# “Neutrality of Molecules by a New Method”

## (新しい方法による分子の電気的中性の検証)

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Contents



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# 1. Introduction

**Does atom have net electric charge?**

- **Neutrality measurements date from 1925**

**Millikan proved that :**

$$\begin{cases} e_e + e_p = \frac{\epsilon}{M} e \\ \frac{\epsilon}{M} \leq \pm 10^{-16} \end{cases}$$

$e_e$ : *electric charge of electron*

$e_p$ : *electric charge of proton*

$e$ : *elementary electric charge*

$\epsilon e$ : *the charge per molecule in units of electric charge*

$M$ : *the total number of nucleons in a molecule*

- **If** $\epsilon \neq 0$

→ **Universe would have very different structure !**

**Net electric charge of atom, even if it exists, does not violate any quantum numbers.**

**Electric charge is not quantized in the standard model of particle physics.**

↓

**Each type of particle can have different electric charge.**

# 2. Experimental Method

- **Three different experimental techniques in the past ：**

  **(1) The gas-efflux method**
  (ガス流出法)

  **ex.) King ;** $\frac{\epsilon}{M} \leq \pm 4.3 \times 10^{-21}$

  **(2) The isolated-body method**
  (単離体を用いた方法)

  **ex.) Millikan ;** $\frac{\epsilon}{M} \leq \pm 10^{-16}$

  **(3) The molecular-beam method**
  (分子線を用いた方法)

  **ex.) Hughes ;** $\frac{\epsilon}{M} \leq \pm 4 \times 10^{-13}$

**It is difficult to further improve the precision.**

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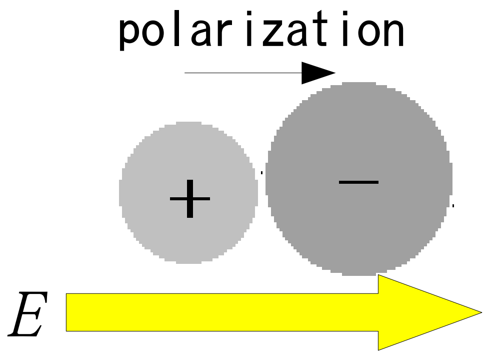
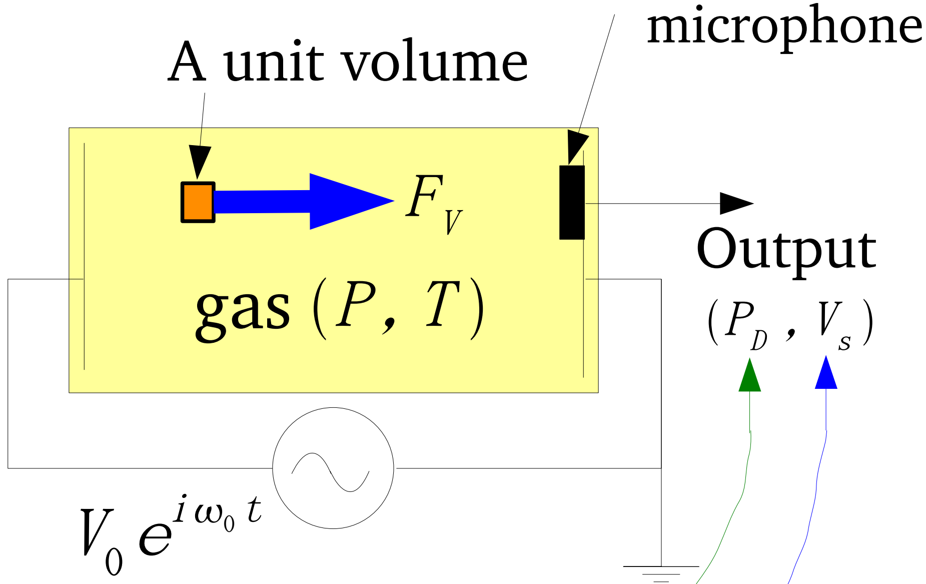
- **A new experimental technique**
  - **easier to handle**
  - **higher sensitivity**

- **A new method**




- $P_D$ : *sound pressure*
- $V_s$ : *surface voltage*
- $V_0$ : *electrode voltage*
- $Q$ : *an indicator of waveform's sharpness*
- $k$ : *Boltzmann's constant*

