Characterization of the cylindrical cavities of Anopore and Nuclepore membranes

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The microscopic properties of the inner surface of the cavities of Anopore and Nuclepore membranes are investigated with scanning electron microscopy (SEM), nitrogen adsorption isotherms, and deuterium nuclear magnetic resonance ($^2$H-NMR). Useful information about the cavity orientation and morphology, and internal surface area is obtained. Analysis of SEM photographs yields estimates of the surface area and the porosity of these membranes which complements the adsorption results. The orientation of liquid crystals permeated in the cavities of Anopore and Nuclepore membranes is probed with the $^2$H-NMR technique. It is found that the orientation of the liquid crystal molecules is governed by the confining volume and surface conditions. The $^2$H-NMR spectral line shape of the confined liquid crystal also provides information on the substrate morphology and roughness that is consistent with SEM and adsorption experiments.

I. INTRODUCTION

The study of the physical properties of liquids and gases confined to geometries more restrictive than bulk has received a great amount of theoretical and experimental attention. The departure from bulk behavior in restricted geometries is an area of fascinating and continuing scientific interest.

A large amount of effort has been devoted to studies of confinement effects in interconnected porous glasses. Recently, results can be found in the literature regarding the superfluid behavior of $^4$He,1,2 geometrical supercooling of confined liquids,3 gas adsorption,4 molecular translational diffusion,5 orientation dynamics of supercooled liquids,6 and dielectric spectroscopy.7 In most instances the confining geometry was provided by the 60 Å diam interconnected pores of Vycor glass.8 A comprehensive analysis of the microstructure of Vycor was recently published.9

In addition to porous glasses, porous materials with larger and nearly cylindrical channels as provided by Nuclepore membranes10 have been available for a variety of studies. Nuclepore membranes are polycarbonate films with well defined pores used principally in critical filtration procedures. The pores in the membranes are etched to the desired dimensions from damaged radiation tracks. They are available as disks of 4.7 cm diam and 10 μm thick, with pore sizes ranging from 0.015 μm to micrometer sizes. The pore size distribution is relatively narrow with 80% of the pores being within 10% of the mean. The pore density is about $3 \times 10^9$ cm$^{-2}$ and the porosity is approximately 12%, calculated from manufacturer's specifications.

Nuclepore membranes have been used for a number of years in the study of the superfluid properties of liquid helium. The effect of finite size as a function of pore size was studied by confining superfluid liquid helium in the cavities of Nuclepore membranes.11,12 They were later used as the confining substrate in optical microscopy measurements for nematic liquid crystals.13 The added interest in the liquid crystal case is that by properly treating the inner surface of the pores, a different nematic director orientation is obtained. Therefore, the interaction of liquid crystal molecules with a solid surface can be studied under controlled conditions. Such studies are vital in applications given the large number of liquid crystal devices that rely on a controlled alignment for their operation.14

The measurements just described stimulated very recent deuterium-NMR work for liquid crystals confined in Nuclepore membranes.15,16 The NMR work provided the first experimental determination of the surface elastic constant $K_{24}$ and the observation of a surface-induced nematic layer deep into the isotropic phase.

Building on the success of the NMR work and the commercial availability of a new confining substrate, Anopore membranes,17 NMR18 and heat capacity measurements19 for liquid crystals confined in Anopore membranes were performed. Systematic heat capacity measurements for helium films in Anopore are in progress.20 Inorganic Anopore membranes are produced by the anodic oxidation of aluminum. Since the process is electrochemical, conditions can be very precisely controlled and a reproducible pore structure with a narrow pore size distribution obtained. They are available as 4.7 cm disks, 60 μm thick, with 2000 Å diam pore size and a pore density nearly a factor of 10 higher than in Nuclepore membranes.21-24 The Anopore membranes, also designed for critical filtration purposes, include a polypropylene ring which is heat glued to the outer edge of the membrane. The actual diameter of the active membrane is 4.3 cm.

