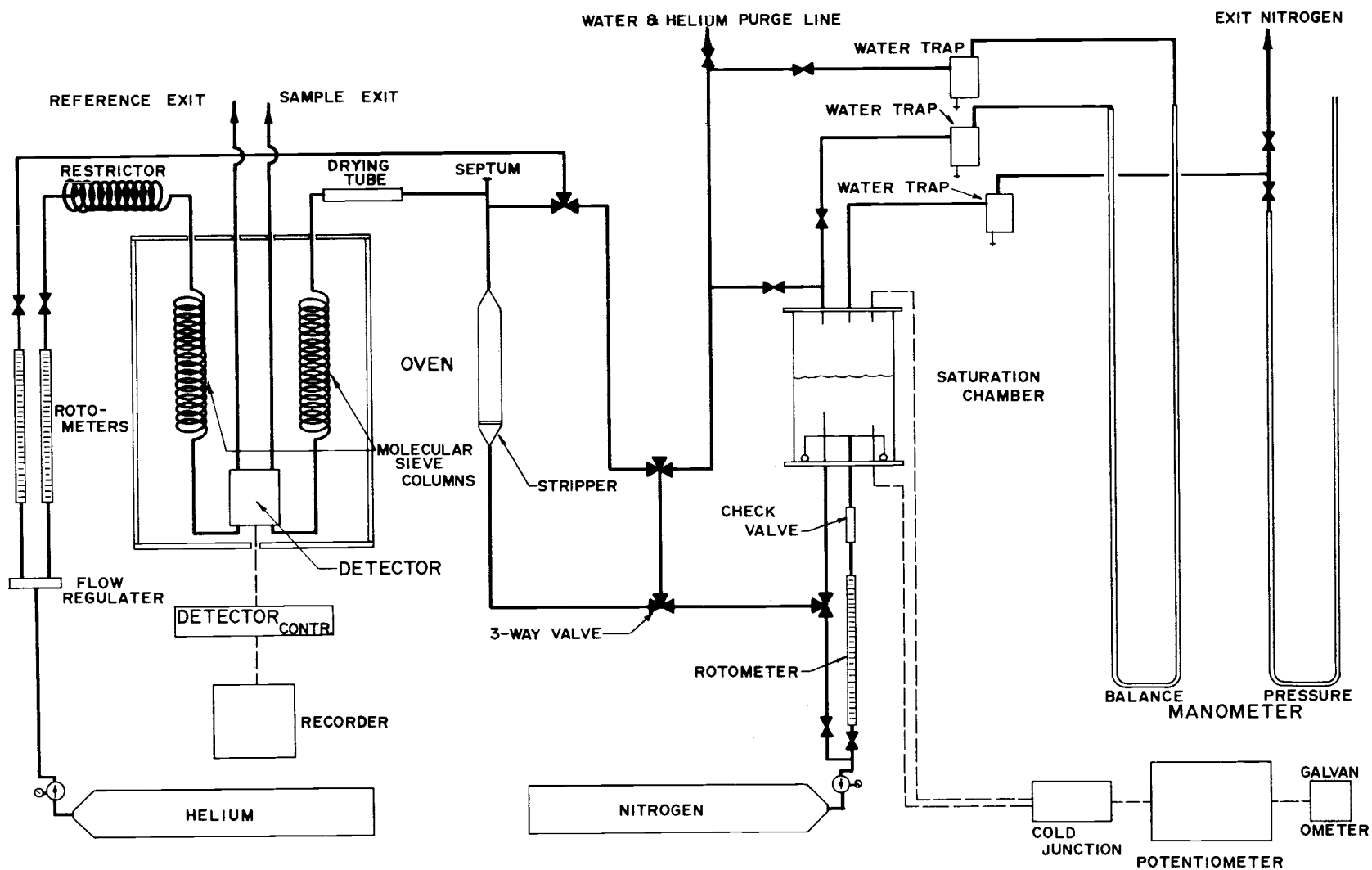


FIGURE 1. GENERAL LAYOUT

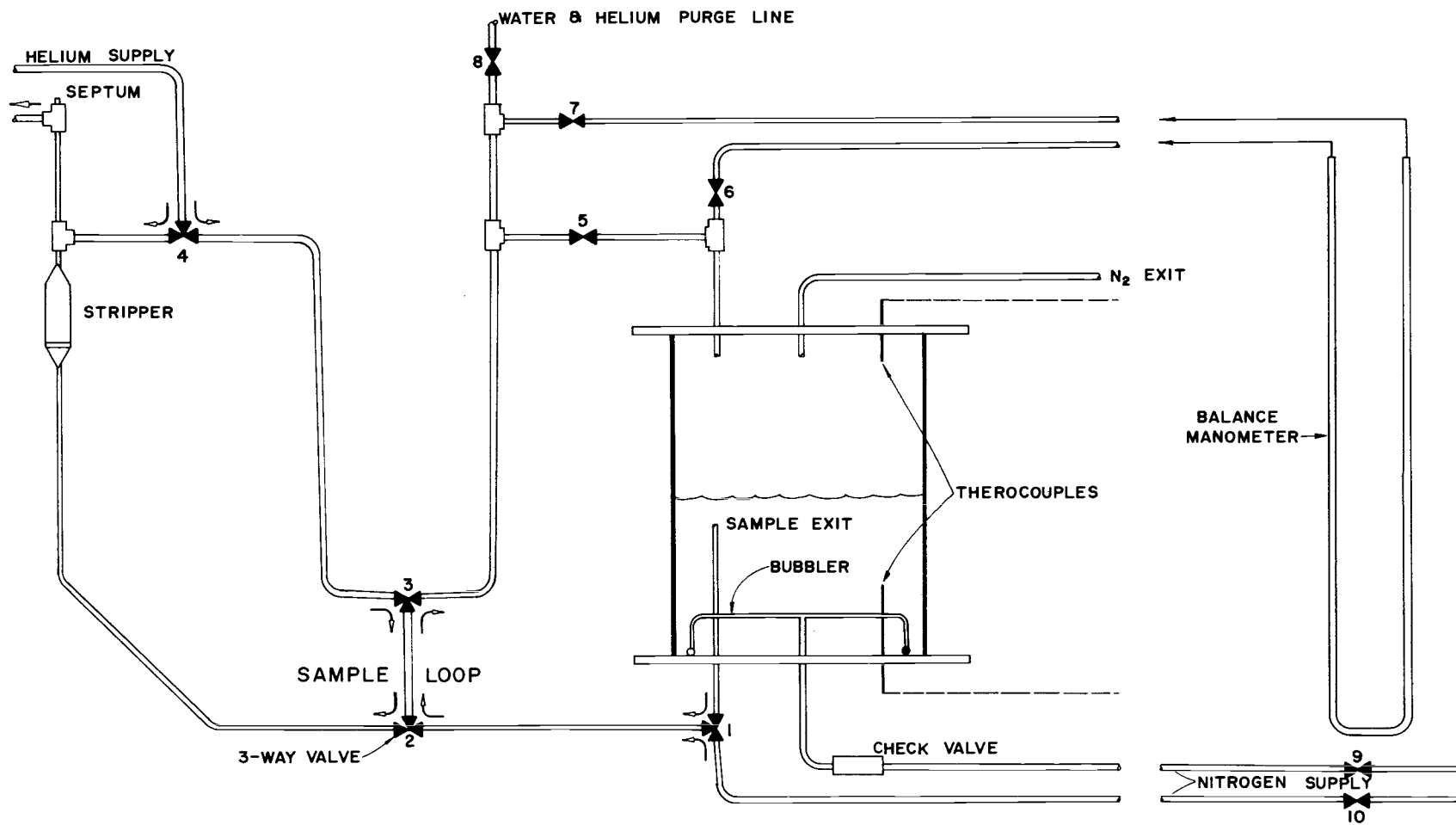


FIGURE 2 SATURATION AND SAMPLING SCHEMATIC

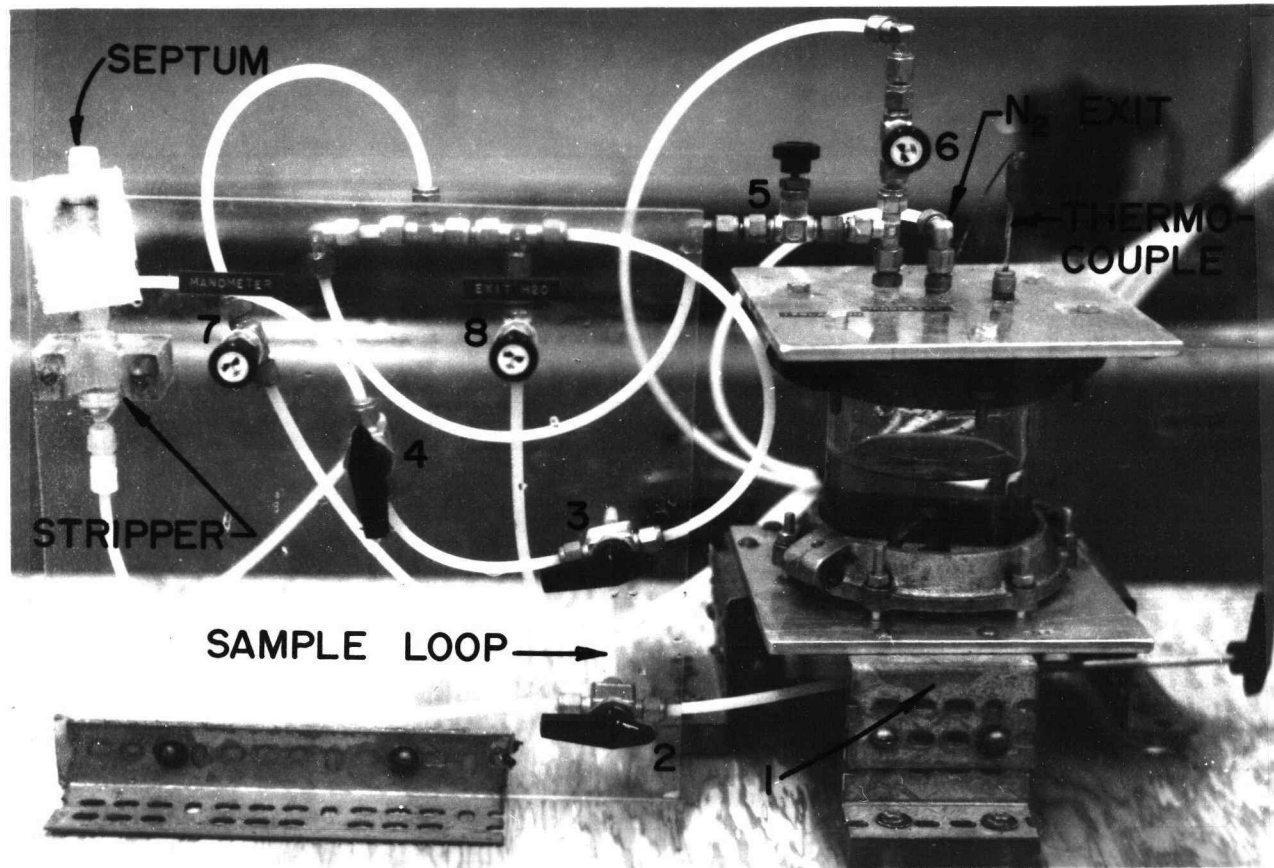


Figure 3. Saturation and sampling photograph.

held the thermocouples and the 1/4-inch adaptors connected the exit/or entrance lines. The bottom flange held the bubbler and sample exit. The bubbler was made of 1/4-inch copper tubing. The tubing was teed and bent so that the gas entered tangentially at the bottom. This gave a violent mixing motion while bubbling the gas through the liquid. The gas flow rate was measured by a Fischer and Porter rotometer, Model 103565A, and controlled by a Nupro, Series L, fine metering valve. A Nupro check valve directly below the bottom flange prevented back flow of water from the saturation chamber when gas flow ceased.

