NEUTRA: Testing the Neutrality of Matter by Acoustic Means in a Spherical Resonator

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INTRODUCTION

In the last century, several measurements have been performed in order to test the symmetry of the elementary charges, using different laboratory approaches. The results of all the experiments performed so far are consistent with the usual view that matter is neutral. The results are best described in terms of two parameters

$$\varepsilon_{p-e} = \frac{q_p + q_e}{e} \quad \text{and} \quad \varepsilon_n = \frac{q_n}{e},$$

where \(q_p\), \(q_e\) and \(q_n\) are the electric charges of protons, electrons and neutrons, respectively. In order to disentangle the two effects, one has to perform independent measurements on at least two systems with different \(Z\) and/or \(N\). A common approach assumes instead charge conservation in the \(\beta\) decay of the neutron \(n \rightarrow p + e^- + \nu\) (and the neutrality of the antineutrino); with these hypotheses \(\varepsilon_{p-e} = \varepsilon_n \equiv \varepsilon_q\) and

$$|\varepsilon_q| \leq \frac{\delta q}{(Z+N)e} \approx \frac{\delta q}{m_p - m},$$

where \(m_p\) and \(m\) are respectively the masses of the proton and of the molecule or the sample. The currently accepted limit for the value of the charge difference between electron and proton is \(\varepsilon_q \lesssim 1 \times 10^{-21}\). A review on this topic can be found in Ref. [1].

EXPERIMENTAL SET-UP AND METHOD

A principle scheme of the experimental apparatus is shown in figure 1: an oscillating voltage is applied to a gas filled spherical capacitor. Forces are exerted on the molecules in the first instance through electric polarization, but also if matter is not neutral. In both cases, acoustic waves are generated [2].

A spherical electrode is suspended in the center of an Al cavity to a metal wire. The cavity can be evacuated and then filled with very high purity gases. Acoustic oscillations of the gas inside the cavity are measured by means of a microphone. The outer shell is in electric contact with ground and isolated from the inner electrode. An HV feedthrough connects the inner electrode to an HV amplifier driven by a waveform generator; in this way an oscillating electric field is established inside the cavity. This system allows pressure measurements of the type:

$$P(t) = P_0 \cos(\omega t + \phi).$$

All the measurements have been performed in correspondence of the first cavity radial modes, having resonance frequencies \(\nu_0\). The dynamic pressure peak values due to electric polarization and to charge asymmetry can be written as [1]

$$P_P(\nu_0) = B_0 Q_0 \alpha \beta V^2(\nu_0)$$
$$P_N(\nu_0) = D_0 Q_0 \varepsilon_q M \delta V(\nu_0),$$

where \(B\), \(\beta\), \(D\) and \(\delta\) are known numerical coefficients, \(Q\) is the merit figure of the cavity, \(\alpha\) the electric polarizability, \(V^2(\nu_0)\) the Fourier component of \(V^2\) at a resonance frequency \(\nu_0\) and \(M\) is the molecular weight of the gas.

Table 1. Experimental parameters for the different configurations of measure.

<table>
<thead>
<tr>
<th>Measurement type</th>
<th>(\nu_{HV})</th>
<th>(\nu_0)</th>
<th>(V_1)</th>
<th>(P) phase</th>
<th>(V^2(\nu_0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarizability I (PI)</td>
<td>(\nu_0)</td>
<td>(\neq 0)</td>
<td>(0\neq 0)</td>
<td>(\phi_{HV} - \pi/2)</td>
<td>(2V_0V_1)</td>
</tr>
<tr>
<td>Polarizability II (PII)</td>
<td>(\nu_0/2)</td>
<td>(0\neq 0)</td>
<td>(2\phi_{HV} - \pi/2)</td>
<td>(V^2_1/2)</td>
<td></td>
</tr>
<tr>
<td>Neutrality (N)</td>
<td>(\nu_0)</td>
<td>(0\neq 0)</td>
<td>(\phi_{HV} - \pi/2)</td>
<td>——</td>
<td></td>
</tr>
</tbody>
</table>

The high voltage signal on the inner electrode is parametrized as:

$$V_{HV}(t) = V_0 + V_1 e^{-i(\omega t + \phi_{HV})}.$$
Three types of measurement are possible, depending on the values of \( V_0 \) and \( V_1 \); all the relevant values of the experimental parameters are summarized in Table 1. The polarizability measurements are used to test and calibrate the apparatus. When the high voltage excitation frequency coincides with the frequency of a resonant mode and \( V_0 \neq 0 \), both effects due to polarization and to an hypothetical non neutrality of matter are present. In this case, considering the pressure signal as a function of \( V_0 \), one sees that the neutrality measurement \( N \) can be obtained as the limit for \( V_0 \to 0 \) of the polarization measurement \( PI \).

**RESULTS AND DISCUSSION**

![Fig. 2. Typical PI-type polarization measurement.](image)

![Fig. 3. PH-type polarization measurements for several SF\(_6\) pressures, as a function of \( V_1 \). The data are fitted with \( V_1^2 \) functions.](image)

In figures 2 and 3 typical results of the polarizability measurements of SF\(_6\) are shown. The slopes and curvatures obtained from the fits allow to calculate the electric polarizability of the gas.

As far as the neutrality measurements are concerned, no direct N-type measurement was possible. In fact, when \( V_0 = 0 \) and \( \omega_{HV} = \omega_{n0} \), a small but significant spurious signal is always present, with the right phase and an amplitude corresponding to a non-neutrality of the matter of the order of \( \varepsilon_q \approx 10^{-19} \). This signal is not an electric pick-up, a large contribution to it must instead come from free charges in the gas.

To go around the impossibility of a direct N-type measurement, we use instead the intercepts in PI-type measurements. As noted before, the intercepts represent a determination of the acoustic effect of the charge asymmetry. We expected that the continuous presence of a DC voltage could sweep away the free charges from the gas. The hypothesis proved to be right. The positive and negative branches of each line have been sampled in different data sets, to keep constant the polarity of the DC voltage during each measurement. A linear regression was performed on each data set; all the points of each set were given the same statistical uncertainty chosen in such a way to have a reduced \( \chi^2 \) of the order of unity.

![Fig. 4. Plot of thirty-six determinations of the charge asymmetry \( \varepsilon_q \). The continuous lines are the averages, taken separately, of the data measured with negative (upper horizontal line, squares) and positive (lower horizontal line, diamonds) \( V_0 \).](image)

All the results obtained for the value of the intercept are shown in figure 4. We note that not all the values are compatible with zero. It is observed that all but a few data sets taken with \( V_0 < 0 \) have positive intercept, while the opposite is true for the data sets taken with \( V_0 > 0 \). If the two groups of intercepts are separately averaged, opposite values are found: this means that besides the effect of polarization, at least another spurious effect of unknown origin must be present which, at variance with the hypothetical non-neutrality of the matter, changes sign with the sign of the excitation signal. We get rid of this unwanted effect, thus extracting the value of the charge asymmetry, by making the half-sum of the two values. Finally, we find for the charge asymmetry of electron and proton as well as for the charge of the neutron

\[
\varepsilon_q = (-0.1 \pm 1.1) \times 10^{-21}.
\]

This limit is compatible with zero and the sensitivity is at the level of the best results reported in the literature [1].