

SURFACE AREA, PORE VOLUME AND PORE DIAMETER OF POROUS SUBSTANCES BY NITROGEN ADSORPTION

UOP Method 425-86

SCOPE

This method is for determining the surface area of porous substances based upon the Brunauer-Emmett-Teller¹ (B.E.T.) theory of multilayer adsorption through the use of measurements at two partial pressures using nitrogen as the adsorption gas. Pore volume is determined according to the capillary condensation theory.² Pore diameter is calculated from surface area and pore volume. The method is limited to substances with surface areas greater than 10 m²/g and pore diameters less than 60 nm. This method uses barometric pressure as the reference pressure while UOP Method 821 is referenced to nitrogen saturation pressure. Therefore, surface areas determined by this method are typically as much as 10% lower than those produced by UOP 821.

OUTLINE OF METHOD

The surface area of a substance is determined by measuring the volume of nitrogen gas adsorbed at liquid nitrogen temperature and relative pressures of 60/760 and 160/760, and applying the B.E.T. theory. The pore volume is determined by measuring the amount of gaseous nitrogen condensed in the pores at liquid nitrogen temperature and at a relative pressure of 735/760. It is assumed, based on the Kelvin equation for capillary condensation and on the proper correction for multilayer adsorption, that all pores of diameters less than 60 nm are filled at this relative pressure.

APPARATUS

General (Note 2)

Balance, readability 0.1-mg

Barometer, aneroid, graduated in mm of Hg, Sargent-Welch Scientific, Cat. No. S-4631, or equivalent

Drying tower, 250-mm in height, Sargent-Welch Scientific, Cat. No. S-28725A, or equivalent

Glass scribe, Sargent-Welch Scientific, Cat. No. S-65736-10, or equivalent

Glass wool, borosilicate, Sargent-Welch Scientific, Cat. No. S-40225, or equivalent

IT IS THE USER'S RESPONSIBILITY TO ESTABLISH APPROPRIATE PRECAUTIONARY PRACTICES AND TO DETERMINE THE APPLICABILITY OF REGULATORY LIMITATIONS PRIOR TO USE. EFFECTIVE HEALTH AND SAFETY PRACTICES ARE TO BE FOLLOWED WHEN UTILIZING THIS PROCEDURE. FAILURE TO UTILIZE THIS PROCEDURE IN THE MANNER PRESCRIBED HEREIN CAN BE HAZARDOUS. MATERIAL SAFETY DATA SHEETS (MSDS) OR EXPERIMENTAL MATERIAL SAFETY DATA SHEETS (EMSDS) FOR ALL OF THE MATERIALS USED IN THIS PROCEDURE SHOULD BE REVIEWED FOR SELECTION OF THE APPROPRIATE PERSONAL PROTECTION EQUIPMENT (PPE).

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Manometer, precision, aneroid, 0-800 mm of Hg, Wallace and Tiernan, Type FA-173, Pro-Quip Inc., or equivalent

Regulator, nitrogen, Matheson, 8-BF, CGA No. 580, or equivalent

Sample cell with connector, Fig. 2B, UOP Inc., or equivalent

Springs, glass grinding joint, 38-mm, Sargent-Welch Scientific, Cat. No. S-40220B, or equivalent

Thermometer, total immersion, -35 to 50 C, Sargent-Welch Scientific, Cat. No. S-80005A, or equivalent

Tubing, glass, 8-mm, standard wall

Tubing, rubber, high vacuum

Vacuum pump, high vacuum, 10 mm Hg, Sargent-Welch Scientific, Cat. No. 1400W-01, or equivalent

Outgassing Section (Fig. 1)

Filter, fritted glass, medium porosity, Sargent-Welch Scientific, Cat. No. S-33730, or equivalent

Furnace, crucible type, Hoskins Type FD-104, complete with rheostat, thermocouple and potentiometer, Sargent-Welch Scientific, Cat. No. S-6525B, or equivalent