In this work we concentrate on Nuclepore and Anopore membranes with 2000 Å in diam pore size. We have measured some properties of these membranes which are not

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available in the literature, and might be of interest to other
investigators. The paper is organized as follows. In Sec. II we
describe the microscopic properties of these materials as ob-
tained from scanning electron microscopy (SEM). Analysis
of SEM photographs at different magnifications allows the
determination of pore size, porosity, and surface area. In
Sec. III we present nitrogen adsorption isotherms to deter-
mine their surface area and the nature of the cavity wall.
Section IV is devoted to orientation of liquid crystal mole-
cules within the cavities as a function of surface treatment.
Monitoring the nematic liquid crystal inside the cavities of
both membranes reveals useful information on the internal
structure, morphology, and surface roughness of the cavities
which is found to be consistent with the SEM and adsorption
studies. In Sec. V we summarize the results and conclude.

II. SCANNING ELECTRON MICROSCOPY

We performed scanning electron microscopy (SEM)
studies on both Nuclepore and Anopore membranes. The
membranes were cut to disks 1 cm in diameter and secured to
a metal stub with an epoxy glue. They were subsequently
sputter coated using gold-palladium to a coating thickness
of 500–700 Å. Several SEM photographs with different
magnifications for both membranes were obtained.

Figure 1 shows SEM photographs for opposite surfaces
of an Anopore membrane with 2000 Å nominal
pore size at 1000 times magnification. The anodic oxidation
of aluminum produces porous membranes with narrow pore
size distribution and high pore density. Both of these highly
desirable features are controlled by the anodizing voltage. A
major difficulty with this technique, however, is that the
membranes remain attached to the aluminum matrix, which
results in the pore base being closed by an oxide barrier layer.
The surface of the membrane originally in contact with the
aluminum metal shows fine pores (honeycomb-type mor-
phology), Fig. 1(a), while the surface of the opposite side of
the membrane shows larger and more circular pores, Fig.
1(b). Higher magnification SEM photographs for both sur-
faces, emphasizing this fact, are presented in Fig. 2.

SEM photographs of a cross section of an Anopore
membrane are shown in Fig. 3. Here, a 0.5 cm strip of mem-
brane is placed upright between two glass microscope slides
and sputter coated as described above. Figure 3(a) gives a
three-dimensional perspective of the membrane near the top
surface while Fig. 3(b) demonstrates the smoothness and
parallelism of the pores.

Based on this and previous SEM studies, we conclude
that Anopore membranes have an asymmetric nature with
larger noninterconnected pores extending through the bulk
of its thickness (60 μm) interconnected with an array of
smaller pores formed at the surface of the membrane originally
attached to the aluminum. The thickness over which the
smaller pores extend is less than 1000 Å as shown by Fur-
neaux et al. Also, as seen from the cross-sectional photo-
graphs shown in Fig. 3, the cavities appear to be nearly cylin-
drical and quite smooth. Further evidence regarding the
smoothness of the inner cavities will be provided in Sec. IV
through our investigation using 2H-NMR to probe the align-
ment and orientational order of liquid crystal molecules

within the cavities. Finally, the pore size distribution ap-
ppears to be rather narrow.

From an analysis of the SEM photographs we have de-
termined that the pore density of Anopore membranes is
$1.23 \times 10^9$ pores/cm² or, equivalently, $1.79 \times 10^{10}$ pores/
membrane. Note that, as previously mentioned, the nominal
4.7 cm. membrane corresponds to a 4.3 cm diameter. The porosity of the membranes, which is clearly a lower bound due to the sputtering process, was calculated to be 39%. The corresponding surface area for the 2000 Å in diameter nominal pore size is then 0.675 m²/membrane. This translates into a surface area of 6.19 m²/g. Comparing with other well known confining materials, it is a factor of 16 lower than in Vycor glass (100 m²/g), a factor of 2 smaller than in graphite (20 m²/g), but, as we discuss below, a factor of 2 larger than in the Nuclepore case. Note that the results of our calculation are independent of the region of Anopore membrane chosen.

The polycarbonate Nuclepore membranes are manufactured using the two-stage "track" etched process. After bombardment with alpha particles, the damaged radiation tracks are chemically etched to obtain the desired pore size.
This manufacturing process allows Nuclepore membranes to be virtually tailor-made with respect to pore size and pore density. Unlike Anopore membranes, available in a single pore size, Nuclepore membranes are available as 4.7 cm disks, up to 10 μm thick depending on pore size, and, with pore sizes ranging in diameter from 0.015 to 12 μm. However, the track-etching technique results in the existence of pore doublets as seen in Fig. 4, denoted by arrows, as well as some interconnection of the pores. Here, SEM photographs of a 2000 Å diam Nuclepore membrane at 1500 and 40 000 magnification are shown. The pore doublets are a consequence of two or more nuclei coinciding during the bombardment process. An SEM photograph for a 1000 Å diam Nuclepore membrane is presented in Fig. 5. We attempted to obtain a SEM photograph for a cross section of a Nuclepore membrane but encountered a number of experimental difficulties. The nonrigidity of the membrane and the length of time for focusing at high magnification hinders such an experiment.