An exit in the top flange provided an escape for the gas while the water was being stripped of atmospheric gases and saturated with nitrogen. A Nupro, Series L, fine metering valve controlled the exit flow. This valve permitted fine adjustments of chamber pressure. The exit line was connected to a large manometer for precise pressure measurement.

A bulkhead adaptor and a two inch piece of 1/4-inch copper tubing protruded into the sampling chamber from the bottom flange. This made the sample exit approximately two inches above the bottom flange (thus a sample could be taken from the middle of the chamber). The sampling system was composed of four Whitey 3-way valves, number 43XS4, and a stripping section. Refer to Figure 2 for correct valve numbering.

Valve 1 was mounted directly beneath the bottom flange. This

valve controlled the saturated water flow through the sample loop or the nitrogen gas flow through the sample loop. Valves 2 and 3 formed the sample loop. Valve 2 had its common port to the sample loop. One side port was connected to the bottom of the stripping section and the other was connected to the common port of valve 1. Valve 3 had its common port attached to the sample loop. One side port of valve 3 was attached to the helium supply (valve 4), and the second side port led to the top flange and the gas phase above the saturated water. Valve 4 allowed the helium carrier gas to be directed through the sample loop and stripper or routed directly to the chromatograph. Thus, the common port of valve 4 was connected to the helium supply, one side port was attached to valve 3, and the other side port was connected to the bottom tee on the top of the stripper.

A tap for the balance manometer, a tap for purging excess water and helium, and a shut-off valve were located in the line between valve 3 and the gas phase in the saturation chamber. The fitting on the top flange was teed. One branch led to the balance manometer and the other led to the sample loop. The balance manometer tap of the saturation chamber was fitted with a Nupro B-4J ball valve (valve 6). The balance manometer tap of the sample loop was equipped with a Nupro Series L fine metering valve (valve 7). The purge tap exit was equipped with a Nupro fine metering Series L valve (valve 8). The shut-off valve was a Nupro B-4J ball valve (valve 5).

The balance manometer measured the pressure difference between the sample loop and the saturation chamber. It was made of two pieces of six foot clear plastic tubing. All lines leading to the manometers had water traps. These traps were four inch pieces of two inch diameter pipe. These pipes were capped and taps were located so water would settle from the lines.

The stripper was made from a 15 milliliter Buchner funnel with a coarse fritted glass disk. The top and the bottom were blown into a 1/4-inch glass tube. Two Swagelok tees were placed on the top of the stripper. Refer to Figure 2 for the exact arrangement. The top swagelok fitting held a silicon rubber septum. This straight through arrangement permitted a long needle to reach the fritted glass for removal of water after stripping. The lower tee was connected to valve 4 and the top tee led to the chromatograph.

All valves, except valve 1 and the two valves on the top flange, valves 5 and 6, were mounted on a 14 x 14 x 1/4 inch piece of clear plastic. All tubing used exterior to the sampling chamber was 1/4-inch Portco polyethylene clear tubing.

A 50 gallon American Instrument Company constant temperature bath was used. The apparatus fitted easily into this bath.

Temperature and Pressure Measurement

A mercury manometer approximately eight feet in height was

used to measure pressure in the saturation chamber. Atmospheric pressure was measured with a Princo, Fortin-type, barometer. This barometer was calibrated using the Oregon State University Weather Bureau barometer for the standardized reference.

The manometer was constructed from two pieces of 1/4-inch glass tubing; one eight feet in length and one four feet in length. Male and female nylon swagelok elbows formed a U which supported and held the glass tubing together at the bottom. The manometer was fastened to a plywood backing and was protected with a clear plastic shield. The four foot leg was connected to the gas exit stream of the saturation chamber. A water trap was placed in the line so no water could be pulled into the manometer. A millimeter scale placed behind the manometer permitted readings to be taken in millimeters.

Four copper-constantan thermocouple beads were made on a small arc welder. Four five inch pieces of 1/8-inch brass tubing were soldered shut at one end. A 1/4-inch plug shut all tubes. The tubes were filled with acetone. After preparing and drying a silicon rubber plug at the appropriate location on each thermocouple wire, the beads were inserted into the tubes and plugged with silicon rubber; the bead was completely sealed in the tube. A tube was placed in the 1/8-inch adaptor on the top and bottom flange and swaged tight.

A Leeds-Northrup K-3 potentiometer and a Leeds-Northrup null detector, catalog number 9834, were used to detect voltage. A cold

reference junction was used to switch the potentiometer from one thermocouple to the next. The junction was kept at 0°C with ice and distilled water.

Chromatograph and Chemicals

A chromatograph was used as an analytical tool in this work. It quantified the amount of nitrogen expelled from the stripper. There were several important components of this system. The components included the detector, the columns, the oven, and the recorder.

The detector was a Carle Model 100 Micro-Detector which was a dual thermistor detector. Accordingly, two gas streams were required. One carried the sample and one stream was used as a reference.

The columns used were 20 feet by 1/8-inch aluminum tubing, filled with 30/60 mesh Linde molecular sieve 5A. Two columns were used to balance the flow on each side of the detector. The columns were wound to three inch diameters and placed in the oven next to the detector. See Figure 4 for this arrangement. A flow restrictor, made from 30 inches of the 1/8-inch aluminum tubing was placed in the reference side to compensate for the pressure drop through the stripper.

A Varian Aerograph series 2100 chromatograph was used to supply the oven, flow regulator, and the supply rotometers. The oven

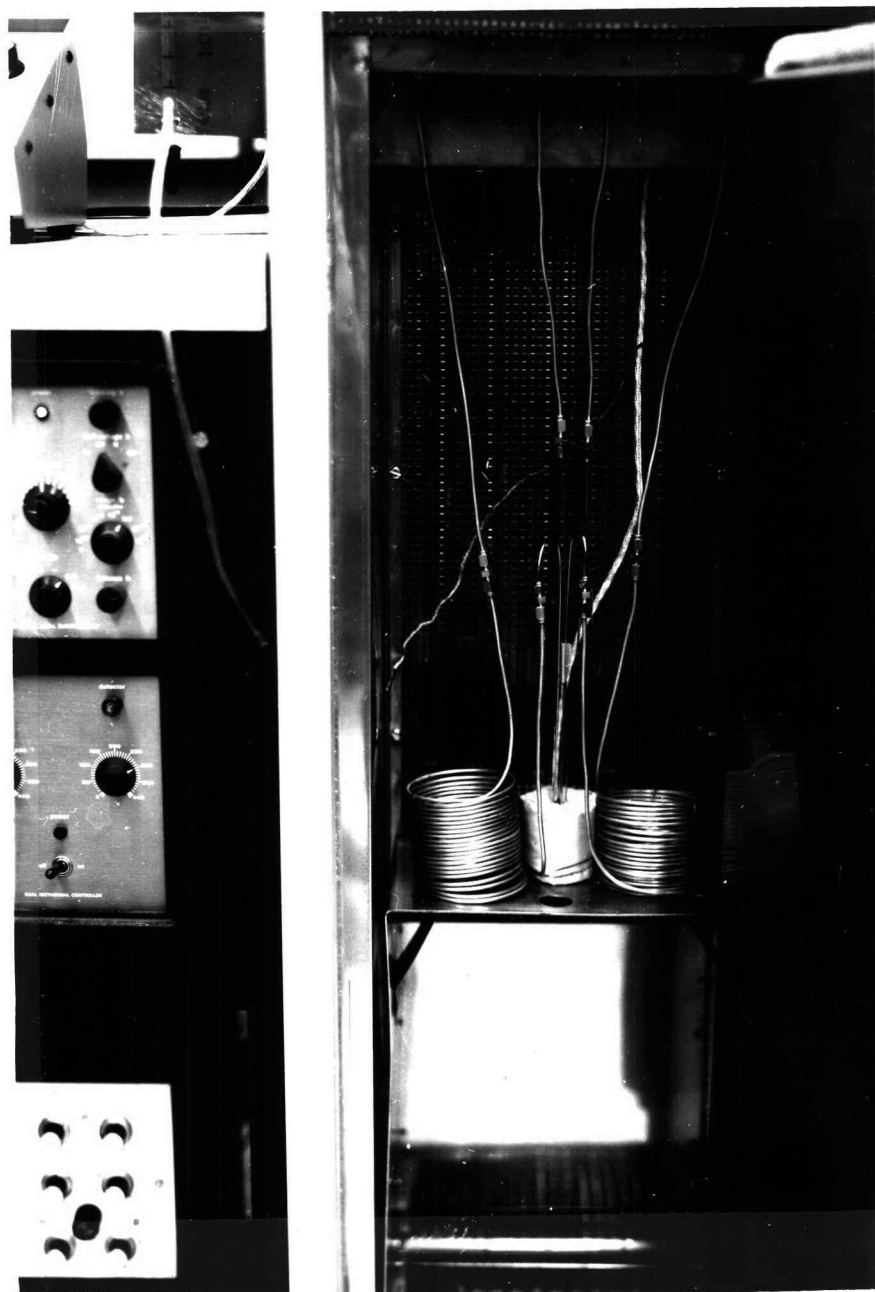


Figure 4. Column and detector arrangement.

on the Varian 2100 was very temperature stable and provided adequate temperature control for the detector. The helium flow regulator and the two carrier gas rotometers were an integral part of the Varian 2100. These devices allowed even flow and regulation of each helium line independently of the other.