Gauge, vacuum, McLeod, Sargent-Welch Scientific, Cat. No. S-39820-50, or equivalent

Manifold, 6-place, equipped with female 12/30 F glass joints, Fig. 2B, UOP Inc., or equivalent

Stopcock, "B", three-way, double-oblique bore, 8-mm OD, precision ground, Sargent-Welch Scientific, Cat. No. S-77195B, or equivalent

Stopcock, "D", three-way, V-bore, 8-mm OD, precision ground, Sargent-Welch Scientific, Cat. No. S-77220C, or equivalent

Adsorption Section (Fig. 1)

Filter, fritted glass, medium porosity (same as in Outgassing Section)

Flask, Dewar, wide-mouth, 4300-mL, Sargent-Welch Scientific, Cat. No. S-34695C, or equivalent

Gloves, Zetex lined, Sargent-Welch Scientific, Cat. No. S-40255-10, or equivalent

Manifold, 6-place, equipped with female 12/30 F glass joints (same as in Outgassing Section)

Stopcock, "C", same as Stopcock "B" in Outgassing Section

Desorption Section (Fig. 2A)

Bottles, leveling, polyethylene, 1000-mL, Sargent-Welch Scientific, Cat. No. S-8690B, or equivalent

Burets, 50-mL, 0.1-mL graduations; 500-mL, 1.0-mL graduations; each with three-way V-bore stopcock attached to zero end, UOP Inc., or equivalent

Clamps, screw compressor, Hoffman, Sargent-Welch Scientific, Cat. No. S-19475, or equivalent

Connector, glass, female 12/30 F , with hooks, connected as indicated by flexible tubing, Corning Glass Works, Cat. No. 6700, or equivalent

Manometer, open-arm, Sargent-Welch Scientific, Cat. No. S-39785, or equivalent

Tubing, Tygon, Sargent-Welch Scientific, Cat. No. S-73650E, or equivalent

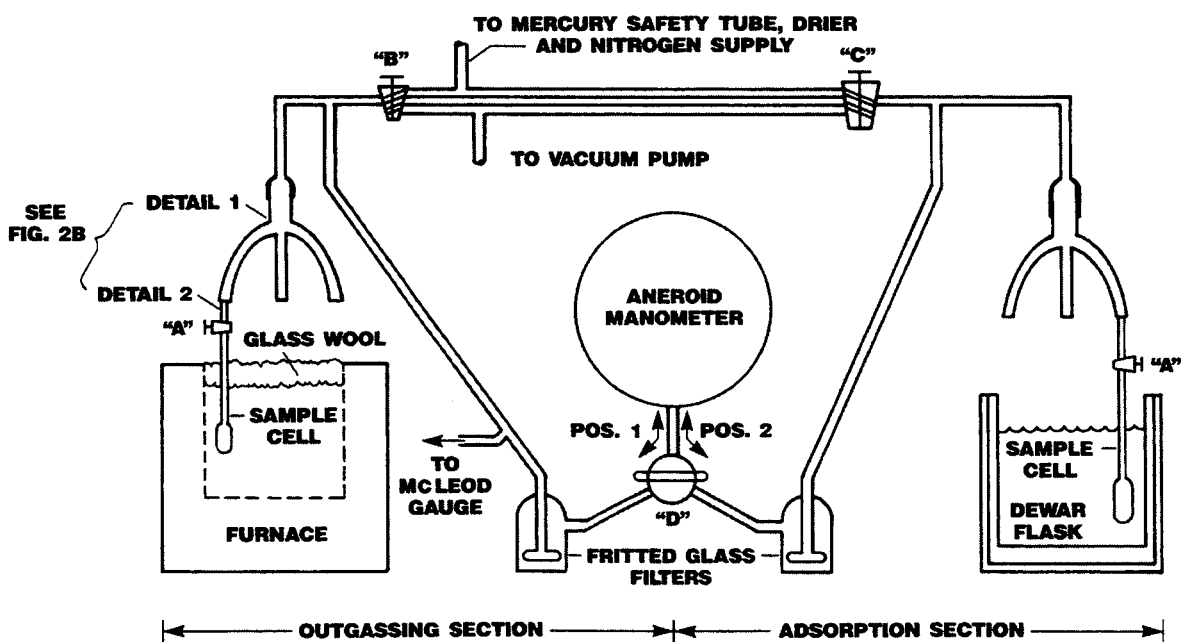


Figure 1

Apparatus for Determination of Surface Area and
Pore Volume
Preparation and Adsorption Sections

