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Reduction and Characterization of Error in Low Current Measurements

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Current Error $\Delta I$

The precision for a single current measurements, $\Delta I$, using an electrometer (Keithley 616) and data acquisition (DAQ) card (National Instruments, Model 6231) over a current range of $10^{-15}$ to $10^{-9}$ A is given by:

$$\Delta I = \left[ \left( \frac{I_{\text{meas}}}{I_{\text{true}}} \cdot \Delta I_{\text{true}} \right) + \Delta I_{\text{True}} \right]$$

where $I_{\text{meas}}$ is the measured current, $I_{\text{true}}$ is the true current, $\Delta I_{\text{true}}$ is the absolute part of the electrometer error, $\Delta I_{\text{true}}$ is the relative DAQ and electrometer error proportional to the measured current.

**Error in Conductivity $\Delta \sigma$**

We are concerned with the estimation of the error in the conductivity, which is calculated as:

$$\sigma = \frac{f}{\rho} \frac{d}{\rho}$$

where $f$ is the current, $\rho$ is the sample thickness, $A$ is the cross sectional area, and $V$ is the applied voltage. The relative error in conductivity (or resistivity) is the sum of relative errors of these four measured components added in quadrature:

$$\Delta \sigma = \left( \Delta f \right)^2 + \left( \Delta \rho \right)^2 + \left( \Delta A \right)^2 + \left( \Delta V \right)^2$$

Based on standard error analysis methods, the magnitudes of the components of random and systematic errors and their relative contribution to the total error in conductivity are described individually in the side panels.

**Voltage Error $\Delta V$**

For the programmable medium voltage supply used (Bertan, Model 230-61R; 1 kV @ 15 mA), the instrumental precision is approximately:

$$\Delta V = \left( N_{\text{true}} - 1 \right)^{-1} \left[ 250 mV + 0.1\% \cdot V_{\text{pp}} \right]$$

The uncertainties in this equation are a combination of uncertainties from the DAQ card and programmable voltage supply. The voltage dependent term, 0.1%, is a sum in quadrature of voltage supply uncertainties.

**Conclusions**

The fundamental limit to measurement of current or conductivity is the Johnson noise of the source resistance. For any resistance, thermal energy produces motion of the constituent charged particles, which results in what is termed Johnson or thermal noise. Based on a standard formula for peak to peak Johnson current noise:

$$M_p = S \cdot T \cdot f$$

where $W_{\text{meas}}$ is the signal band width approximated as $(0.35/f)$. For the lowest $10^{-15}$ A range of the Keithley 616 electrometer this $f$ is $3 s$ and $W_{\text{meas}}$ is 5.12 Hz. For a typical LDPE sample at $-300 K$, $I_{\text{true}}=10^{-14}$ A with a corresponding $R_{\text{true}}=10^{11}$ (ohm) at 100 V. This is 1% of the ultimate instrument conductivity resolution.

Due to extreme sensitivity of the CVC, it has the potential of measuring conductivities comparable to noise produced by Radiation Induced Conductivity (RIC) resulting from cosmic ray background radiation, which is ~50% of the ultimate instrument conductivity resolution.