Comparing with the equivalent Anopore membrane, the pore size distribution for Nuclepore membranes is not as narrow and the pore density is nearly a factor of 5 lower, or \(3.5 \times 10^8\) pores/cm\(^2\), as calculated from the nominal membrane's specification.\(^{12}\) A comparison of the pore size distribution for the two membranes as obtained from the manufacturer's brochure\(^{17}\) is presented in Fig. 6. The actual pore size is 1650 Å indicating that the nominal pore size of 2000 Å is not a mean but rather, an upper bound.\(^{10}\) Determination of the surface area and the porosity of these membranes from the SEM photographs are not very reliable as they are strongly dependent on which region of the membrane is chosen for the calculations. However, using manufacturer's specifications one calculates a surface area of 0.0379 m\(^2\)/membrane.

It was pointed out and it can be seen from Fig. 3 that the inner surface of the Anopore membranes is rather smooth. In contrast, as observed in Fig. 7, the inner surface of the cavities of Nuclepore membranes shows corrugations which are a consequence of the etching process. The grooved internal surface, typical to all pore size Nuclepore membranes, can be clearly seen from the SEM photograph of an 8 μm diam cavity taken at an angle with respect to the membrane's normal (4400 times magnification). The implications of this internal "roughness" regarding liquid crystal alignment will be discussed in light of the NMR work described in Sec. IV.

In summary, Anopore membranes possess a larger and more uniform pore size distribution than Nuclepore membranes, and appear to have a smoother cavity surface. They also have a much larger surface area. However, unlike Nuclepore membranes, they are only available with a single pore size. Thus, for studies where changing the pore size is a requirement, Nuclepore membranes are still a very good candidate.

### III. ADSORPTION ISOTHERMS

Adsorption isotherms are frequently used to determine surface areas. The monolayer completion and the surface area are obtained when adsorption isotherms are analyzed by using the Brunauer, Emmett, and Teller (BET) model for multilayer adsorption.\(^{22}\) We have performed nitrogen adsorption isotherms at 77 K for both types of membranes. A brass cell 4.8 cm in diameter and sealed with an indium ring was built. It was attached to a gas handling system of known volume and kept in a liquid nitrogen bath. The cell with the membranes was repeatedly pumped and flushed...
with helium gas prior to cool down. All needed volumes were determined using helium expansion from the known volume into the experimental cell. When nitrogen gas was used to determine the volume of the experimental cell containing the Nuclepore membranes, larger volumes were obtained. This indicates that some room-temperature adsorption is taking place. Also, it is interesting to note that during the helium expansion we were able to determine the volume occupied by the Anopore membranes. The loss of available volume resulting from introducing Anopore membranes is consistent with a 40% porosity. This is the same porosity that was calculated from the SEM photographs. Nitrogen gas was admitted in the gas handling system and later expanded into the experimental cell. All pressures were recorded after equilibrium was achieved. The amount of gas ad-

FIG. 6. Comparison of pore size distribution for Anopore and Nuclepore membranes as provided by Anotec Separations, LTD.

FIG. 5. SEM photograph for a nominal 1000 Å diam Nuclepore membrane at two different magnifications. Pore doublets are indicated by the arrows.

sorbed by the membranes was calculated from the known volumes and temperatures and is plotted in Fig. 8 as a function of $P/P_o$, with $P_o$ the saturated vapor pressure at 77 K.

Three nitrogen isotherms are shown in Fig. 8. We tried to identify the $B$ point which indicates the monolayer completion and is identified as the point where the isotherms deviate from a straight line fitted through the plateau region. This is complicated by the presence of gentle curvature in the adsorption data at 0.1 in reduced pressure. The $B$-point graphic determination for Anopore and Nuclepore membranes in fact overestimates the surface area by 10% to 15%.