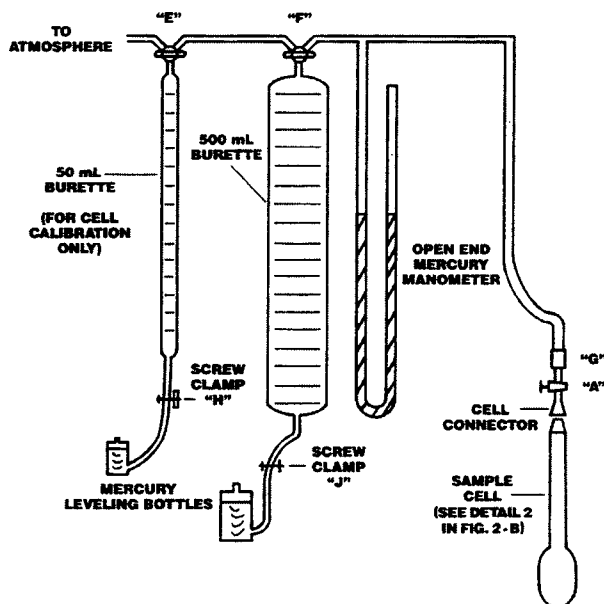


Figure 2A

Apparatus for Determination of Surface
Area and Pore Volume Desorption Section

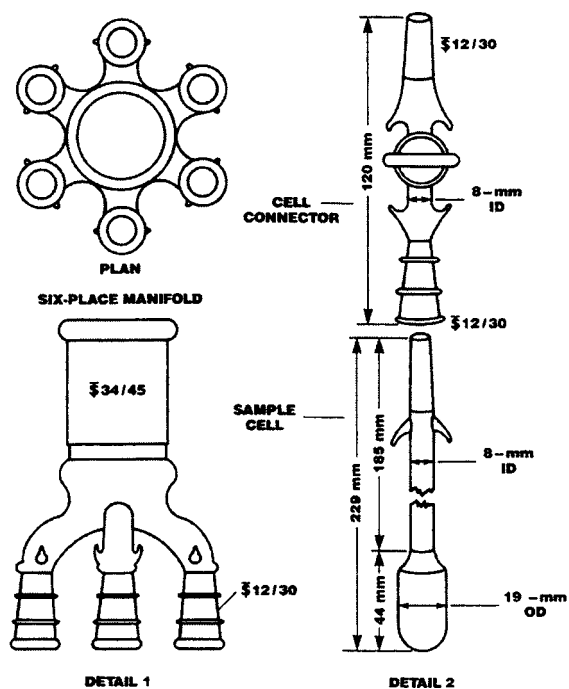


Figure 2B

Detail of Manifold, Cell Connector and
Sample Cell

REAGENTS AND MATERIALS

All reagents shall conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, when such specifications are available, unless otherwise specified. References to water mean deionized or distilled water.

Drierite, indicating, Sargent-Welch Scientific, Cat. No. SC11989, or equivalent

Grease, high vacuum, silicone, Sargent-Welch Scientific, Cat. No. S-77324-01, or equivalent

Mercury, triple distilled, Sargent-Welch Scientific, Cat. No. SC13462, or equivalent

Nitrogen, (gas), cylinder, extra-dry

Nitrogen, (liquid), fresh each day

CALIBRATION OF APPARATUS

Buret Calibration

Fill the 50-mL buret (Fig. 2A) to the stopcock with mercury. Open the stopcock to air and release the mercury to the first reference graduation on the buret. Record the reference volume and weigh the mercury released to the nearest 0.01 g. Repeat at 10 evenly-spaced intervals throughout the entire buret.