A drierite drying tube was placed between the stripper and the detector. The 12 inch long drying tube, made out of a 1/2-inch plastic pipe, was fitted with the appropriate reducers to adapt to the 1/4-inch lines. Several of these tubes were made so they could be changed daily.

A Texas Instruments Incorporated Servo/riter recorder, Model number FS01W6D, was used. It was fitted with a Disc integrator. The recorder had a one millivolt sensitivity over a nine inch span.

Syringes used to standardize the chromatograph were Hamilton gas-tight microliter syringes. The sizes used were 50, 150, 250 and 500 microliters. A separate nitrogen tank was fitted with a septum and purge valve. This septum allowed nitrogen gas to be drawn into the micro syringes for injection into the stripper.

Matheson High-Purity grade helium was used for the carrier gas. This gas had a 99.995% minimum quality requirement. Matheson Pre-Purified nitrogen was used; it had a quality of 99.997%. Factory analysis of the gas proved the gas well within the specifications. The water used in all experiments was doubly distilled.

PROCEDURE

Standardization

After construction, the system was sealed and purged with nitrogen. At this time two important standardizations were made. The thermocouples were calibrated and the volume of the sample loop was determined.

The thermocouples were calibrated using a comparison method. A platinum resistance thermometer with a Mueller bridge and accompanying galvanometer measured the temperature of a water bath that was slowly increasing in temperature. At the same time measurements were made with the resistance thermometer, readings were being taken on the thermocouples. A temperature versus millivolt curve was generated for each thermocouple.

The volume of the sample loop was determined by using six glass tubes filled with drierite. One end of each tube was drawn down to a 1/4-inch glass tube so it could be attached to the stripping side of valve 2. The sample loop was filled with water and subsequently blown out into the drierite tube. Each tube was blown into for approximately five minutes. The difference in weight, gave the volume of water held in the sample loop.

To check for any vapor blow-by, two tubes were connected in

series. The weight change in the second tube was insignificant. Figure 5 gives a picture of these tubes.

Saturation

Doubly distilled water was syphoned into the saturation chamber through the bubbler exit. This water was stripped of other gases and then saturated with nitrogen by bubbling nitrogen through the chamber at approximately 4500 milliliters per minute. The nitrogen was allowed to bubble for one hour. Various settling times were allowed before taking the analytical samples.

One series of experiments used vacuum degassed water and eliminated the bubbling of nitrogen gas. Absorption of the nitrogen resulted by mass transfer through the surface. The following procedure for this series was followed: a 4000 milliliter filtering flask filled with 3000 milliliters of doubly distilled water was boiled and held under vacuum for six hours, the water was transferred to the saturation chamber by back pressuring the flask with helium. Nitrogen was allowed to purge the saturation chamber while it was being filled with water to the appropriate level. The system was sealed and after a period of time, to allow for mass transfer, the liquid was sampled as in the bubbling method.

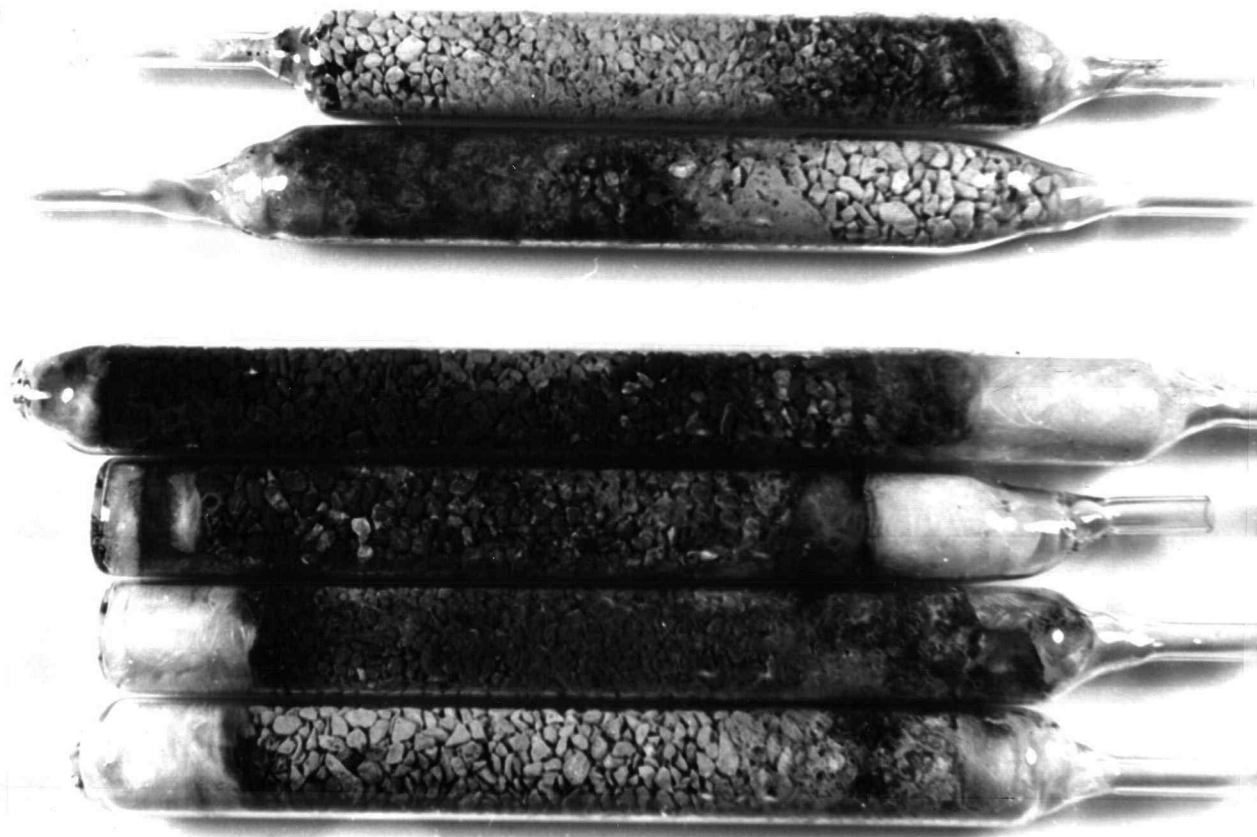


Figure 5. Drying tubes used to standardize sample loop.

Sampling

The sampling technique involved a cycle of filling the sample loop, stripping the sample, injecting microquantities of nitrogen to obtain a standard curve, purging the sample loop, and filling the sample loop once again. A description of this cycle will start with the sample loop ready to accept a sample. Refer to Figure 2 for correct valve numbers. Arrows placed by each valve indicate possible direction of flow.

At the start of the cycle the valves were in the following positions: valve 1 was open to nitrogen gas flow, valves 2 and 3 were open to the saturation chamber, valve 4 was positioned so helium flowed to the top of the stripper, valves 5, 6, and 7 were open, and valves 8, 9, and 10 were closed.

Valve 2 was closed to flow in any direction and valve 1 was rotated to accept water from the saturation chamber. Valve 2 was slowly opened and the sample loop was allowed to fill. The sample loop had been placed low enough so that the head pressure pushed some water above valve 3. This gave a more representative sample.

Valves 2 and 3 were now closed to flow in any direction. These two valves were then rotated to allow flow towards the stripper. Valve 4 was rotated so that the helium carrier gas forced the sample to the stripper. The nitrogen was then stripped and carried into the

chromatograph for measurement. After the nitrogen peak passed from the chromatograph a series of nitrogen injections were made. These injections were made through the septum on the top of the stripping column. Hamilton microliter gas tight syringes were used. A series of these injections gave a quantity versus peak-area curve from which the quantity of gas in a sample could be determined. Usually two or three injections were made per sample. By the end of the day a curve with approximately 20 points had been generated.

To obtain an accurate measurement of the nitrogen injected, a small quantity of water was initially drawn up into the needle. A quantity of nitrogen was drawn into the syringe and then some more water was drawn up. Thus, a quantity of nitrogen was isolated between two water seals. The quantity of nitrogen was easily read. Upon injection this method assured that no nitrogen would be left in the needle. A correction for water vapor was made by knowing atmospheric temperature and pressure.

Valve 4 was now rotated to direct helium to the top of the stripping section, by-passing the fritted glass. A syringe with a seven inch needle removed the sample water from the stripper. Valve 5 was closed and valve 1 turned to allow nitrogen flow into the sample loop. Valve 8 was opened and valves 2 and 3 were returned to their original positions. The excess water and helium were purged to the atmosphere. Valve 8 was then closed and the sample loop was

pressurized to the same pressure as the saturation chamber. This was done by noting the difference in mercury levels in the balance manometer, and adjusting sample loop pressure with valve 10. While purging the sample loop the lines to the balance manometer were isolated from the sample loop by closing valves 6 and 7. This was necessary to prevent helium from flowing into these lines. The sampling system was now ready for another sample.

Temperature and pressure readings were made immediately after the sample was taken and before it had been discharged to the stripper.

The recorder chart speed was 3/8-inch per minute and the attenuation was set on 100. The gas flow rate was approximately 26 milliliters per minute with a pressure reading of 39 pounds per square inch at the exit of the helium tank. The temperature of the oven was 50°C.

RESULTS AND DISCUSSION

Table 4 and Table 5 give a concise report of the data collected during this study. Three temperatures were investigated at three pressures. The pressures are reported as absolute pressures. Table 4 gives the data in mole fraction and Table 5 gives values of the modified Bunsen coefficient, and, in parenthesis, the Bunsen coefficient. At 760 mm Hg the modified Bunsen coefficient equals the Bunsen coefficient.

Table 4. Nitrogen solubility in distilled water, (mole fraction $\times 10^6$).

Temperature °(C)	Pressure (mm Hg absolute)		
	760	1520	2280
12.3	18.78	33.88	56.30
19.6	18.08	34.27	53.32
25.5	15.96	33.01	48.60

Table 5. Nitrogen solubility in distilled water (α' and $\alpha \times 10^3$).

Temperature °(C)	Pressure (mm Hg absolute)			
	760	1520		2280
	α	α'	α	α' α
12.3	22.95	42.15	(21.08)	70.05 (23.35)
19.6	22.50	42.64	(21.32)	66.34 (22.11)
25.5	19.95	41.08	(20.54)	60.47 (20.16)

A comparison of Table 5 with Table 2 shows a significant

difference in solubilities. The solubilities shown in Table 5 are approximately 30 percent higher than values shown in Table 2.