- **An alternating electric field** $E(\omega_0)$
- **The force per volume of gas** $F_V$

$$F_v = n\epsilon e E + \left(\frac{n}{8\pi}\right)\alpha \nabla E^2 \quad \cdots(1)$$

$F_{v2}$: molecular polarization term

- $\omega_0$ : *electric field's frequency*
- $n$ : *the number of molecules per unit volume*
- $\alpha$ : *molecular polarizability*

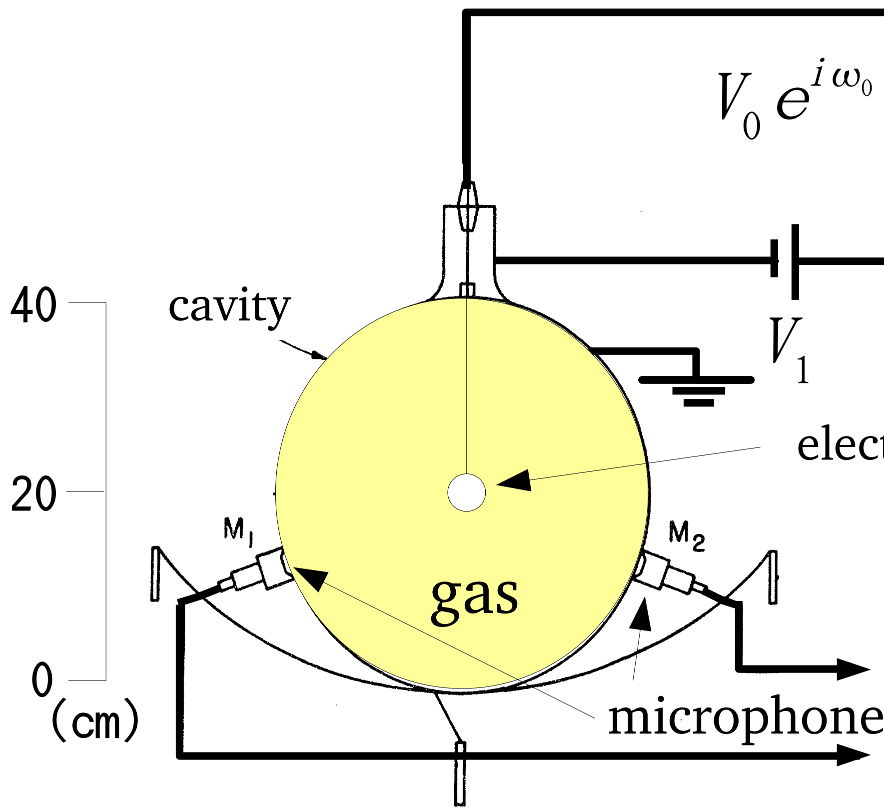
**Sound waves in the gas**

$$\left( n\epsilon e E \ll \left(\frac{n}{8\pi}\right)\alpha \nabla E^2 \right)$$

**In the experiment**

$$|\epsilon| e \leq (0.45)\frac{P_D k T}{Q P V_0} \quad \cdots(2)$$

# 3. Apparatus




- **Two gases; $SF_6$ and $N_2$**
  - $SF_6$
    - large mass number (M=146)
    - small acoustic absorption coefficient

    ⇨ neutrality measurements
  - $N_2$

    ⇨ as a check

- **A static potential $V_1$**

  ⇨ { **· To set the frequency**
  **· To remove stray charged particles from the cavity** }

**The effect stray charged particles is not important.**
**⇨ No special precautions are needed.**

# 4. Result

**From the Eq(2):** $|\epsilon| e \le (0.45)\dfrac{P_D kT}{QPV_0}$

$$|\epsilon| e \le (0.45)\frac{kT}{QPV_0}\frac{\Delta P_D}{\Delta V_s} V_s \cdots (2)'$$