From the known density of mercury at the temperature of the room (see Table) and the masses obtained, calculate the absolute volume from the filled position to the reference graduations on the buret. Plot the observed reference buret volumes against the absolute calculated volumes and use the resulting curve as the buret volume correction in subsequent determinations.

Repeat the above procedure, calculations and calibration plot for the 500-mL buret.

Table

Density of Mercury

Temperature, C	Density, g/cc	Temperature, C	Density, g/cc
18.0	13.5512	25.2	13.5335
19.0	13.5487	25.4	13.5330
20.0	13.5462	25.6	13.5325
21.0	13.5438	25.8	13.5320
22.0	13.5413	26.0	13.5315
22.2	13.5408	26.2	13.5310
22.4	13.5403	26.4	13.5305
22.6	13.5399	26.6	13.5301
22.8	13.5394	26.8	13.5296
23.0	13.5389	27.0	13.5291
23.2	13.5384	27.2	13.5286
23.4	13.5379	27.4	13.5281
23.6	13.5374	27.6	13.5276
23.8	13.5369	27.8	13.5271
24.0	13.5364	28.0	13.5266
24.2	13.5359	29.0	13.5242
24.4	13.5354	30.0	13.5217
24.6	13.5350	31.0	13.5193
24.8	13.5345	32.0	13.5168
25.0	13.5340	33.0	13.5144

Sample Cell Calibration

Adsorption Procedure

Mark an identification on each sample cell and on its respective connector unit. Carefully apply grease to the ground-glass joints and assemble the corresponding connector unit to each of 6 dry, clean cells (Note 3). Attach these assemblies to the adsorption section. Open stopcock "A" and evacuate the cells through stopcock "C" to at least 0.1 mm absolute. Close stopcock "C". The aneroid manometer, when tapped, must not show a detectable rise in pressure over a 15-minute period. Place the Dewar flask in position to contain the 6 sample cells. Fill the flask with sufficient liquid nitrogen (Note 4) to cover the cells at least 50 mm above the bulb. Add more liquid nitrogen as necessary to maintain this approximate level. (Placing glass wool over the top will reduce the rate at which the liquid nitrogen evaporates.)

Open stopcock "C" to the gaseous nitrogen and admit gas into the system to a nominal pressure of 700 mm, as measured on the aneroid manometer. Let stand for 5 minutes. Record the actual pressure attained in the system to the nearest 0.5 mm. Close stopcock "A" on each of the cells and disconnect the cell assemblies from the adsorption section, but keep them in the Dewar flask. Move the flask and cells to the desorption section.

Desorption Procedure

Fill the burets with mercury (Note 5) by opening stopcocks "E" and "F" to the atmosphere and raising the leveling bottles. When filled to the top zero graduation, close the screw clamps tightly and set the bottle down. Make sure the manometer shows zero differential pressure.

Attach one of the cell assemblies to connector "G" without removing the cell from the liquid nitrogen bath. Turn stopcock "F" to close the passage to the 500-mL buret and to open the passage to the 50-mL buret. Turn stopcock "E" to a position closed to the atmosphere but opened to allow passage into the 50-mL buret.

Now open stopcock "A" of the cell, remove the cell from the liquid nitrogen bath and slightly open the screw clamp "H". Warm the cell slowly by placing it in a beaker of water at approximately 25 C for about 2 minutes and, at the same time, allow mercury to be displaced by the gas. Keep the manometer at zero differential pressure. Close screw clamp "H", remove the cell from the water and wipe it dry. Wait 5 minutes for the cell to reach room temperature. Adjust the buret volume again to maintain the manometer at zero differential. Record the buret volume to the nearest 0.1 mL. Close stopcock "A", remove the cell assembly and replace it on the adsorption section.

Repeat this desorption procedure for the other 5 cells.

Record the room temperature and the barometric pressure before each adsorption and desorption procedure.