It was interesting to note the previous means used to saturate water with nitrogen. In only one reference (5) were the formation of bubbles mentioned. Shaking, and gently rocking appeared to be predominant modes of saturation. Even in the flow system (19) bubbles were not mentioned. The system described in this study turbulently mixed nitrogen and water. Many bubbles are formed in this process. It can be recognized that this study is attempting to put an excess amount of nitrogen into the liquid (either in solution or fine bubbles). Thus equilibrium is approached from a greater than saturated level. All bubbles and excess dissolved nitrogen must leave the liquid to have true equilibrium. Most experiments in literature approach equilibrium from the unsaturated conditions.

Considering the approach from different sides of equilibrium, it was not unusual to expect some differences in the direction noted. The unusual situation was the time for equilibrium to be attained. The values in Table 4 and Table 5 were taken on the fifth day after bubbling and turbulent mixing ceased. There were three reasons for selection of the fifth day as the most appropriate day on which to take data.

Since it was desired to model the turbulent system developed at spillways on the Columbia River and the subsequent stagnation in the pools between dams, a time representative of the mean residence

time of water between dams was determined. The flow volume on the Columbia River varies from a low of 70,000 cfs to 660,000 cfs (14). In calculating an average travel time between dams 150,000 cfs was used. Morse (21) gave some velocities for the Rocky Reach pool. These velocities were approximately 3000 feet per hour. Since the distance between Rocky Reach Dam and Wells Dam is 41 miles (33) the travel time is less than three days. Robeck, Henderson, and Palange (23) gave travel times for the larger pool between McNary and Priest Rapids Dam. At a flow of approximately 150,000 cfs, the travel time is 117 hours or five days. Although the mean residence time is somewhat greater than travel time, an average residence time of 5 days seems appropriate for the Columbia system (9).

A time dependent experiment was performed by holding temperature and pressure constant and sampling at different time intervals from the time of bubble stoppage. It was desired to determine if equilibrium was achieved rapidly. Table 6 gives the results of this study. All data points are given to show possible overlap. Values are expressed in Bunsen coefficients. The conditions of the experiment were 25.5°C and one atmosphere.

It appears that there is a slight decrease in concentration up to the fifth day. However there is a 90 percent probability that data from day 4 and day 5 could have come from the same population. Also there is a 90 percent probability that data from day 5 and day 7 came from

the same population.

Table 6. Time versus concentration for mixed system
($\alpha \times 10^3$).

Day 3	Day 4	Day 5	Day 7
21.30	19.93	19.98	20.58
21.71	20.39	19.87	21.26
21.71	20.73	20.43	23.88
21.57	19.73	20.10	21.49
22.76	22.75	17.57	22.25
22.23	23.82	20.20	18.46
22.35	21.62	21.86	21.35
22.69	24.18	---	21.57
<u>21.69</u>	<u>21.31</u>	<u>19.63</u>	<u>20.01</u>
21.99	21.60	19.96	21.20

To test the hypothesis that bubbles and turbulent mixing are in some way responsible for the observed phenomena, a system to saturate water without bubbling was devised. Mass transfer of nitrogen into degassed water was allowed only through the surface. The same sampling technique was used as before. Results are shown in Table 7.

Table 7. Time versus concentration for unmixed system
($\alpha \times 10^3$).

Day 1	Day 3	Day 5
14.18	15.08	15.69
11.94	15.33	15.89
12.93	15.55	15.66
12.39	15.88	15.65
13.28	15.98	15.77
<u>13.37</u>	<u>---</u>	<u>---</u>
13.01	15.56	15.73

Comparing the data from Table 7 with Table 2 a deviation of 7-9 percent is observed. Also a statistical check shows that within 80 percent probability day 3 and day 5 come from the same population. It is therefore assumed that equilibrium has been achieved by day 5.

Comparing Table 6 and Table 7 a significant difference in solubilities exist over the five day period. This difference can be attributed directly to bubbles and turbulent mixing versus surface absorption only.

It is of interest to note that the data of Table 4 approximates Henry's Law quite closely. See Figure 6 for this illustration.

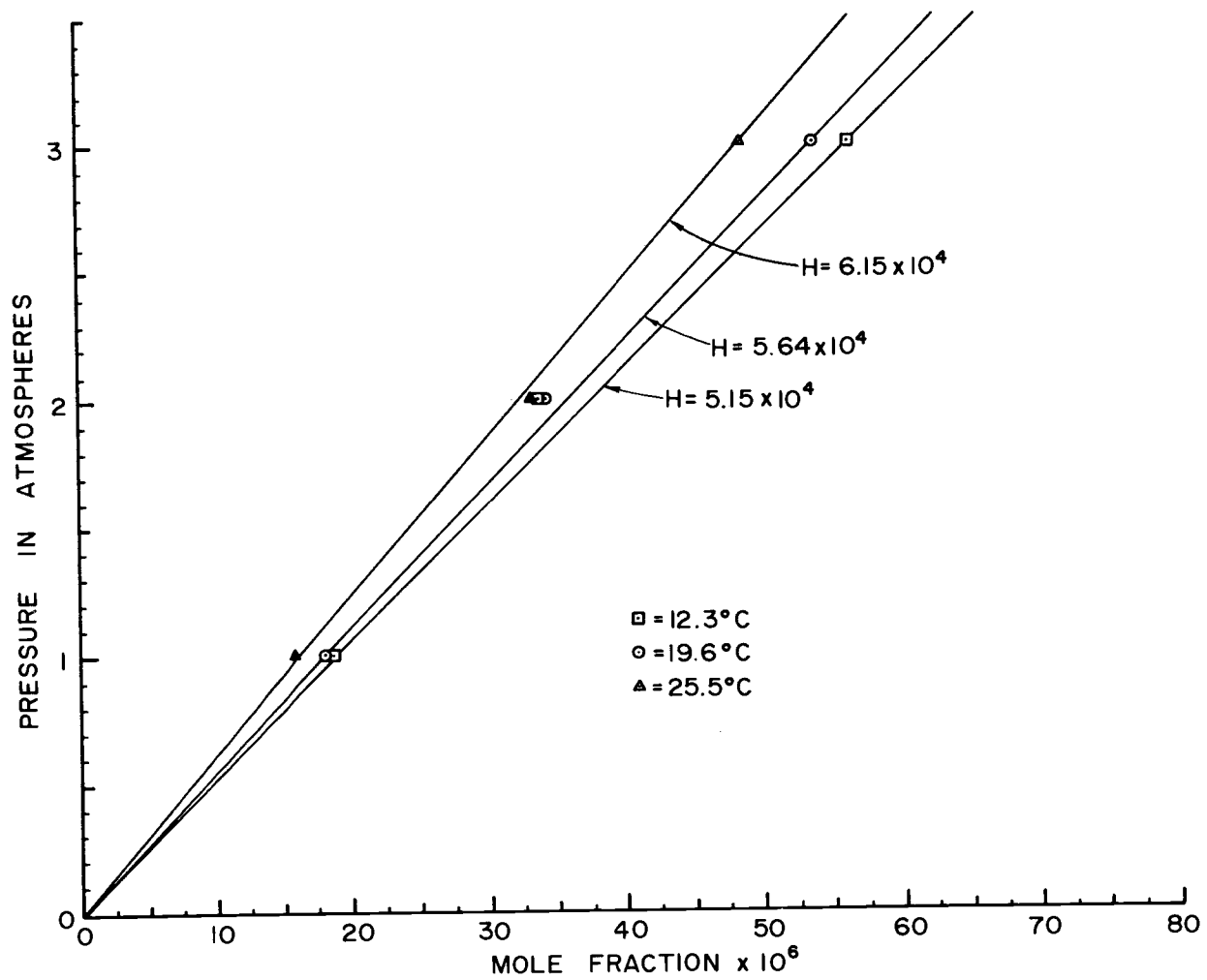


FIGURE 6 PRESSURE-MOLE FRACTION RELATIONSHIP EXPRESSING HENRY'S LAW

CONCLUSIONS

A distinct difference between concentrations in the turbulently mixed system and the unmixed system is noted. It is highly unlikely that these differences are due to experimental error. This difference can be explained by surface tension effects on small bubbles.

The term "nitrogen supersaturation" may have some validity from the standpoint of turbulent mixing and bubble phenomena.

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APPENDICES

APPENDIX A

Nomenclature

<u>Symbol</u>	<u>Explanation</u>	<u>Typical Units</u>
A	Bubble surface area	cm ²
MW _{H₂O}	Molecular weight of water	$\frac{\text{grams}}{\text{gram mole}}$
P ⁰ _{H₂O}	Partial pressure of water at conditions inside saturation chamber	mm Hg
P* _{H₂O}	Partial pressure of water at room temperature	mm Hg
P _{atm}	Atmospheric pressure	mm Hg
P _g	Partial pressure of gas whose solubility is being determined	mm Hg
P _{CH}	Pressure inside saturation chamber	mm Hg
r	Radius of bubble	cm
R	Universal gas constant	$\frac{(\text{atm})(\text{ml})}{(\text{gram moles})(^\circ\text{K})}$
T ₁	Temperature of measurement	°C
T ₀	°C (273.15°K)	°K
T _{CH}	Temperature in saturation chamber	°C
T _{atm}	Room temperature	°C
V	Volume of a bubble	cm ³
V _g	Volume of gas whose solubility is being determined	cm ³
V _s	Volume of solvent (in the case of water it is assumed 1 gram = 1 milliliter)	ml

<u>Symbol</u>	<u>Explanation</u>	<u>Typical Units</u>
V_{g_1}	Volume gas injected into chromatograph	ul
V_{g_0}	Corrected volume of gas injected into chromatograph	ul
V_{g_s}	Volume of gas evolved from sample	ul
W_{SL}	Weight of water in sample loop	ul
X'_{N_2}	Mole fraction nitrogen in sample (uncorrected for pressure variations)	$\frac{\text{mole } N_2}{\text{mole } N_2 + H_2O}$
X_{N_2}	Corrected mole fraction	$\frac{\text{mole } N_2}{\text{mole } N_2 + H_2O}$
α	Bunsen coefficient	$\frac{\text{ml gas}}{\text{ml solvent}}$
α'	Modified Bunsen coefficient	$\frac{\text{ml gas}}{\text{ml solvent}}$
σ	Surface tension water-nitrogen	$\frac{\text{dynes}}{\text{cm}}$
Δp	Pressure difference of small bubbles due to surface tension effects	mm Hg

APPENDIX B

Sample Calculations

The sample calculation is performed on data taken from Run 8-1 to 30. The calculations involve a general four step process. Step 1 deals with constructing a standard curve for the data collected during a particular run. Step 2 uses the standard curve to determine the volume of nitrogen evolved from the sample. Step 3 calculates the mole fraction representative of the sample and Step 4 calculates the Bunsen coefficient, α , and the modified Bunsen coefficient, α' .