This difficulty is eliminated by using the BET equation, which may be regarded as an analytical means of locating the $B$ point. The adsorption data were fit to the BET equation

$$N_{ad}(P_o/P - 1)^{-1} = 1/(n_m c) + ((c - 1)/n_m c)(P/P_o),$$

with $n_m$ the monolayer capacity and $c$ a constant to be determined and usually related to the heat of adsorption. Equation (1) was used over the range of $P/P_o$ from 0.05 to 0.3. Assuming the adsorption cross section for nitrogen to be 16.2 Å (Ref. 2) and evaluating the slope and intercept of the plot of the isotherm data fit to the BET equation shown in Fig. 9, we determine the surface area for the Anopore membranes to be 0.832 m²/membrane, which is an average value of our two isotherms. We obtain 0.0682 m²/membrane for the Nuclepore membranes. The experimentally obtained surface areas are clearly larger than the geometrical surface areas calculated using manufacturer's specifications, 0.675 m²/membrane and 0.0379 m²/membrane for Anopore and Nuclepore, respectively. The ratio of experimental to geometrical surface area, 1.233 for Anopore and 1.799 for Nuclepore, is the roughness factor and is on the same order of what is found with other systems when geometrically determined areas are compared with adsorption areas. The lower ratio of areas found for the Anopore membranes, reflects the fact that its cavities are smoother than those in Nuclepore membranes. This is in agreement with our SEM observations.

A summary of the nitrogen isotherms adsorption data for 20 and 40 Anopore membranes and 93 Nuclepore membranes is presented in Table I. The results are quoted per

<table>
<thead>
<tr>
<th>Substrate</th>
<th>$S$(m²/membrane)</th>
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<th>Roughness</th>
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<tbody>
<tr>
<td></td>
<td>expt.</td>
<td>calc.</td>
<td>expt.</td>
<td>calc.</td>
<td>factor</td>
</tr>
<tr>
<td>20 Anopore</td>
<td>0.8650 ± 0.045</td>
<td>0.6/30</td>
<td>7.899</td>
<td>6.190</td>
<td>1.281</td>
</tr>
<tr>
<td>40 Anopore</td>
<td>0.7980 ± 0.024</td>
<td>0.6750</td>
<td>7.283</td>
<td>6.190</td>
<td>1.182</td>
</tr>
<tr>
<td>(Anopore)</td>
<td>0.8315 ± 0.036</td>
<td>0.6750</td>
<td>7.591</td>
<td>6.190</td>
<td>1.231</td>
</tr>
<tr>
<td>93 Nuclepore</td>
<td>0.0682 ± 0.003</td>
<td>0.0379</td>
<td>4.247</td>
<td>2.360</td>
<td>1.799</td>
</tr>
<tr>
<td>100 Nuclepore</td>
<td>0.0664 ± 0.003</td>
<td>0.0379</td>
<td>3.765</td>
<td>2.360</td>
<td>1.594</td>
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membrane. We have also included the Nuclepore data from Ref. 12 recalculated using 16.2 Å for the nitrogen molecular area instead of 15 Å which they used. The difference between our Nuclepore results and those of Ref. 12 is 10%. A similar difference is found between our isotherms for 20 and 40 Anopore membranes which again we attribute to the use of membranes from a different lot. We note that variations of 5% have been measured in porous glasses samples from the same lot, while differences up to 30% have been seen when the samples were from different lots. 9

To summarize, from our nitrogen adsorption isotherms, we have found that the surface area per membrane is approximately 12 times larger in Anopore than in Nuclepore membranes. The ratio of experimental to geometrical surface area is larger for Nuclepore membranes. This is indicative of a rougher nature of the inner cavity walls of Nuclepore membranes, in agreement with our SEM results.

IV. DEUTERIUM NUCLEAR MAGNETIC RESONANCE

Nematic liquid crystals are characterized by the long range orientational order of their elongated molecules about a preferred direction, given by the nematic director. A nematic liquid crystal, when confined to a small volume, exhibits a specific nematic director field configuration which is the result of the competition among elastic forces, strength of surface interactions, and confining volume size and shape. The deuterium nuclear magnetic resonance technique ($^2$H-NMR) is extremely useful in monitoring the distribution of directors of a liquid crystal sample which also provides information on the substrate morphology. We have used $^2$H-NMR to obtain information about the orientation of liquid crystal molecules confined to the cavities of Nuclepore and Anopore membranes. Information on the surface roughness of the cavity walls was also obtained by measuring the degree of orientational order at the cavity wall boundary. Details about the nematic materials and its molecular interactions with the cavity walls have already been published, 15,16,18 so only information pertinent to the characterization of Anopore and Nuclepore membranes will be presented here.