Repeat the above adsorption and desorption procedure by changing the nominal adsorption pressures to 600-, 500- and 400-mm, respectively.

Next, repeat the same procedures for a nominal pressure of 50 mm. In this procedure the 50-mL buret level must be set initially at the 50-mL mark instead of at zero.

Calculations for Cell Calibration

Correct the volumes observed in the desorption procedure to standard temperature and pressure (S.T.P.) as follows:

$$V_c = \frac{273 \times P \times (V_f - V_i)}{(273 + t) \times 760}$$

where:

P = barometric pressure, mm

t = room temperature, C

V_c = corrected volume, mL

V_f = final buret volume, mL

V_i = initial buret volume, mL

Plot the series of corrected volumes versus their corresponding equilibrium pressures for each individual cell assembly. Draw a straight line through all the points. The cell corrections to be used for any equilibrium pressure can be readily read from this graph.

PROCEDURE

Sample Preparation

Weigh to the nearest 0.1 mg each of 6 clean, calibrated sample cells. Place approximately 1.5 to 2 g of each sample into respective tared cells. This amount is adequate for most samples. However, if a surface area of less than 50 m²/g is expected, use a larger sample to fill the cell. Similarly, for surface areas greater than 400 m²/g, a sample of 0.5 g is adequate. The exact masses of the samples will be determined later (Note 6).

Grease and attach the corresponding cell stopcock connector to each cell and connect the assemblies to the outgassing section. Open stopcock "B" and turn on the vacuum. Surround the cells with glass wool for insulation. Bring the temperature to 300 C (572 F) and maintain the system for 2 hours under a vacuum of 0.1 mm Hg, or below, as read on the McLeod gauge (Note 7).

After 2 hours at 300 C in vacuum, turn off the heater, lower the furnace and allow the cells to cool for 15-20 minutes while still under vacuum. Close stopcock "B" to vacuum and open it to nitrogen. Allow nitrogen to enter the system *slowly* until the aneroid manometer reads approximately 700 mm pressure. Now close stopcock "A" of each cell assembly, turn off the nitrogen and remove the cell assemblies from the outgassing section.

Surface Area Measurement

Connect the cell assemblies to the adsorption section, turn on the vacuum through stopcock "C", position stopcock "D" to connect the aneroid manometer to the adsorption section, and slowly open the cell stopcocks. Evacuate to 2.5 mm Hg or below, then close stopcock "C". The aneroid manometer must not show a detectable rise in pressure over a period of 15 minutes.

Place the Dewar flask containing liquid nitrogen in position to contain the sample cells. Add sufficient liquid nitrogen to cover them at least 50 mm above the bulb end.

Add gaseous nitrogen through stopcock "C" in small amounts to create and maintain an equilibrium pressure of exactly 60 mm absolute at 760 mm atmospheric pressure. If prevailing atmospheric pressure is not 760 mm, the equilibrium pressure to be used must be determined as follows:

$$\text{Equilibrium pressure, mm} = \frac{60}{760} \times \text{atmospheric pressure, mm}$$

Do not exceed this pressure.

Allow the cells to remain at equilibrium pressure for 15 to 20 minutes. The pressure must not show a change greater than one millimeter during this time. Close the cell stopcocks and remove the cells from the adsorption section without removing them from the liquid nitrogen bath. Transfer the cells to the desorption section.

Fill the 500-mL buret with mercury to the zero graduation mark as directed under cell calibration.

Attach one of the cell assemblies to connector "G" without removing it from the liquid bath. Turn stopcock "F" to open the 500-mL buret to the system.

Open the cell stopcock, remove the cell from the liquid nitrogen bath, and open screw clamp "J" slightly. Warm the cell slowly by placing it in a beaker of water at approximately 25 C for about 2 minutes. As the mercury is displaced by the nitrogen from the cell, keep the manometer close to zero differential pressure by using the screw clamp adjustment. Close the screw clamp, remove the cell from the water, wipe it dry, and wait 5 minutes for the cell to reach room temperature. Finally, reopen the screw clamp and change the level of mercury in the buret to adjust the manometer to zero differential. Record the final buret volume to the nearest 0.5 mL. Reconnect this cell to the adsorption section and proceed with desorption measurements for the remaining cells.