Step 1:

- a) Calculate amount nitrogen injected minus water vapor present in syringe. (Peak 8-1 is an example)

$$V_{g_0} = V_{g_1} \frac{(P_{\text{atm}} - P_{\text{H}_2\text{O}}^*)}{P_{\text{atm}}} = 104 \text{ ul} \frac{(762.1 - 20.7)}{762.1} = 101.2$$

- b) A plot of V_{g_0} versus peak area is made. An example of Run 8-1 to 30 is shown in Figure 7.

Step 2:

- a) Knowing a peak area for a sample the volume of nitrogen at injection conditions can be determined. Consider peak 8-12 for example.

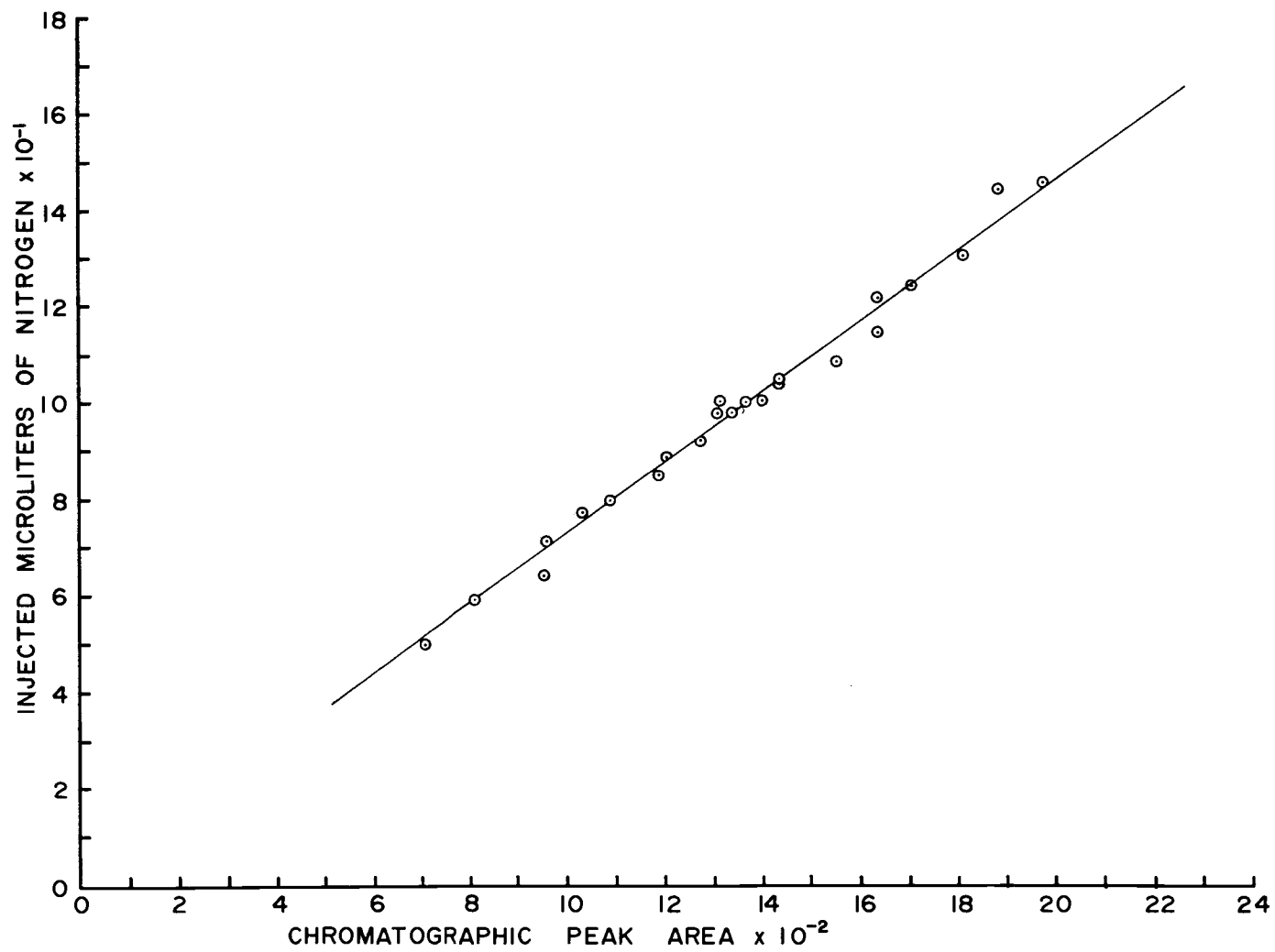


FIGURE 7 STANDARD CURVE FOR 8-1 to 8-30

Peak area = 1362

$$\therefore V_{g_s} = 100.00 \text{ ul.}$$

Step 3:

- a) Calculate the number of moles 100 ul represents (assuming the ideal gas law)

$$N_0 = \frac{P_{\text{atm}} \cdot V_{g_s}}{R \cdot T_{\text{atm}}} = \frac{\left(\frac{761.1 \text{ atm}}{760}\right) 100.0 \times 10^{-3}}{82.06 \frac{\text{atm ml}}{^\circ\text{K mole}} 295.45^\circ\text{K}} = 4.131 \times 10^{-6} \text{ gmoles}$$

- b) Calculate mole fraction at injected conditions

$$X'_{N_2} = N_0 \left(\frac{MW_{H_2O}}{W_{SL}} \right) = 4.121 \times 10^{-6} \left(\frac{18.015 \frac{\text{gr } H_2O}{\text{gmoles } N_2}}{4.2795 \text{ gr } H_2O} \right) \\ = 17.39 \times 10^{-6}$$

- c) Correct mole fraction for pressure variations and deviations from 760 mm Hg, 1520 mm Hg, or 2280 mm Hg. Since 8-12 was taken at approximately chamber conditions of 1 atmosphere it is corrected to 760 mm Hg.

$$X_{N_2} = X'_{N_2} \left(\frac{760}{P_{CH} - P_{H_2O}^0} \right) = 17.39 \times 10^{-6} \left(\frac{760}{783.4 - 24.5} \right) \\ = 17.40 \times 10^{-6}$$

- d) At pressures of two and three atmospheres the calculation is performed with consideration to these pressures:

$$\text{at two atmospheres} \quad X_{N_2} = X'_{N_2} \left(\frac{1520}{P_{CH} - P_{H_2O}^0} \right)$$

$$\text{at three atmospheres} \quad X_{N_2} = X'_{N_2} \left(\frac{2280}{P_{CH} - P_{H_2O}^0} \right)$$

Step 4:

a) The Bunsen coefficient is calculated

$$\begin{aligned} \alpha &= \frac{(N_0 R T_0)}{W_{SL}} \left[\frac{760 \text{ mm Hg}}{P_{CH} - P_{H_2O}^0} \right] \\ &= \left[\frac{4.131 \times 10^{-6} \cdot 82.06 \cdot 273.15}{4.2795} \right] \left[\frac{760}{783.4 - 24.5} \right] = 21.71 \times 10^{-3} \end{aligned}$$

b) At pressures of two and three atmospheres the modified Bunsen coefficient is defined as

$$\alpha' = \frac{(N_0 R T_0)}{W_{SL}} \left[\frac{1520 \text{ mm Hg}}{P_{CH} - P_{H_2O}^0} \right]$$

or

$$\alpha' = \frac{(N_0 R T_0)}{W_{SL}} \left[\frac{2280 \text{ mm Hg}}{P_{CH} - P_{H_2O}^0} \right]$$

APPENDIX C

Standardization of Sample Loop

<u>Final Weight</u> (grams)	<u>Initial Weight</u> (grams)	<u>Weight of Water</u> (grams)
72.8356	68.6959	4.1397
61.7959	57.6861	4.1098
63.9643	59.7638	4.2005
64.6059	60.3066	4.2993
60.2554	55.9079	4.3475
72.9148	68.5700	4.3448
59.0291	54.7945	4.2346
64.5969	60.1985	4.3984
63.8875	59.6802	4.2073
57.0815	52.8776	4.2039
59.3431	55.1071	4.2360
63.9075	59.6614	4.2461
64.4893	60.1756	4.3137
72.9109	68.5355	4.3754
57.1345	52.8634	4.2709
59.3346	55.0978	4.2368
59.0425	54.7622	4.2803
59.3362	55.1061	4.2301
64.5261	60.1729	4.3532
57.1334	52.8576	4.2758
59.0740	54.7620	4.3120
72.9737	68.5408	4.4329
63.8004	59.6733	4.1271
63.9723	59.6746	4.2977
57.1115	52.8549	4.2566
72.8930	68.5359	4.3571
59.1607	54.7615	4.3992
59.3906	55.1127	4.2779
64.5117	60.1691	<u>4.3426</u>
	Average =	4.2795

APPENDIX D

Tabulated Data

The run number code is as follows: The first number represents a set of data taken on one day and the second number represents the individual sample or injection number within the series. Columns 2 to 4 and 6 to 9 are observed data and columns 5, 10, 11, and 12 are calculated data.