The observed quadrupole splitting frequency for a nematic liquid crystal depends upon the angle $\Theta$ between the local nematic director $\mathbf{n}$ and the direction of the magnetic field $\mathbf{B}$ of the NMR spectrometer. It is expressed as

$$\delta v = \pm \delta v_B (3 \cos^2 \Theta(x) - 1)/2,$$

where $\delta v_B$ is the quadrupole splitting of the bulk nematic phase. If a macroscopic nematic sample is aligned by the external magnetic field of the NMR spectrometer, the $^2$H-NMR spectrum shows two absorption lines separated in frequency by $\delta v_B$. If the alignment of the nematic sample is caused by other mechanisms, the quadrupole splitting will be a reflection of the specific configuration of the directors in the sample. The orientation of the liquid crystal molecules within the cavities of Nuclepore and Anopore membranes serves as a probe to investigate some of the basic properties of these membranes.

The samples studied were prepared by filling the cavities of our membranes with the liquid crystal material 4'-pentyl-4-cyanobiphenyl deuterium labeled on the second position of the hydrocarbon chain (SCB-$\beta d_2$). 29 To ensure complete filling, the liquid crystal filled membranes were kept at 40 °C for approximately 1 h. At this temperature the sample is isotropic and flows freely into the cavities. After removing the samples from the oven, the excess liquid crystal, residing on the outer surfaces of the membranes, was removed by pressing the membranes between Whatman filtration papers.

NMR investigations also show that the liquid crystal molecular alignment can be modified if the internal surfaces of the membranes are chemically treated prior to introduction of the liquid crystal molecules. It was found that the natural orientation along the cavities axis became perpendicular if the cavities were filled with a 2% by weight solution of lecithin in hexane and then evaporating the solvent away by keeping the membranes in a vacuum oven at 50 °C for several hours. 16,18

$^3$H-NMR spectra for SCB-$\beta d_2$ confined to the 2000 Å cavities of Anopore membranes for parallel ($\Theta_\alpha = 0$) and perpendicular ($\Theta_\alpha = 90^\circ$) orientations of the cavity axis with respect to the magnetic field are shown in Fig. 10. The aligned bulk spectra is also shown for a direct comparison.

![FIG. 10. $^3$H-NMR spectral patterns of the liquid crystal SCB-$\beta d_2$ confined to the 2000 Å cavities of Anopore membranes for parallel ($\Theta_\alpha = 0$) and perpendicular ($\Theta_\alpha = 90^\circ$) orientations of the cavity axis with respect to the magnetic field.](image-url)
matic; for the Anopore membranes, it is a cylindrical-type powder pattern. This indicates that the symmetry axis of the planar–polar configuration prefers to align parallel to the magnetic field in Nuclepore membranes, but it is randomly oriented in Anopore membranes as schematically depicted. The schematic representation of nematic order in an Anopore cavity and the aligned bulk is presented in Fig. 10. The quadrupole splitting frequency for the parallel orientation is identical to the macroscopically aligned bulk sample. For the perpendicular orientation, the quadrupole splitting frequency is 1/2 that of the bulk sample. This is an indication that the liquid crystal molecules preferentially align parallel to the cavity axis in an axial configuration. The angular dependence of the quadrupole splitting is rather insensitive to small distributions in the neighborhood of $\Theta = 0^\circ$ or $90^\circ$. A fit to Eq. (2) for the complete angular dependence of the quadrupole splitting frequency is shown in Fig. 10 where the solid line denotes the fit to Eq. (2). We interpret this as an indication that the Anopore membrane cavities extend straight through the membrane’s thickness, which is consistent with the SEM photographs shown in Sec. II. No axial configuration has been obtained with Nuclepore membranes. This is likely due to the internal roughness (corrugations) present at the cavities’ walls preferentially aligning the liquid crystal molecules perpendicular to the cylinder axis.30

By treating the Anopore and Nuclepore cavities with lecithin and repeating the deuterium NMR study, information on the morphology is obtained. When the liquid crystal molecules are oriented perpendicular to the cavity axis, a planar-polar structure of the nematic director is energetically favorable,16 as shown in Fig. 11 for two different orientations of the cavity axes and the magnetic field. The quadrupole splitting frequency for both membranes is exactly 1/2 that of the nematic bulk sample for the $\Theta_B = 90^\circ$ orientation. This is consistent with our interpretation that the liquid crystal molecules are oriented perpendicular to the cavity axes, i.e., $\Theta = 90^\circ$ in Eq. (2).