After reconnecting all 6 cells to the adsorption section, repeat the above procedure at an adsorption equilibrium pressure of 160 mm absolute, at 760 mm atmospheric pressure. If prevailing atmospheric pressure is not 760 mm, the equilibrium pressure to be used must be determined as follows:

$$\text{Equilibrium pressure, mm} = \frac{160}{760} \times \text{atmospheric pressure, mm}$$

Do not exceed this pressure.

Record all measurements on a record sheet.

Reconnect all the cell assemblies to the adsorption section and proceed with the pore volume measurements.

Pore Volume Measurement

Repeat the procedure used for surface area measurement, except that the adsorption equilibrium pressure is 735 mm absolute at 760 mm atmospheric pressure.

$$\text{Equilibrium pressure, mm} = \frac{735}{760} \times \text{atmospheric pressure, mm}$$

The desorption procedure is exactly the same as in the surface area section except that the volume desorbed may be greater than 500 mL. In this case, when the volume of desorbed gas approaches 500 mL close the screw clamp, close the cell stopcock and reimmerse the cell temporarily in the liquid nitrogen bath. Equalize the manometer arms to zero differential pressure. Record the volume. Refill the buret with mercury, venting the desorbed gas to the atmosphere. Continue the desorption as initially, and add the resulting volume to the volume desorbed in the previous desorption to obtain the total volume desorbed.

Note and record all volumes on the record sheet.

After all measurements are completed, remove the connector from each cell. Wipe all grease from each cell, and weigh each to the nearest 0.1 mg as rapidly as possible to minimize the adsorption of moisture. Record the mass for each cell on the record sheet. Subtract the previously determined tare weight of each cell to obtain the mass of sample used.

CALCULATIONS

Surface Area

The derivation of the following formula is given in the *APPENDIX*.

Calculate the surface area as follows:

$$\text{Surface area, m}^2/\text{g} = \frac{435}{\frac{186.7W}{V_{160} - V_C^{160}} - \frac{51.4W}{V_{60} - V_C^{60}}}$$

where:

V_{160} = volume adsorbed (corrected to S.T.P.) at $p = 160$ mm Hg, mL

V_{60} = volume adsorbed (corrected to S.T.P.) at $p = 60$ mm Hg, mL

V_C^{160} = cell correction volume taken from calibration plot at $p = 160$ mm Hg, mL

V_C^{60} = cell correction volume taken from calibration plot at $p = 60$ mm Hg, mL

W = sample mass, g

V_C^{60} and V_C^{160} are usually negative. The algebraic difference of volume in this equation, therefore, is equal to the sum of absolute values (see *APPENDIX*).

Pore Volume

The Kelvin equation for capillary condensation in closed-end pores determines the diameter of the largest pores that will be filled by capillary condensation at any relative pressure, P/P_0 . The use of this equation with the necessary correction for the thickness of the multilayer at the measured P/P_0 indicates that all pores smaller than 60 nm diameter will be filled with condensed nitrogen at a relative pressure of 735/760. If the volume adsorbed is measured at a pressure of atmospheric pressure times this ratio, the inclusion of appropriate densities of gaseous nitrogen and liquid nitrogen at the boiling point of nitrogen yields the expression:

$$\text{Pore volume, mL/g} = \frac{0.00154 (V_{735} - V_C^{735})}{W}$$

where:

pore volume = actual volume per gram of all pores of diameter smaller than 60 nm, mL/g

V_{735} = volume adsorbed (corrected to S.T.P.) at 735 mm Hg, mL

V_C^{735} = cell correction volume taken from calibration plot for $p = 735$ mm Hg, mL