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X _{N₂} ¹ x 10 ⁶	(11) X _{N₂} x 10 ⁶	(12) α or α' x 10 ³
1-2	Sample	22.8	765.8								
-3	108			105.2			1320				
-4	98			95.4			1191				
-5	96			93.5			1121				
-6	55			53.6			741				
-7	57			55.5			670				
-8	51			49.7			649				
-9	Sample		765.7		19.6	779.7	1320	103.5	18.08	18.01	22.41
-10	80			77.8			947				
-11	78			75.9			1009				
-12	74			72.0			998				
-13	148			144.0			1769				
-14	145			141.0			1824				
-15	145			141.0			1729				
-16	Sample	22.8	765.5		19.6	773.5	1314	103.0	17.98	18.06	22.47
-17	178			173.2			2125				
-18	179			174.1			2145				
-19	175			170.3			2078				

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{g_s} ul	(10) X _{N₂} ¹ x 10 ⁶	(11) X _{N₂} x 10 ⁶	(12) α or α ¹ x 10 ³
1-20	Sample		765.4		19.6	772.4	1194	93.0	16.23	16.33	20.32 ⁺
-21	122			118.7			1542				
-22	119			115.8			1445				
-23	125			121.6			1539				
-24	Sample	22.8	765.1		19.6	771.1	1280	100.5	17.54	17.68	21.99
-25											
-26	90			87.6			1124				
-27	85			82.7			1186				
-28	90			87.6			1186				
-29	Sample		764.5		19.6	768.5	1340	105.0	18.31	18.52	23.04
-30	110			107.0			1367				
-31	106			103.1			1361				
-32	110			107.0			1432				
-33	Sample		763.1		19.6	767.1	1310	103.0	17.92	18.16	22.60
-34	108			105.1			1378				
-35	105			102.1			1330				
-36	100			97.3			1280				
2-1	Sample	24.9	760.4								
-2	145			140.5			1757				
-3	103			99.8			1280				
-4	55			53.3			775				
-5	101			98.2			1098				
-6	Sample		760.3		19.7	1587.3	2502	199.0	34.26	33.16	41.27
-7	125			121.2			1550				
-8	129	24.8		125.0			1595				
-9											
-10	124			120.2			1530				
-11	Sample		760.3		19.6	1573.3	1555	120.0	20.67	20.18	25.11 ⁺
-12	155			150.1			1744				
-13	152	24.0		147.3			1845				
-14	154			149.5			1891				

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{g_s} ul	(10) X _{N₂} ' x 10 ⁶	(11) X _{N₂} x 10 ⁶	(12) a or a' x 10 ³
2-15	Sample	23.5	759.9		19.6	1586.9	2586	205.0	35.46	34.20	42.70
-16	Sample		759.8		19.5	1570.8	2421	192.0	33.19	32.47	40.40
-17	57			55.4			806				
-18	56			54.4			738				
-19	80			77.7			1069				
-20	77	23.0		74.7			1046				
-21	Sample		759.4		19.3	1584.4	3525	283.0	48.98	47.49	59.09
-22	113			109.8			1423				
-23	175			170.1			2162				
-24	203			197.4			2458				
-25	Sample		759.0		19.5	1583	2645	210.0	36.33	35.26	43.87
-26	Sample		759.0		19.4	1584	3020	241.0	41.69	40.44	50.31
-27	350			340.0			3828				
-28	200			194.3			2433				
-29	174			169.0			2138				
-30	160			155.6			2000				
-31	161			156.2			2021				
-32	Sample	23.0	758.9		19.2	1586.6	2750	219.0	37.88	36.67	45.63
-33	185			179.9			2315				
-34	185			179.9			2346				
3-1	Sample	22.8	763.0								
-2	153			148.8			2070				
-3	157			152.6			2202				
-4	150			145.9			2006				
-5	Sample	22.8	762.6		19.7	1551.6	2713	196.0	34.09	33.77	42.06
-6	103			100.1			1523				
-7	125			121.5			1652				
-8											
-9	180			175.0			2431				
-10	Sample	23.0	762.4		19.6	1521.4	4160	299.0	51.96	52.50	65.32
-11	Sample	23.0	762.5		19.6	1524.5	2630	189.0	32.84	33.12	41.21

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} ° C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} ° C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X _{N₂} ' x 10 ⁶	(11) X _{N₂} x 10 ⁶	(12) a or a' x 10 ³
3-12	218			212.0			2695				
-13	112			109.0			1620				
-14	140			136.2			1709				
-15	Sample	22.9	762.4		19.7	1521.4	2960	213.0	37.02	37.41	46.55
-16	58			56.4			735				
-17	67			65.2			1025				
-18	55			53.5			778				
-19	77			74.8			868				
-20	79			76.7			1132				
-21	Sample	22.9	761.5		19.7	1509.5	2567	185.0	32.12	32.71	40.70
-22	228			221.7			3078				
-23	201			195.5			2446				
-24	173			168.0			2382				
-25	Sample	23.0	760.9		19.7	1515.9	2512	181.0	31.39	31.83	39.60
-26	194			188.8			2718				
-27	167			162.5			2001				
-28	148			144.0			2032				
-29	142			138.0			1998				
-30	Sample		759.8		19.7	1527.8	2568	185.0	32.04	32.23	40.10
-31	128			124.5			1820				
-32	115			112.0			1261				
-33	100			97.5			1498				
-34	112			109.0			1594				
-35	Sample	22.9	759.1		19.6	1491.1	4160	299.0	51.75	53.36	66.39
-36	Sample		758.9		19.6	1494.9	2708	195.0	33.74	34.70	43.18
-37	130			126.5			1888				
-38	157			153.0			2140				
4-1		24.8	759.5								
-2	104			100.8			1430				
-3	202			195.7			2730				
-4	150			145.4			1812				

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} ° C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} ° C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X _{N₂} ' x 10 ⁶	(11) X _{N₂} x 10 ⁶	(12) α or α' x 10 ³
4-5	Sample	24.8	759.4		19.7	1501.4	2486	187	32.17	32.94	40.99
-6	227			220.0			2663				
-7	169			163.8			2253				
-8	112			108.5			1550				
-9	Sample	24.2	759.5		19.6	1508.5	2574	194	33.45	34.09	42.41
-10	216			209.0			2863				
-11	163			158.0			1960				
-12	121			117.5			1710				
-13	Sample	23.7	760.0		19.6	1505.0	2393	180	31.10	31.78	39.54
-14	246			238.5			3026				
-15	185			179.5			2525				
-16	138			133.8			1640				
-17	Sample	23.6	760.0		19.5	1504.0	2592	196	33.88	34.63	43.09
-18	Sample	23.6	759.8		19.6	1514.8	2430	182	31.45	31.92	39.71
-19	131			127.0			1617				
-20	186			180.3			2466				
-21	236			229.0			3003				
-22	Sample	23.6	759.4		19.4	1509.4	2922	222	38.35	39.05	48.59
-23	Sample	23.6	759.2		19.4	1507.2	2468	185	31.95	32.58	40.54
-24	145			140.5			1640				
-25	165			160.0			2235				
-26											
-27	195			189.0			2450				
-28	Sample	23.4	758.6		19.4	1513.6	2815	214	36.95	37.52	46.69
-29	Sample	23.4	758.5		19.4	1509.5	2558	193	33.32	33.93	42.22
-30	173			167.8			2220				
5-1		22.8	759.8								
-2	200			194.6			1791				
-3	155			150.8			1359				
-4	118			114.8			1015				
-5	Sample	22.9	760.0		19.7	2269	2995	285	49.38	50.00	62.21

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X _{N₂} ' x 10 ⁶	(11) X _{N₂} x 10 ⁶	(12) α or α' x 10 ³
5-6	255			248.0			2505				
-7	242			235.5			2423				
-8	305			296.6			3148				
-9	Sample	22.9	760.3		19.7	2267	3375	317	54.95	55.67	69.29
-10	Sample		760.0		19.6	2265	2825	271	46.96	47.63	59.26
-11	222			216.0			2183				
-12	168			163.5			1750				
-13											
-14	191			185.9			1918				
-15	Sample	23.4	760.0		19.6	2267	2345	229	39.61	40.14	49.95
-16	135			131.2			1328				
-17	180			174.9			1720				
-18	215			209.0			2036				
-19	Sample	23.7	759.7		19.6	2258	4165	386	66.68	67.84	84.41
-20	Sample	23.6	759.4		19.6	2258	3168	300	51.82	52.72	65.60
-21											
-22	285			277.0			2453				
-23	274			266.2			2071				
-24											
-25	238			231.2			2491				
-26	Sample	23.8	758.8		19.5	2260	2694	259	44.67	45.40	56.50
-27	Sample	24.0	758.7		19.6	2267	2842	272	46.87	47.50	59.10
-28	150			145.7			1392				
-29	175			170.5			1500				
6-1		23.5	759.9								
-2	205			199.0			2335				
-3	155			150.6			1508				
-4	100			97.1			1073				
-5	Sample	22.9	760.2		19.7	2262	2883	263	45.58	46.30	57.60
-6	255			248.0			2614				
-7	225			218.8			2407				

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} °C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} °C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) α or $\alpha' \times 10^3$
6-8	225			218.8			2414				
-9	Sample	23.0	760.3		19.6	2257	3144	287	49.73	50.62	62.99
-10											
-11	167			162.4			1698				
-12	175			170.0			1785				
-13	190			184.6			1934				
-14	Sample	22.8	760.3		19.5	2249	3654	332	57.57	58.81	73.17
-15	190			184.6			2056				
-16	207			201.0			2125				
-17	218			212.0			2268				
-18											
-19	Sample	23.0	760.0		19.5	2263	3595	327	56.64	57.70	71.54
-20	230			224.0			2548				
-21	240			233.5			2478				
-22	138			134.2			1465				
-23	Sample	22.8	759.6		19.5	2254	2808	257	44.52	45.37	56.46
-24	160			155.5			1582				
-25	170			165.5			1824				
-26	180			175.0			1887				
-27	Sample	22.7	759.1		19.5	2257	3687	335	58.02	59.05	73.47
-28	Sample	22.8	759.0		19.4	2245	3451	314	54.35	55.62	69.20
-29	194			188.5			2067				
-30	205			199.7			2135				
7-1		22.7	748.1								
-2	98.0			95.3			1228				
-3	150.0			145.8			1888				
-4	200.0			194.5			2435				
-5	Sample	22.6	748.3		19.8	753.3	1374	107.0	18.27	18.87	23.47
-6	110.0			107.0			1447				
-7	129.0			125.4			1527				
-8	135.0			131.3			1669				

(1) Run No.	(2) V_{g1} ul	(3) T_{atm} ° C	(4) P_{atm} mm Hg	(5) V_{g0} ul	(6) T_{CH} ° C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{gs} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) $\alpha \text{ or } \alpha' \times 10^3$
7-9											
-10	Sample	23.5	748.0	.	19.6	752.0	1800	142.0	24.29	25.12	31.26
-11	72.0			70.0			930				
-12	82.0			79.7			1022				
-13	91.0			88.4			1106				
-14	Sample	23.5	747.4		19.6	751.4	1197	93.5	15.90	16.46	20.48
-15	56.0			54.4			554				
-16	139.0			135.0			1724				
-17	160.0			155.4			1962				
-18	Sample	23.4	748.4		19.6	752.4	1388	108.0	18.40	19.01	23.66
-19	102.0			99.1			1046				
-20	Sample	23.4	748.2		19.5	752.2	1115	87.0	14.81	15.31	19.05
8-1		22.7	762.1								
-2	104.0			101.2			1312				
-3	150.0			145.9			1881				
-4	125.0			121.6			1628				
-5	Sample	22.7	761.8		25.6	784.5	1334	98.5	17.12	17.12	21.30
-6	52.0			50.5			710				
-7	61.0			59.2			808				
-8	74.0			72.0			964				
-9	Sample	22.4	761.5		25.5	783.9	1360	100.0	17.39	17.40	21.71
-10	80.0			77.9			1025				
-11	92.0			89.5			1212				
-12	Sample	22.3	761.1		25.5	783.4	1362	100.0	17.39	17.40	21.71
-13	96.0			93.5			1274				
-14	104.0			101.2			1401				
-15	Sample	22.2	760.7		25.5	782.9	1350	99.5	17.30	17.33	21.57
-16	107.0			104.2			1425				
-17	113.0			110.0			1543				
-18	Sample	22.2	760.2		25.6	782.4	1432	105.0	18.24	18.29	22.76
-19	120.0			116.8			1627				

