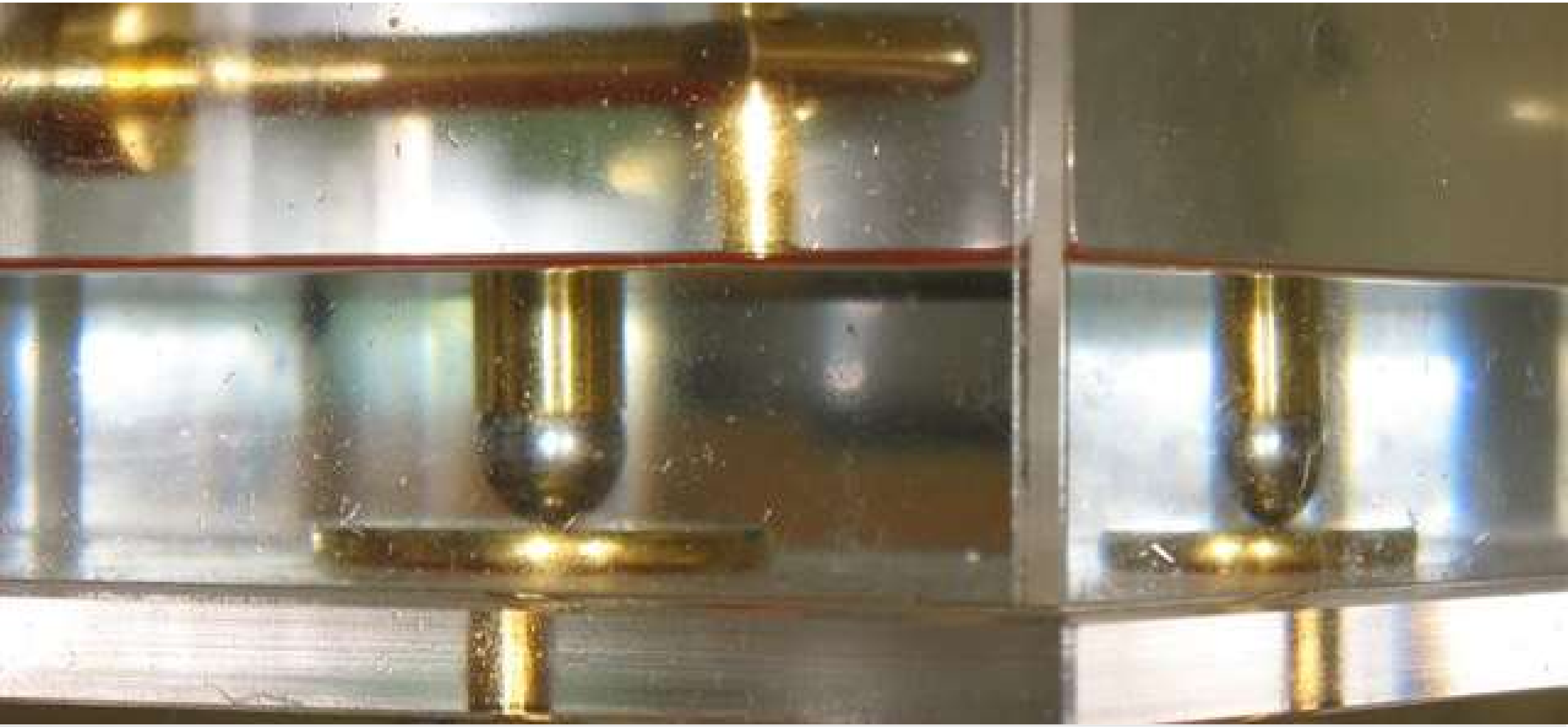

# Selected Electrical Poperties of Silicone Elastomers – Measurement and Interpretation of the Results


Dr. Jens Lambrecht, Dr. Christiane Bär, Wacker Chemie AG

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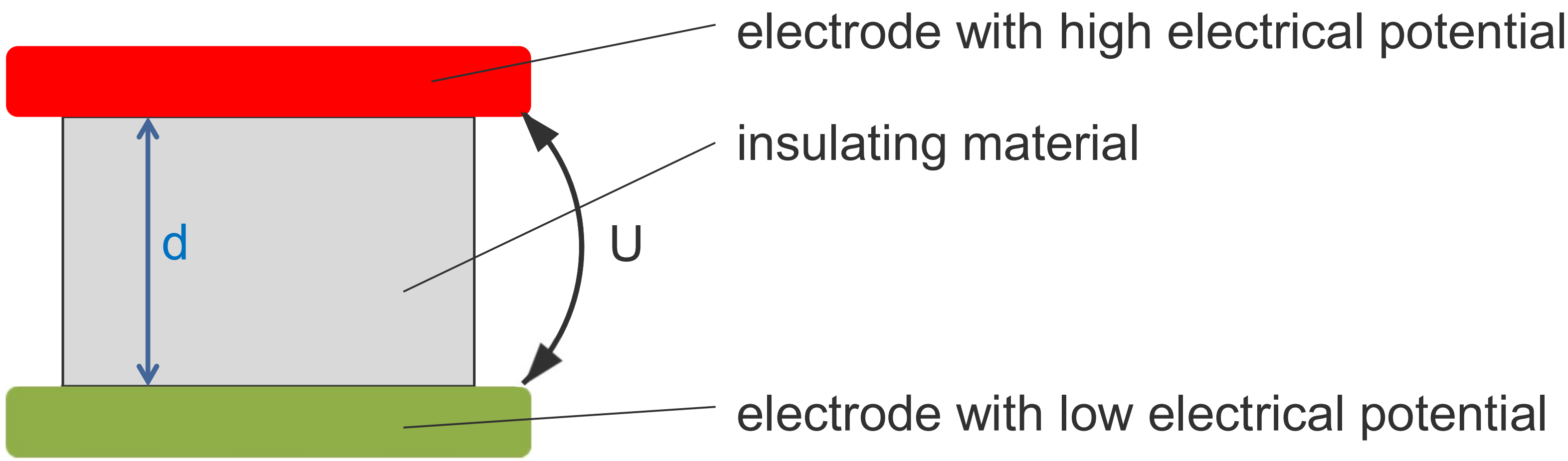
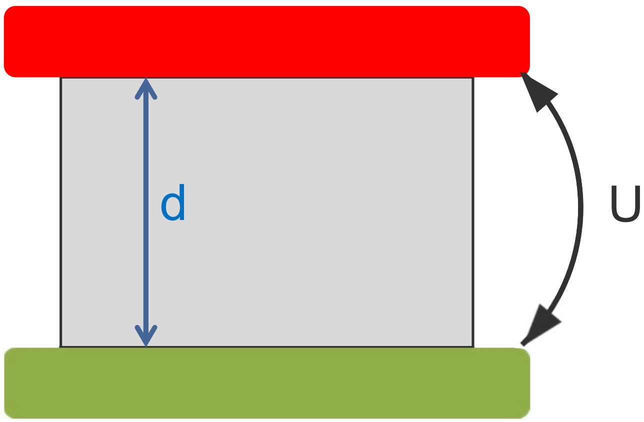
- Tasks of Silicone Elastomers as Electrical Insulation Materials
- Electrical Strength of Silicone Elastomers and their Evaluation
- Specific Volume Resistivity of Conductive Silicone Elastomers

# Tasks of Silicone Elastomers as Electrical Insulating Materials



# Tasks of Silicones as Electrical Insulating Materials




$$electrical\ stress = \frac{voltage}{distance}$$

$$E = \frac{U}{d} \quad \left[\frac{V}{m}\right]$$

Electrical (breakdown) strength $E_b$ (of an insulating material) is the maximum electrical stress E that a material can withstand without undergoing an electrical breakdown.

## Tasks of Silicones as Electrical Insulating Materials

It is the task of the electrical insulating material to always keep the electrical stress caused by the electric field E significantly lower than its electrical strength $E_b$ !

$$E \ll E_b$$

For insulating arrangement consisting of polymeric materials, discharges in the volume of material and in interfaces between materials need to be avoided to guarantee a long service life.

# Measurement of the Electric Strength

**IEC 60243-1 Ed. 3:** Electric strength of insulating materials - Test methods - Part 1: Tests at power frequencies

The standard says:

“The measured electric strength of most materials is significantly affected by the intensity and the duration of surface *(partial)* discharges prior to breakdown. For designs which are free from partial discharges up to the test voltage, it is very important to know the electric strength without discharges prior to breakdown.”

However, the test arrangements described in this standard are generally not suitable for testing without partial discharges and thus don’t allow to provide this information.