- **Step1:** $\dfrac{V_s}{V_0^2}$
  - **From the Fig. 2 ;**

$$\frac{V_s}{V_0^2} = 0.59\left[\frac{\mathrm{V}}{(\mathrm{KV})^2}\right]$$

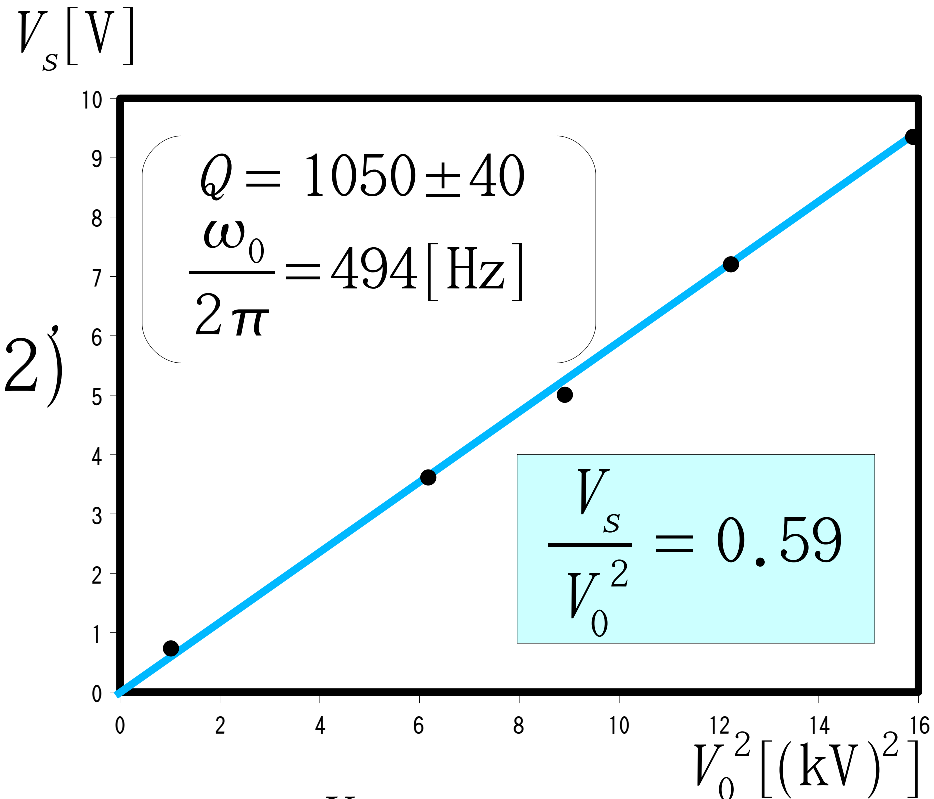



Fig. 2. $\dfrac{V_s}{V_0^2}$ measurement ( $SF_6$ )

- **Step2:** $\dfrac{\Delta V_s}{\Delta P_D}$
  - **From the second term of Eq.(2):** $F_{v2}(r) = \left(\dfrac{n}{8\pi}\right)\alpha \nabla E^2 \equiv F_0 j_0(k_0 r)$

⇩ The solution of wave equation

$$\frac{P_D}{V_0^2} \approx 1.02\frac{Qk_0 n\alpha r_0^2}{a^3 j_0(k_0 a)} = 3.2\times 10^4\left[\frac{\mathrm{N/m^2}}{(\mathrm{KV})^2}\right]$$

$a_0$ : *radius of the cavity* ( $a_0 = 19.7$[cm] )

$r_0$ : *radius of the electrode* ( $r_0 = 1.27$[cm] )

$k_0$ : *wave number* ( $k_0 = 0.228$[cm$^{-1}$] )

⇨ $$\frac{\Delta V_s}{\Delta P_D} = \frac{V_s}{V_0^2}\frac{V_0^2}{P_D} = 1.9\times 10^4\left[\frac{\mathrm{V}}{\mathrm{N/m^2}}\right] \cdots (3)$$