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X' _{N2} x 10 ⁶	(11) X _{N2} x 10 ⁶	(12) a or a' x 10 ³
8-20	130.0			126.6			1708				
-21	Sample	22.8	759.9		25.5	783.7	1405	103.0	17.85	17.87	22.23
-22	150.0			145.9			1968				
-23	100.0			97.3			1303				
-24	Sample	22.0	759.1		25.5	781.1	1355	100.0	17.36	17.43	21.69
-25	82.0			79.9			1092				
-26	89.0			86.7			1194				
-27	Sample	22.0	758.9		25.5	780.9	1400	103.0	17.87	17.96	22.35
-28	67.0			65.3			935				
-29	135.0			131.5			1810				
-30	Sample	22.8	758.4		25.5	781.2	1424	105.0	18.16	18.24	22.69
9-1		22.5	756.9								
-2	102.0			99.2			1311				
-3	151.0			147.0							
-4	125.0			121.6							
-5	Sample	22.7	756.7		25.6	757.7	1195	89.5	15.45	16.02	19.93
-6	53.0			51.6			744				
-7	63.0			61.3			804				
-8	70.0			68.1			910				
-9	Sample	22.4	756.2		25.6	757.2	1215	91.5	15.80	16.39	20.39
-10	81.0			78.8			1061				
-11	93.0			91.7			1195				
-12	Sample	22.4	755.9		25.6	756.9	1237	93.0	16.05	16.66	20.73
-13	98.0			96.5			1303				
-14	114.0			112.3			1501				
-15	Sample	22.3	756.2		25.6	757.2	1176	88.5	15.29	15.86	19.73
-16	121.0			118.0			1578				
-17	130.0			126.6			1639				
-18	Sample	22.1	755.8		25.5	756.8	1346	102.0	17.62	18.29	22.75
-19	143.0			139.3			1830				
-20	157.0			152.9			2018				

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X _{N2} ' x 10 ⁶	(11) X _{N2} x 10 ⁶	(12) α or α' x 10 ³
9-21	Sample	22.1	755.1		25.5	756.1	1256	94.5	16.49	17.12	21.31
-22	107.0			104.1			1450				
-23	111.0			108.2			1466				
-24	Sample	22.7	755.7		25.5	756.7	1415	107.0	18.45	19.15	23.82
-25	66.0			64.2			976				
-26	89.0			87.6			1250				
-27	Sample	22.3	755.4		25.4	756.4	1290	97.0	16.74	17.38	21.62
-28	104.0			101.2			1381				
-29	106.0			103.2			1403				
-30	Sample	23.8	755.5		25.4	756.5	1440	109.0	18.72	19.43	24.18
10-1		27.8	762.8								
-2											
-3	150.0			144.5							
-4	127.0			122.3							
-5	Sample	27.0	762.4		25.5	762.9	1090	91.0	15.60	16.06	19.98
-6	50.0			48.2			586				
-7	63.0			60.8			738				
-8	72.0			69.5			843				
-9	Sample	26.8	762.7		25.4	763.2	1087	90.5	15.53	15.97	19.87
-10	84.0			81.2			997				
-11	95.0			91.7			1120				
-12	Sample	26.8	763.0		25.4	763.5	1123	93.0	15.97	16.42	20.43
-13	103.0			99.5			1206				
-14	110.0			106.2			1262				
-15	Sample	26.8	763.0		25.4	763.5	1102	91.5	15.71	16.15	20.10
-16	121.0			118.3			1390				
-17	135.0			132.0			1580				
-18	Sample	26.8	763.3		25.4	763.8	964	80.0	13.74	14.12	17.57
-19	143.0			138.1			1650				
-20	86.0			83.0			1028				
-21	Sample	26.8	762.7		25.4	763.2	1039	86.0	14.76	15.18	19.63

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} °C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} °C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) α or $\alpha' \times 10^3$
10-22	75.0			72.4			859				
-23	129.0			124.5			1524				
-24	Sample	26.8	762.5		25.4	763.0	1537	128.0	21.96	22.56	28.07 ⁺
-25	152.0			146.7			1777				
-26	58.0			55.9			708				
-27	Sample	26.8	762.8		25.7	763.3	1108	92.0	15.79	16.24	20.20
-28	83.0			80.2			1003				
-29	114.0			110.1			1186				
-30	Sample	26.8	762.4		25.6	762.9	1200	99.5	17.07	17.57	21.86
11-1											
-2											
-3	152.0			147.9			1684				
-4	128.0			124.7			1504				
-5	Sample	22.0	759.8		26.0	759.8	1140	92.0	15.98	16.54	20.58
-6	51.0			49.7			653				
-7	60.0			58.4			735				
-8	73.0			71.1			883				
-9	Sample	22.1	759.8		26.0	759.0	1177	95.0	16.50	17.09	21.26
-10	83.0			80.8			1019				
-11	94.0			91.6			1258				
-12	Sample	22.6	759.3		25.9	759.3	1306	107.0	18.54	19.19	23.88
-13	101.0			98.3			1207				
-14	110.0			107.0			1353				
-15	Sample	23.2	759.0		25.9	759.0	1191	96.5	16.68	17.27	21.49
-16	125.0			121.5			1470				
-17	141.0			137.0			1519				
-18	Sample	23.4	758.1		25.8	758.1	1233	100.0	17.26	17.89	22.25
-19	87.0			84.6			1064				
-20	98.0			95.2			1199				
-21	Sample	23.7	757.7		25.8	757.7	1120	90.0	15.50	16.08	20.01
-22	79.0										

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X' _{N2} × 10 ⁶	(11) X _{N2} × 10 ⁶	(12) α or α' × 10 ³
11-23	81.0			78.6			945				
-24	Sample	23.7	757.3		25.9	757.3	1040	83.0	14.29	14.83	18.46
-25	109.0			105.9			1293				
-26	135.0			131.1			1565				
-27	Sample	23.6	756.8		25.9	756.8	1188	96.0	16.52	17.16	21.35
-28	93.0			90.2			999				
-29	145.0			140.7			1682				
-30	Sample	23.7	756.4		25.8	756.4	1200	97.0	16.68	17.33	21.57
12-1		24.8	758.6								
-2	110.0			106.6			1344				
-3	152.0			147.3			1790				
-4	200.0			193.8			2441				
-5	Sample	25.6	758.6		25.9	1545.6	2612	205.5	35.22	35.21	43.81 ⁺
-6	106.0			102.6			1271				
-7	115.0			111.3			1351				
-8	130.0			125.8			1586				
-9	Sample	26.0	758.6		25.8	1544.6	2410	190.0	32.52	32.53	40.47
-10	237.0			229.1			2713				
-11	250.0			241.7			2797				
-12	Sample	26.1	758.6		25.8	1544.6	2468	194.5	33.28	33.28	41.41
-13	175.0			169.2			2163				
-14	190.0			183.7			2232				
-15	Sample	26.0	758.4		25.7	1544.4	2456	193.5	33.11	33.12	41.21
-16	212.0			205.0			2584				
-17	233.0			225.3			2830				
-18	Sample	26.2	758.4		25.7	1545.4	2375	187.0	31.98	31.96	39.77
-19	225.0			217.5			2760				
-20	170.0			164.3			2083				
-21	Sample	26.2	758.0		25.8	1544.0	2535	200.0	34.18	34.20	42.56
-22	197.0			190.4			2443				
-23	205.0			198.0			2532				

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} °C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} °C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) α or $\alpha' \times 10^3$
12-24	220.0			212.5			2703				
13-1		22.4	768.3								
-2	156.0			151.8			2039				
-3	255.0			248.3			3282				
-4	358.0			348.5			4402				
-5	Sample	22.9	768.3		25.9	2289.3	3821	290.0	50.80	51.15	63.64
-6	275.0			267.5			3607				
-7	305.0			296.7			3947				
-8	325.0			316.2			4138				
-9	Sample	22.9	768.4		25.8	2291.4	3833	291.0	50.98	51.28	63.81
-10	295.0			287.0			3718				
-11	320.0			311.3			3885				
-12	340.0			330.8			4305				
-13	Sample	23.0	766.8		25.7	2295.8	3569	266.0	46.49	46.67	58.07
-14	375.0			364.7			4670				
-15	405.0			394.0			4843				
-16	270.0			262.6			3315				
-17	Sample	22.8	766.4		25.7	2295.4	3549	264.0	46.15	46.34	57.65
-18	315.0			306.0			4052				
-19	365.0			355.0			4474				
-20	Sample	22.5	765.8		25.7	2294.8	3635	271.0	47.38	47.59	59.21
-21	275.0			265.0			3628				
-22	235.0			229.0			3111				
14-1		23.9	762.7								
-2	54.5			52.9			587				
-3	79.0			76.7			865				
-4	103.0			100.0			1038				
-5	Sample	24.5	762.7		25.9	763.2	690	64.0	11.07	11.40	14.18
-6	41.0			39.8			427				
-7	33.0			32.0			347				
-8	66.0			64.0			648				