On the other hand, when $\Theta_B = 90^\circ$, a drastically different pattern for the two systems is obtained. For the Nuclepore membranes, the quadrupole splitting is that of bulk nematic; for the Anopore membranes, it is a cylindrical-type powder pattern. This indicates that the symmetry axis of the planar–polar configuration prefers to align parallel to the magnetic field in Nuclepore membranes, but it is randomly oriented in Anopore membranes as schematically depicted in Fig. 11. The discrepancy in the $\Theta_B = 90^\circ$ spectra may be the result of differences in cavity morphology or surface roughness between the two membranes which is currently under investigation. A restrictive cylindrical geometry facilitates the alignment of the symmetry axis of the liquid crystal configuration in the magnetic field. This would suggest that the Nuclepore membranes have a concise cylindrical geometry (evident from the SEM photographs) while the Anopore membranes have an aspect ratio preferentially aligning the symmetry axis of the configuration. However, a close examination of the Anopore cross-section SEM photograph, Fig. 3, reveals very cylindrical cavities.

Another explanation for the $\Theta_B = 90^\circ$ spectra is related to the surface roughness. The orientational order parameter of a liquid crystalline material at a solid substrate has been shown to depend on surface roughness.31 It was demonstrated that as the surface roughness increases, the degree of orientational order at the surface decreases. Deuterium-NMR was used to measure the orientational order parameter of $5\text{CB}-\beta_d$ liquid crystal confined to the cavities of Anopore and Nuclepore membranes.15,18 At temperatures slightly above the nematic–isotropic transition $T_{NI}$, it was found that $S_0$, the orientational order parameter is substantially smaller in Nuclepore ($S_0 = 0.02$) than in Anopore ($S_0 = 0.11$) membranes for the same (lecithin) surface treatment. We attribute this difference to the degree of surface roughness as established by the SEM and adsorption work. A smaller degree of ordering at the cavities’ walls results in a weaker anchoring energy at the surface, allowing the symmetry axis of the liquid crystal configuration to be easily aligned. This is the case in Nuclepore membranes. We are further investigating this discrepancy.32

Clearly, from the deuterium-NMR work we have found evidence regarding the internal structure of the cavities which nicely complements the SEM and molecular adsorption work already presented.

![Diagram](image_url)
V. SUMMARY

We have performed scanning electron microscopy, adsorption isotherms and deuterium-NMR spectroscopy on the nearly cylindrical, 2000 Å cavities of Anopore and Nuclepore membranes. We have pointed out some of their properties, namely, the pore size, pore size density and distribution, surface area and porosity. By chemically treating the cavities and confining liquid crystals, we learned about liquid crystal molecular orientation which reveals features of the membranes consistent with the SEM photographs and nitrogen adsorption isotherms experiments.

It is evident from the variety of experimental techniques applied on the two membrane technologies, that the internal surfaces of the cavities of Nuclepore membranes are substantially rougher than their Anopore counterpart. This is revealed by SEM photographs which show corrugations on the internal cavity wall of Nuclepore membranes, while the internal walls of Anopore membranes appear smooth, up to the magnification employed. This was further verified by molecular adsorption isotherms where a larger ratio of experimental to geometrical surface area, roughness factor was found for Nuclepore membranes.

The orientational order parameter of a liquid crystal molecule at the cavity wall of both membranes, using the same surface treatment, was measured using deuterium-NMR. The magnitude of the order parameter at the surface is substantially smaller for Nuclepore membranes. This is suggestive of a rougher surface in the Nuclepore cavities, consistent with SEM and molecular adsorption observations.

Both membranes offer nearly cylindrical cavities extending through the membrane's thickness. Although Anopore membranes are quite suitable to study finite size effects due to their smoother cavities, larger surface area and capability to withstand a variety of surface treatments, Nuclepore membranes are advantageous in that they are available in many pore sizes and systematic studies as a function of pore size can be performed.

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