W = sample mass, g

Pore Diameter

The assumption is made that all of the pore volume and surface area in a gram of catalyst exists in a single cylinder. The diameter of this hypothetical cylinder is referred to as the pore diameter, or average pore diameter, and is given by

$$\text{Pore diameter, nm, average} = \frac{4.0 \times 10^3 \times \text{pore volume}}{\text{surface area}}$$

where:

pore volume and surface area are as previously defined

NOTES AND PRECAUTIONS

1. In actual practice the measured saturation pressure of nitrogen gas at liquid nitrogen temperature generally exceeds barometric pressure by 10-15 mm. This difference is significant in surface property measurements, since the absolute pressure of sorption at each relative pressure point is directly related to the chosen reference pressure. The absolute difference between saturation pressure and barometric pressure will vary with time and is probably due to contaminants in the liquid nitrogen which raise its boiling point.

2. Computerized, automatic instruments are available from several manufacturers as alternatives to the apparatus described in this method. It is the user's responsibility to ensure that all of the manufacturer's instructions for operating the instrument are followed.

3. Whenever ground-glass joints or stopcocks are assembled, grease sparingly. Assemble and inspect each carefully to be absolutely sure that a uniform film is obtained.

4. Liquid nitrogen is very injurious when allowed to come in contact with the skin. Protective gloves and cautious handling are mandatory.

5. Mercury and mercury vapors are hazardous to health. Precautions must be taken during the handling of the metal to avoid contact and to prevent inhalation of the vapors. Spills must be cleaned up immediately.

6. For very fine powders, a small wad of borosilicate glass wool may be inserted in the neck of the sample cell. The weight of this packing is added to the tare weight of the cell.

7. Outgassing for 2 hours at 300 C (572 F) under vacuum is standard procedure for all samples except fluid cracking catalyst, which must be calcined 2 hours at 600 C (1112 F) in a muffle furnace prior to analysis.

PRECISION

Based upon five replicate samples, the estimated standard deviation (esd) for surface area, pore volume and pore diameter at two levels is shown below. Duplicate results by the same operator should not be considered suspect unless they differ by more than the amount shown in the "Allowable Difference" column (95% probability).

Surface Area	esd, m²/g	Allowable Difference, m²/g
450	8.93	35
40	1.51	5
Pore Volume	esd, mL/g	Allowable Difference, mL/g
0.73	0.015	0.06
0.06	0.005	0.02
Pore Diameter	esd, nm	Allowable Difference, nm
65	1.10	4
68	5.91	20

TIME OF ANALYSIS

The elapsed time for one sample is 9 hours, or 10.5 hours for 6 samples analyzed simultaneously. The labor requirement is 4.5 hours for one analysis, or 7.0 hours for 6 samples analyzed simultaneously.

REFERENCES

1. Brunauer, S., Emmett, P.H., and Teller, E., *J. Am. Chem. Soc.* **60**, 309 (1938)
2. Barrett, E. P., Joyner, L. G., and Halenda, P. P., *J. Am. Chem. Soc.* **73**, 373 (1951)
3. Halsey, G. D., *Advances in Catalysis*, edited by W. G. Frankenburg, V. I. Komarewsky and K. E. Rideal, **Vol. 4**, p. 259, Academic Press, Inc., New York (1952)
4. UOP Method 821
5. *CRC Handbook of Chemistry and Physics*, 65th Edition, CRC Press, Boca Raton, FL, 1984, p. F-6

SUGGESTED SUPPLIERS

Corning Glass Works, 814 Busse Highway, Park Ridge, IL 60068
 Matheson, P.O. Box 96, Joliet, IL 60434
 Pro-Quip Inc., 418 Shawmut Ave., La Grange, IL 60525
 Sargent-Welch Scientific Co., 7300 N. Linder, Skokie, IL 60077
 UOP Inc., Box 5017, Des Plaines, IL 60017-5017