(1) Run No.	(2) V _{g1} ul	(3) T _{atm} °C	(4) P _{atm} mm Hg	(5) V _{g0} ul	(6) T _{CH} °C	(7) P _{CH} mm Hg	(8) Peak Area	(9) V _{gs} ul	(10) X _{N2} ' x 10 ⁶	(11) X _{N2} x 10 ⁶	(12) α or α' x 10 ³
14-9	Sample	24.7	762.3		25.8	762.8	975	89.5	15.46	15.92	19.81 ⁺
-10	74.0			71.7			752				
-11	92.0			89.1			965				
-12	Sample	25.0	762.3		25.8	762.8	591	54.0	9.32	9.60	11.94
-13	126.0			122.2			1300				
-14	115.0			111.6			1206				
-15	Sample	25.0	762.0		25.6	762.5	630	58.5	10.09	10.39	12.93
-16	108.0			104.7			1143				
-17	88.0			85.3			916				
-18	Sample	25.0	762.0		25.6	762.5	604	56.0	9.66	9.96	12.39
-19	63.0			61.1			672				
-20	47.0			45.6			542				
-21	Sample	25.0	761.2		25.6	761.7	652	60.0	10.34	10.67	13.28
-22	98.0			94.9			990				
-23	75.0			72.7			750				
-24	Sample	25.0	761.0		25.6	761.5	658	60.5	10.42	10.75	13.37
15-1		22.0	764.2								
-2	50.0			48.7			563				
-3	72.0			70.1			798				
-4	100.0			97.4			970				
-5		22.8	764.3								
-6	120.0			116.7			1347				
-7	65.0			63.2			708				
-8	84.0			81.7			901				
-9	Sample	23.4	764.5		25.8	765.5	860	77.5	13.48	13.84	17.22 ⁺
-10	40.0			38.9			429				
-11	58.0			56.4			700				
-12	Sample	23.6	765.0		25.6	766.0	758	68.0	11.83	12.12	15.08
-13	107.0			104.0			1093				
-14	96.0			93.3			1003				
-15	95.0			92.3			997				

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} °C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} °C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) a or a' $\times 10^3$
15-16	Sample	23.2	765.1		25.6	766.1	765	69.0	12.02	12.32	15.33
-17	125.0			121.5			1260				
-18	111.0			107.9			1180				
-19	Sample	23.2	765.1		25.5	766.1	775	70.0	12.19	12.50	15.55
-20	75.0			72.9			790				
-21	57.0			55.4			638				
-22	Sample	23.2	765.0		25.5	766.0	791	71.5	12.46	12.77	15.88
-23	90.0			87.5			954				
-24	80.0			77.8			843				
-25	Sample	23.1	765.1		25.5	767.1	805	72.0	12.54	12.84	15.98
16-1		22.6	763.8								
-2	59.0			57.4			723				
-3	84.0			81.7			999				
-4	100.0			97.3			1190				
-5	Sample	22.9	764.2		25.9	764.7	1010	80.5	14.02	14.40	17.92 ⁺
-6	27.0			26.3			456				
-7	44.0			42.8			615				
-8	68.0			66.1			845				
-9	Sample	23.1	764.2		25.8	764.7	893	70.5	12.28	12.61	15.69
-10	88.0			85.6			1000				
-11	123.0			119.6			1520				
-12	Sample	23.4	764.3		25.8	764.8	906	71.5	12.44	12.77	15.89
-13	111.0			107.9			1262				
-14	102.00			99.1			1312				
-15	Sample	23.6	764.2		25.7	764.7	889	70.5	12.25	12.59	15.66
-16	78.0			75.8			1035				
-17	39.0			37.9			484				
-18	Sample	23.7	764.1		25.7	764.6	895	70.5	12.25	12.58	15.65
-19	90.0			87.4			1116				
-20	115.0			111.7			1435				
-21	Sample	23.6	764.1		25.7	764.6	901	71.0	12.34	12.67	15.77

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} ° C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} ° C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) α or $\alpha' \times 10^3$
16-22	101.0			98.1			1248				
-23	69.0			67.0			885				
17-1		22.1	759.6								
-2	100.0			97.4			1001				
-3	49.0			47.7			522				
-4	152.0			148.0			1647				
-5	Sample	22.3	759.3		12.2	761.3	1083	100.0	17.34	17.56	21.85
-6	115.0			111.9			1205				
-7	131.0			127.5			1410				
-8	141.0			137.2			1554				
-9	Sample	22.5	759.6		12.1	761.6	1133	105.0	18.21	18.43	22.92
-10	85.0			82.7			910				
-11	90.0			87.6			916				
-12	Sample	22.5	759.6		12.1	761.6	1145	106.0	18.38	18.61	23.14
-13	99.0			96.4			1041				
-14	75.0			73.0			787				
-15	Sample	22.4	759.1		12.0	761.1	1148	106.5	18.46	18.70	23.26
-16	108.0			105.1			1100				
-17	122.0			118.7			1260				
-18	Sample	22.5	758.9		12.0	759.9	1016	94.0	16.28	16.51	20.55
-19	129.0			125.6			1345				
-20	138.0			134.4			1436				
-21	Sample	22.3	759.0		12.0	759.5	1300	120.5	20.89	21.20	26.38
-22	65.0			63.3			692				
-23	164.0			159.7			1728				
-24	Sample	22.3	758.8		12.0	759.3	1160	107.5	18.63	18.91	23.53
18-1		22.5	761.8								
-2	81.0			78.8			1000				
-3	100.0			97.3			1273				
-4	153.0			148.9			1852				
-5	Sample	22.7	762.0		12.4	764.0	1556	121.0	21.04	21.23	26.17

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} °C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} °C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) α or $\alpha' \times 10^3$
18-6	48.0			46.8			651				
-7	127.0			123.6			1521				
-8	Sample	23.0	762.2		12.4	764.2	1444	113.0	19.63	19.80	24.42
-9	114.0			110.8			1463				
-10	90.0			87.6			1224				
-11	Sample	23.0	762.0		12.4	764.0	1433	112.0	19.45	19.62	24.20
-12	133.0			129.3			1755				
-13	141.0			137.1			1753				
-14	Sample	23.0	761.8		12.4	763.8	1310	103.0	17.88	18.04	22.46
-15	131.0			127.4			1644				
-16	107.0			104.0			1250				
-17	Sample	23.2	761.3		12.4	763.3	1507	117.5	20.37	20.57	25.34
-18	63.0			61.4			745				
-19	85.0			82.8			1028				
-20											
-21	80.0			78.0			1018				
-22	90.0			87.7			1145				
19-1		25.5	748.3								
-2	105.0			101.6			918				
-3	150.0			145.1			1320				
-4	55.0			53.2			451				
-5	Sample	24.6	748.6		12.5	750.6	1495	167.0	28.34	29.12	35.26 ⁺
-6	78.0			75.6			681				
-7	124.0			120.2			1069				
-8	Sample	24.8	748.8		12.5	750.8	1055	118.0	20.02	20.56	24.91
-9	90.0			87.2			828				
-10	143.0			138.5			1292				
-11	Sample	24.8	748.4		12.5	750.4	919	104.0	17.63	18.12	21.94
-12	116.0			112.4			967				
-13	71.0			68.7			625				
-14	Sample	24.8	748.4		12.5	750.4	987	112.0	18.99	19.51	23.63

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} ° C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} ° C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) a or $a' \times 10^3$
19-15	161.0			156.0			1365				
-16	130.0			126.0			1103				
-17	Sample	24.8	748.2		12.5	750.2	907	103.0	17.46	17.95	21.72
-18	140.0			135.5			1237				
-19	170.0			164.7			1438				
-20	Sample	24.8	747.6		12.5	749.6	925	105.0	17.78	18.29	22.76
-21	135.0			130.8			1144				
-22	70.0			67.7			606				
-23	Sample	24.8	747.7		12.5	749.7	925	105.0	17.79	18.30	22.76
20-1			749.4								
-2	100.0	23.0		97.2			1205				
-3	202.0			196.3			2350				
-4	305.0			296.4			3454				
-5	Sample	23.0	748.8		12.5	1545.8	2357	198.0	33.79	33.46	41.63
-6	130.0			126.3			1533				
-7	160.0			155.5			1898				
-8	Sample	22.9	749.2		12.5	1545.2	2596	219.0	37.41	37.06	46.11
-9	236.0			230.0			2765				
-10	270.0			263.0			3069				
-11	Sample	23.2	748.8		12.5	1544.8	2150	180.0	30.70	30.42	37.85
-12											
-13											
-14	Sample	23.2	748.8		12.5	1545.8	2370	199.0	33.94	33.61	41.82
-15	210.0			204.1			2450				
-16	221.0			214.8			2525				
-17	Sample	23.2	748.8		12.5	1545.8	2395	201.5	34.37	34.03	42.35
-18	240.0			233.2			2740				
-19	192.0			186.6			2224				
-20	Sample	23.2	748.6		12.5	1545.6	2425	204.0	34.78	34.45	42.86
-21	184.0			179.0			2160				
-22	174.0			169.1			1980				

(1) Run No.	(2) V_{g_1} ul	(3) T_{atm} °C	(4) P_{atm} mm Hg	(5) V_{g_0} ul	(6) T_{CH} °C	(7) P_{CH} mm Hg	(8) Peak Area	(9) V_{g_s} ul	(10) $X'_{N_2} \times 10^6$	(11) $X_{N_2} \times 10^6$	(12) a or a' $\times 10^3$
20-23	Sample	23.2	749.1		12.5	1546.1	2402	202.0	34.47	34.12	42.46
21-1											
-2											
-3											
-4											
-5	Sample	22.5	763.6		12.5	2283.6	3495	322.0	56.06	56.24	69.97
-6	280.0			272.5			2895				
-7	330.0			321.2			3451				
-8	310.0			301.7			3112				
-9	Sample	22.5	763.6		12.5	2283.6	3427	315.5	54.93	55.10	68.56
-10	260.0			253.0			2839				
-11	350.0			341.0			3708				
-12	Sample	22.5	763.6		12.5	2281.6	3564	328.5	57.27	57.50	71.54
-13	300.0			292.0			3170				
-14	322.0			313.5			3406				
22-1	Sample	22.5	763.6		12.5	2282.6	3803	320.0	55.79	55.99	69.66
-2	290.0			282.3			3458				
-3	330.0			321.2			3813				
-4	Sample	22.5	763.6		12.5	2283.6	3800	320.0	55.79	55.97	69.63
-5	336.0			327.0			3950				
-6	300.0			292.0			3540				
-7	Sample	22.5	762.8		12.5	2282.8	3837	323.0	56.25	56.45	70.23
-8	320.0			311.5			3703				
-9	280.0			273.0			3254				
-10	Sample	22.5	762.7		12.5	2282.7	3860	325.5	56.68	56.88	70.77
-11	335.0			326.0			3868				
-12	310.0			302.0			3554				

⁺ Experimental value disregarded. The disregarded values were thrown out on the basis of a 95% significance level test described by J.D. Hinchey, Practical Statistics for Chemical Research, Methuen & Co., Ltd., 11 New Fetter Lane, London 1969. p. 26.