# Measurement of the Electric Strength

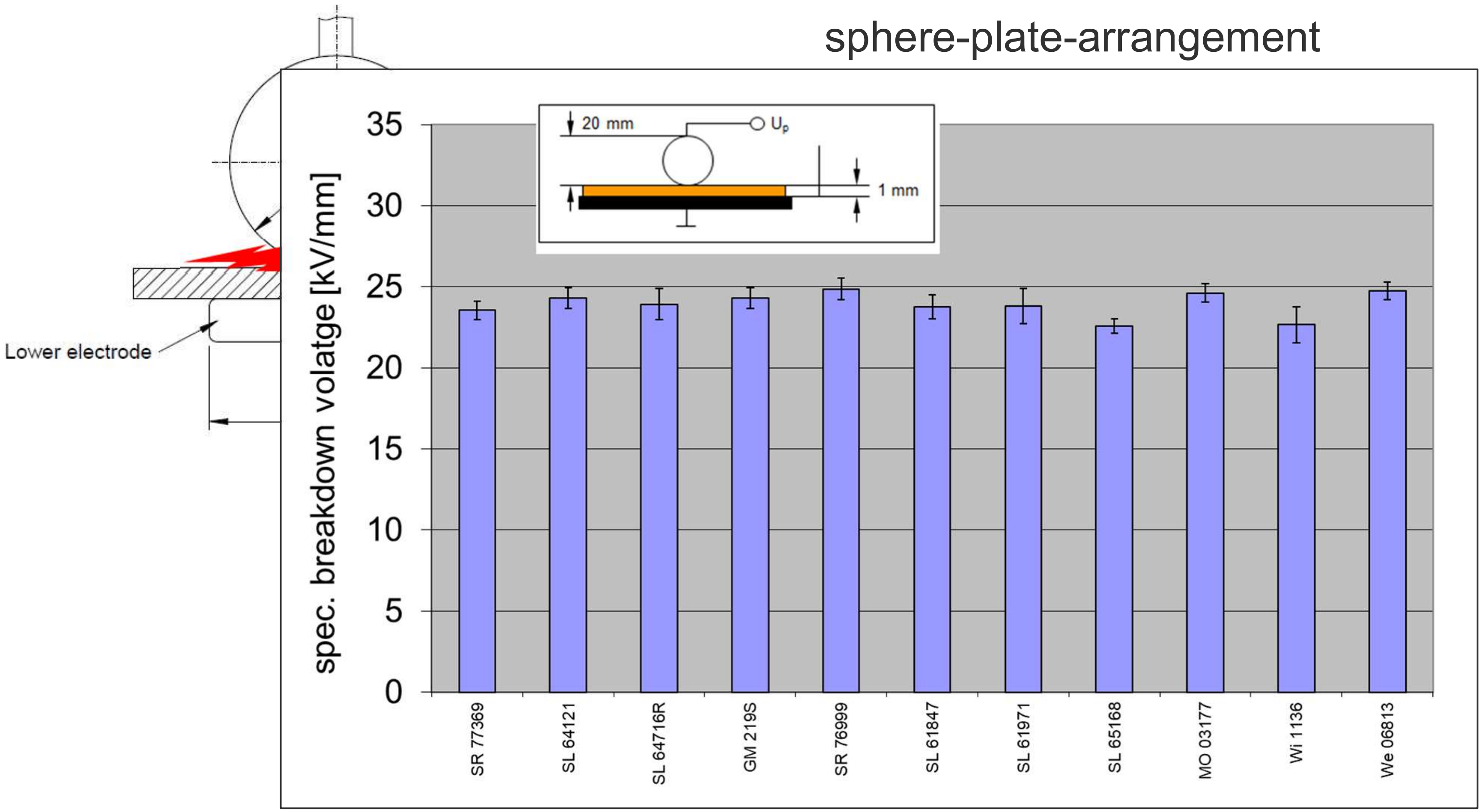
**IEC 60243-1 Ed. 3:** Electric strength of insulating materials - Test methods - Part 1: Tests at power frequencies

In other words:

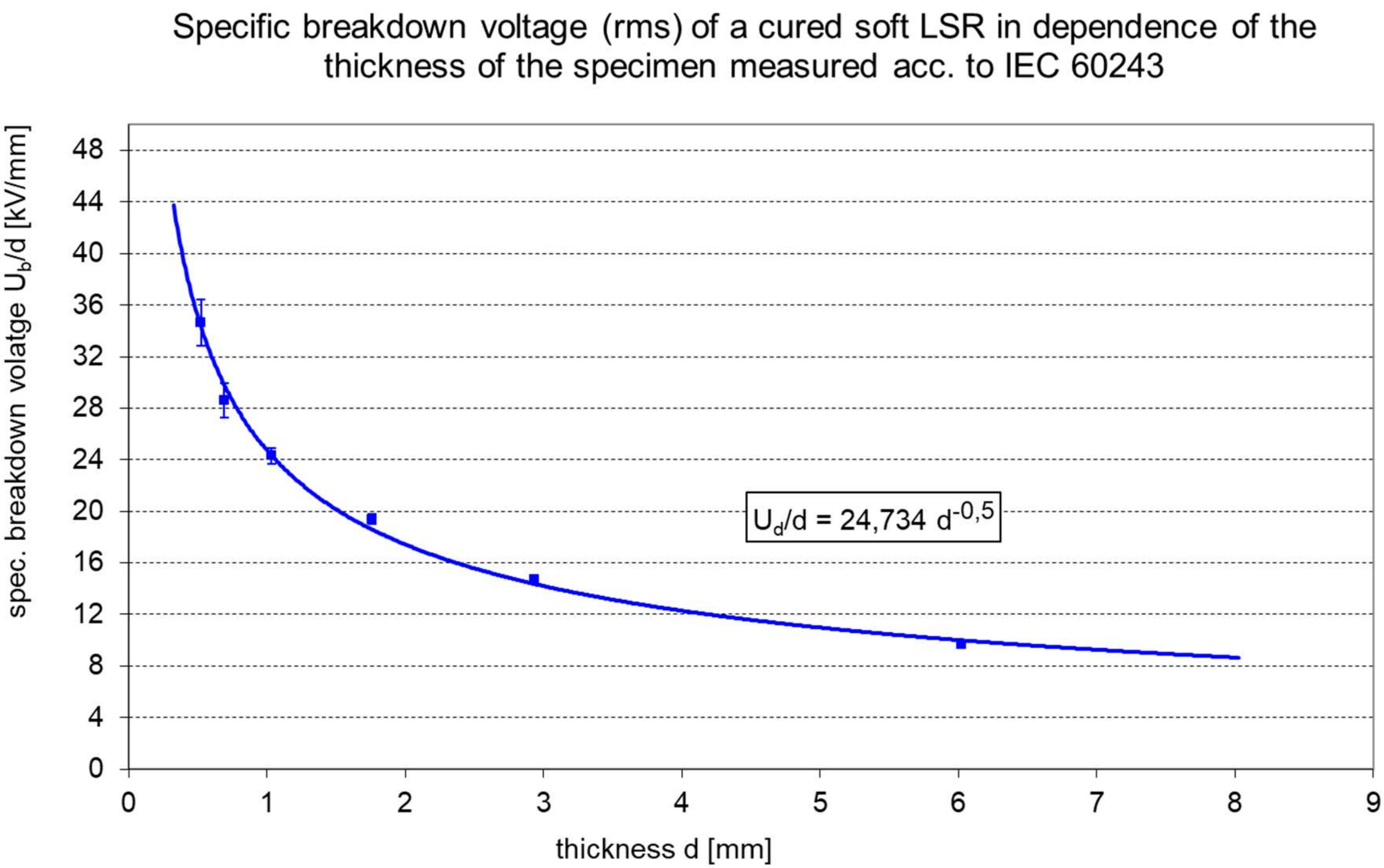
The electrode arrangements recommended in the standard do not allow to avoid partial discharges.

The value of the breakdown voltage (and the resulting value of the electrical breakdown strength) is therefore NOT an indication of the pure electrical strength but rather an indication for the stability of an insulating material that is exposed to a prestress of partial discharges, followed by the final electrical breakdown.