- **Step3:** $V_s$

**From Fig.3 and Fig.4 ;**

**No charge signal is observed.**
**(Total electronic noise is 0.1V)**

- **A signal-to-noise ratio is about 1.**

$\Rightarrow V_s = 0.1[\mathrm{V}] \cdots (4)$

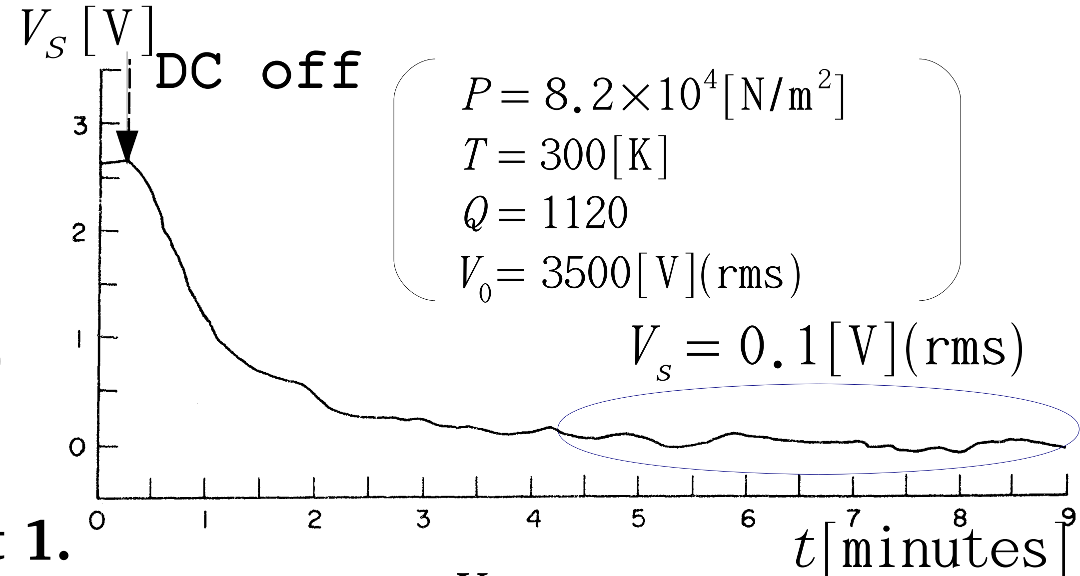



Fig. 3. $V_s$ measurement ($SF_6$)

- **Step4: From Eq.(2)'~(4)**

$$
\begin{cases}
|\epsilon| e \le (0.45)\dfrac{kT}{QPV_0}\dfrac{\Delta P_D}{\Delta V_s} V_s \cdots (2)' \\
\dfrac{\Delta V_s}{\Delta P_D} = 1.9\times10^4\left[\dfrac{\mathrm{V}}{\mathrm{N/m^2}}\right] \cdots (3) \\
V_s = 0.1[\mathrm{V}] \cdots (4)
\end{cases}
$$

$$\Rightarrow |\epsilon| \le 1.9\times10^{-19}$$

$$\Rightarrow \frac{|\epsilon|}{M} \le 1.3\times10^{-21} \quad (M = 146 \text{ for } SF_6)$$

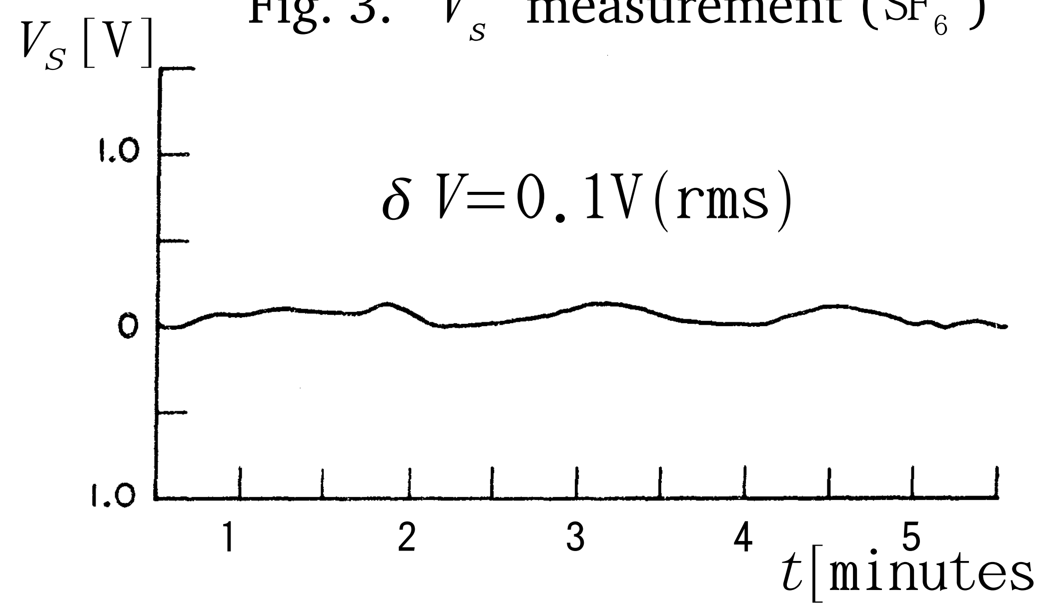



Fig. 4. Total electronic noise

(rms : root mean square)