APPENDIX

Surface Area

The surface area is calculated by application of the Brunauer-Emmett-Teller (B.E.T.)¹ theory of multilayer adsorption. A critical review of this method by Halsey³ summarizes the assumptions used in the B.E.T. theory to derive the general expression:

$$v = \frac{v_m c x}{(1-x)} \left[\frac{1 - (n+1)x^n + nx^{n+1}}{1 + (c-1)x - cx^{n+1}} \right]$$

where:

- c** = factor proportional to the exponential of the difference between the heat of adsorption in the first layer and the heat of adsorption in all subsequent layers (heat of condensation)
- n** = number of layers that can be adsorbed
- v** = volume of nitrogen adsorbed by a sample at a pressure, p, and at a temperature at which p₀ is the saturation pressure
- v_m** = volume adsorbed in the monolayer
- x** = p/p₀, called the relative pressure, where p and p₀ are as defined under v, above

In the case of n = 1, this equation reduces to the Langmuir equation for monolayer adsorption:

$$\frac{v}{v_m} = \frac{cx}{1+cx}$$

In the case of multilayer adsorption, allowing n to approach infinity yields the usual form of the B.E.T. equation:

$$\frac{p}{v(p_0 - p)} = \frac{1}{v_m c} + \frac{(c-1)p}{v_m c p_0}$$

When p/v(p₀-p) is plotted against p/p₀, a linear section is obtained in the region of relative pressure (p/p₀) of 0.05 to 0.35 if multilayer adsorption is occurring. It is easily shown that the volume adsorbed in the monolayer (v_m) is given by:

$$v_m = \frac{1}{S+I}$$

where S is the slope and I is the intercept of the linear portion of the B.E.T. plot.

In the present method, the intercept and slope (equal to 1/v_mc and (c-1)/v_mC, respectively) are evaluated from 2 experimental points within the linear region. The first set of measurements is referred to as p₁ and V₁, the second as p₂ and V₂, and p₀ is the saturation pressure (atmospheric pressure if the measurements are made at the boiling point of nitrogen as in the present method). The resulting equation for v_m is as follows:

$$v_m = \frac{p_2 - p_1}{\frac{p_2(p_0 - p_1)}{v_2(p_0 - p_2)} - \frac{p_1(p_0 - p_2)}{v_1(p_0 - p_1)}}$$

The surface area is given by the relationship:

$$\text{Surface area} = \frac{v_m NA}{M_v W}$$

where:

- A** = area occupied by one adsorbed nitrogen molecule, $16.2 \times 10^{-20} \text{ m}^2$
- M_v** = gram-molecular-volume, 22,414, mL
- N** = Avogadro's number, 6.023×10^{23} molecules per gram mole
- v_m** = volume of gas in monolayer measured at S.T.P. (0 C and 760 mm Hg), mL
- W** = sample mass, g

Upon substitution, the equation becomes:

$$\text{Surface area, m}^2/\text{g} = \frac{4.35 v_m}{W}$$

where:

v_m and W are as previously defined.

Using the previous expression for v_m, the area using a two-point method is given by:

$$\text{Surface area} = \frac{4.35(p_2 - p_1)}{\frac{Wp_2(p_0 - p_1)}{V_2(p_0 - p_2)} - \frac{Wp_1(p_0 - p_2)}{V_1(p_0 - p_1)}}$$

Substituting the following:

$$p_1 = 60$$

$$p_2 = 160$$

$$p_0 = 760$$

this becomes:

$$\text{Surface area} = \frac{4.35(160 - 60)}{\frac{160(760 - 60)W}{(760 - 160)V_2} - \frac{60(760 - 160)W}{(760 - 60)V_1}}$$

$$\text{Surface area} = \frac{435}{\frac{160 \times 700 \times W}{600 \times V_2} - \frac{60 \times 600 \times W}{700 \times V_1}}$$

$$\text{Surface area} = \frac{435}{\frac{186.7 W}{V_2} - \frac{51.4 W}{V_1}}$$

where V₁ and V₂ are the volumes adsorbed at pressures of 60 and 160 mm Hg, respectively, corrected to S.T.P. and for the cell calibration.