Laboratory Methods

_A New Concept for the Continuous Monitoring of Anesthetic Gases:_

I. Detector Theory and Clinical Uses

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A new detector for the determination of anesthetic vapor concentrations measures the dielectric constants of gases. Theory, operational characteristics, and clinical uses are presented.

A study was undertaken to devise a monitor which measures dielectric constants for the on-stream analysis of anesthetic gases. This concept is new: although the use of the dielectric constant as a means of detection is an old one, its use as an anesthetic vapor analyzer has not heretofore been described.

**Detector Theory**

When two parallel metal plates are connected to a source of electric potential, one plate acquires a negative charge (−Q), and the other a positive charge (+Q) of equal magnitude (fig. 1); this constitutes a condenser. The charge accumulated is proportional to the potential applied in relation to the area of the plates and is inversely proportional to the distance between them.

The capacitance also depends on the nature of the medium between the plates, since the electric field causes orientation of molecular charges, as indicated in figure 2. The molecular dipoles orient themselves (fig. 3) in the field and reduce its value in the region between the plates, thus permitting a greater accumulation of charge for a given voltage than

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Fig. 1. Basic condenser.

Fig. 2. Polarization of a dielectric in a condenser.
is observed when the condenser is evacuated. The ratio of the capacitance with a given filling (C) to the capacitance in a vacuum (C₀) is called the dielectric constant of the medium (E), and

\[ E = \frac{C}{C₀} \]

All substances have dielectric constants greater than unity whether or not the molecules have permanent electric moments. This results from the fact that an electric field induces an electric moment even in a completely nonpolar molecule such as hydrogen. The dielectric constant of the medium is due to both permanent and induced dipoles in the molecule.

The electric moment often gives considerable insight into the structure of a molecule. For example, CO₂, O₂ and N₂ molecules have no electric moments, whereas certain molecules, such as the anesthetic gases, can have either permanent or induced electric moments. The property of a permanent electric moment is the result of the interaction between carbon, oxygen, and the halogens within the molecular structure. Evidently, then, an air capacitor should specifically detect a voltage disturbance for anesthetic agents (with electric moments) in the presence of gases that have no (or negligible) electric moments.

Table 1 lists the dielectric constants for various gases. To measure capacitance, various electronic circuits which use alternating current and frequencies of 10⁶ and 10⁷ cycles/sec are available.

**Equipment**

Such a device was constructed for us by L.S.G. Industries Corporation.† The instrument consists of a wiring circuit and an air-condenser detector (fig. 4). C₁ and C₂ are identical air condensers charged positively in reference to their common body, which is charged negatively. Two air condensers are necessary, since one must act as a thermostat to stabilize the circuit against environmental temperature changes. The reference condenser (C₂) also serves an additional purpose, that of compensating for any changes in the

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**Reference:** Water Molecule

![Diagram of water molecule](image)

**Fig. 3.** Orientation of a dielectric under applied potential as seen by its electric moment.

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**Operational Characteristics**

A change in the relative resonant frequencies of the tuned circuits L₂C₂ and L₁C₁ is reflected in a voltage change at the V₁ anode. The detector cell was constructed from a rectangular brass block. The positively charged

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**Table 1. Dielectric Constants of Various Gases**

<table>
<thead>
<tr>
<th>Dielectric Constant (s)</th>
<th>Temperature (°C)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>25</td>
<td>Air</td>
</tr>
<tr>
<td>1.0005</td>
<td>23</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>1.0005</td>
<td>100</td>
<td>Oxygen</td>
</tr>
<tr>
<td>1.0009</td>
<td>100</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>1.0011</td>
<td>23</td>
<td>Nitrous oxide</td>
</tr>
<tr>
<td>1.004</td>
<td>100</td>
<td>Chloroform</td>
</tr>
<tr>
<td>1.007</td>
<td>23</td>
<td>Diethyl ether</td>
</tr>
<tr>
<td>1.007†</td>
<td>23</td>
<td>Methoxyflurane</td>
</tr>
<tr>
<td>1.008†</td>
<td>23</td>
<td>Fluothane</td>
</tr>
<tr>
<td>1.008†</td>
<td>23</td>
<td>Trichloroethylene</td>
</tr>
</tbody>
</table>

* All readings at frequencies of approximately 3-5 megacycles/sec.

† Extrapolated.
part of the condenser was separated from the negatively charged part by viton quad rings. Adjustment of coil L\textsubscript{1} acted as a coarse zero. Limits of detection of the agents being measured were taken as a signal-to-noise ratio of 2:1. The instrument is completely insensitive to changes in the rate of flow from 10 ml/min to 10 l/min and to pressure changes up to 40 psg, and is nondestructive in its analysis. The intrinsic response speed (time constant) of the apparatus (meter excepted) was determined by the V\textsubscript{1} anode lead filter to be 500 microseconds.

**Table 2. Effect on the System of Changing Nitrous Oxide-Oxygen Mixtures**

<table>
<thead>
<tr>
<th>Nitrous Oxide (Per Cent)</th>
<th>Oxygen (Per Cent)</th>
<th>Microamperes</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>40</td>
<td>300</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>350</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>300</td>
</tr>
</tbody>
</table>

* Basis: reference cell 100 per cent oxygen set at 50 microamperes.

**Clinical Uses**

This on-line analyzer was used successfully for the continuous monitoring of methoxyflurane, halothane, chloroform and diethyl ether. In this circuit, the concentration was read out directly on a 5-milliampere meter or could be recorded on a 5-millivolt strip chart recorder. The possible effect of a change in the reference condenser due to a change in the ratio of oxygen to nitrous oxide was considered and examined (table 2). Adding or subtracting 10 per cent did not affect the stability of the electrical circuit. The change noted, i.e., 50 microamperes, was the noise level of the instrument and is 1 per cent of full scale. Full scale of the instrument represents 5 per cent halothane and 3 per cent methoxyflurane, and thus the noises were 0.05 per cent v/v and 0.03 per cent v/v, respectively. The instrument scale was calibrated by passing through the analyzing condenser known concentrations (v/v) of anesthetic gases in a 50 per cent oxygen-50 per cent nitrous oxide mixture. These calibrated gases were blended into cylinders and the gas chromatographically analyzed independently to obtain the above data. In addition, the cylinders were then used to study the reliability and accuracy of various vaporizers' outputs using this analyzer.

**References**


§ Matheson Gas Company, East Rutherford, New Jersey.