# 5. Conclusions

- $e_e + e_p = \frac{\epsilon}{M} e$
- **A new method**
  **( The sound waves in the cavity )**
- **Avoiding the problem of stray charged particles**
- $|\epsilon| \leq 1.9\times10^{-19}$ , $\frac{|\epsilon|}{M} \leq 1.3\times10^{-21}$

## Outlook

- **To increase the sensitivity**
  - **Using a higher pressures** → $\times 10 \sim 100$
  - **Using a higher voltage** → $\times 10$
  - **Using a better-quality microphones** → $\times 5$

  ⇒ $\frac{|\epsilon|}{M} \leq 10^{-24}$

$\frac{|\epsilon|}{M} \leq 1.3\times10^{-21}$ **is the highest sensitive limit at present (2007).**

| | Method | Molecule | Upper limit[a] for $\epsilon$ | Upper limit[b] for $\epsilon/M$ |
|---|---|---|---|---|
| Millikan | (2) | ... | ... | $\pm 10^{-16}$ |
| Stover, Moran, and Trischka | (2) | ... | ... | $\pm 0.8 \times 10^{-19}$ |
| Piccard and Kessler | (1) | $CO_2$ | $\pm 2 \times 10^{-19}$ | $\pm 5 \times 10^{-21}$ |
| Hillas and Cranshaw | (1) | Ar | $(4 \pm 4) \times 10^{-20}$ | $(1 \pm 1) \times 10^{-21}$ |
| | | $N_2$ | $(6 \pm 6) \times 10^{-20}$ | $(2 \pm 2) \times 10^{-21}$ |
| King | (1) | $H_2$ | $(1.8 \pm 5.4) \times 10^{-21}$ | $+(0.9 \pm 2.7) \times 10^{-21}$ |
| | | He | $(-0.7 \pm 4.7) \times 10^{-21}$ | $(-0.2 \pm 1.2) \times 10^{-21}$ |
| | | $SF_6$ | $(0 \pm 4.3) \times 10^{-21}$ | $(0 \pm 3.0) \times 10^{-23}$ |
| Hughes | (3) | CsI | $4 \times 10^{-13}$ | $2 \times 10^{-15}$ |
| Zorn, Chamberlain, and Hughes | (3) | Cs | $(1.3 \pm 5.6) \times 10^{-17}$ | $(1.0 \pm 4.2) \times 10^{-19}$ |
| | | K | $(-3.8 \pm 11.8) \times 10^{-17}$ | $(-1.0 \pm 3.0) \times 10^{-18}$ |
| | | $H_2$ | $\pm 2 \times 10^{-15}$ | $\pm 1 \times 10^{-15}$ |
| | | $D_2$ | $\pm 2.8 \times 10^{-15}$ | $\pm 7 \times 10^{-16}$ |
| Fraser, Carlson, and Hughes | (3) | Cs | $\pm 1.7 \times 10^{-18}$ | $\pm 1.3 \times 10^{-20}$ |
| | | K | $\pm 1.3 \times 10^{-18}$ | $\pm 3.3 \times 10^{-20}$ |
| Shapiro and Estulin | (3) | $n$ | $6 \times 10^{-12}$ | $6 \times 10^{-12}$ |
| Shull, Billman, and Wedgwood | (3) | $n$ | $(-1.9 \pm 3.7) \times 10^{-18}$ | $(-1.9 \pm 3.7) \times 10^{-18}$ |

[a]Measured charge per molecule in units of the electronic charge.

[b]Measured charge per molecule divided by the total number of nucleons.

**Eq.(2)**

$$|\epsilon|e \leq \frac{P_D k T}{Q P V_0} \frac{\pi k_0 / 2 r_0}{[(\sin(k_0 r_0))/k_0 r_o^3 + (\sin(k_0 a))/k_0 a^3]}$$