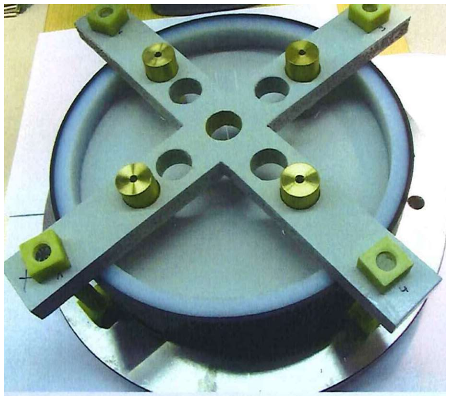
# Measurement of the Electric Strength

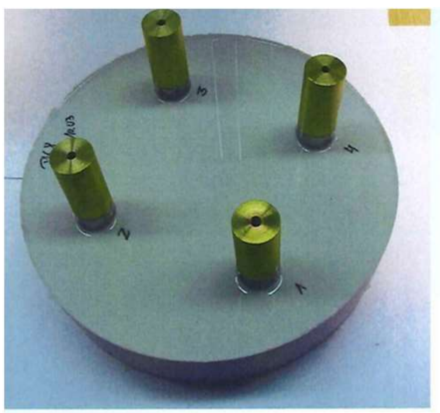


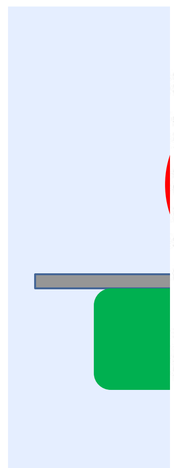
# Measurement of the Electrical Strength

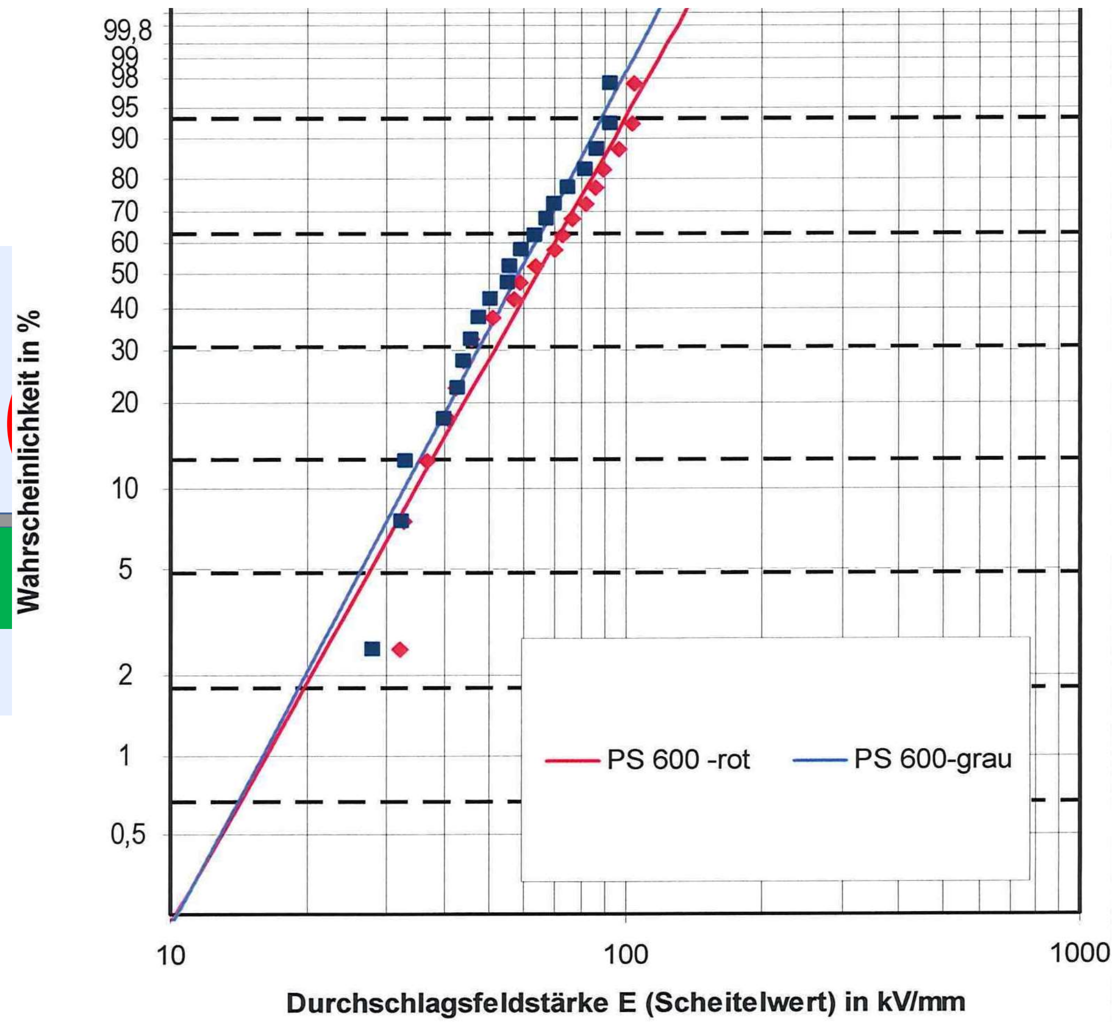


# Measurement of the Electrical Strength

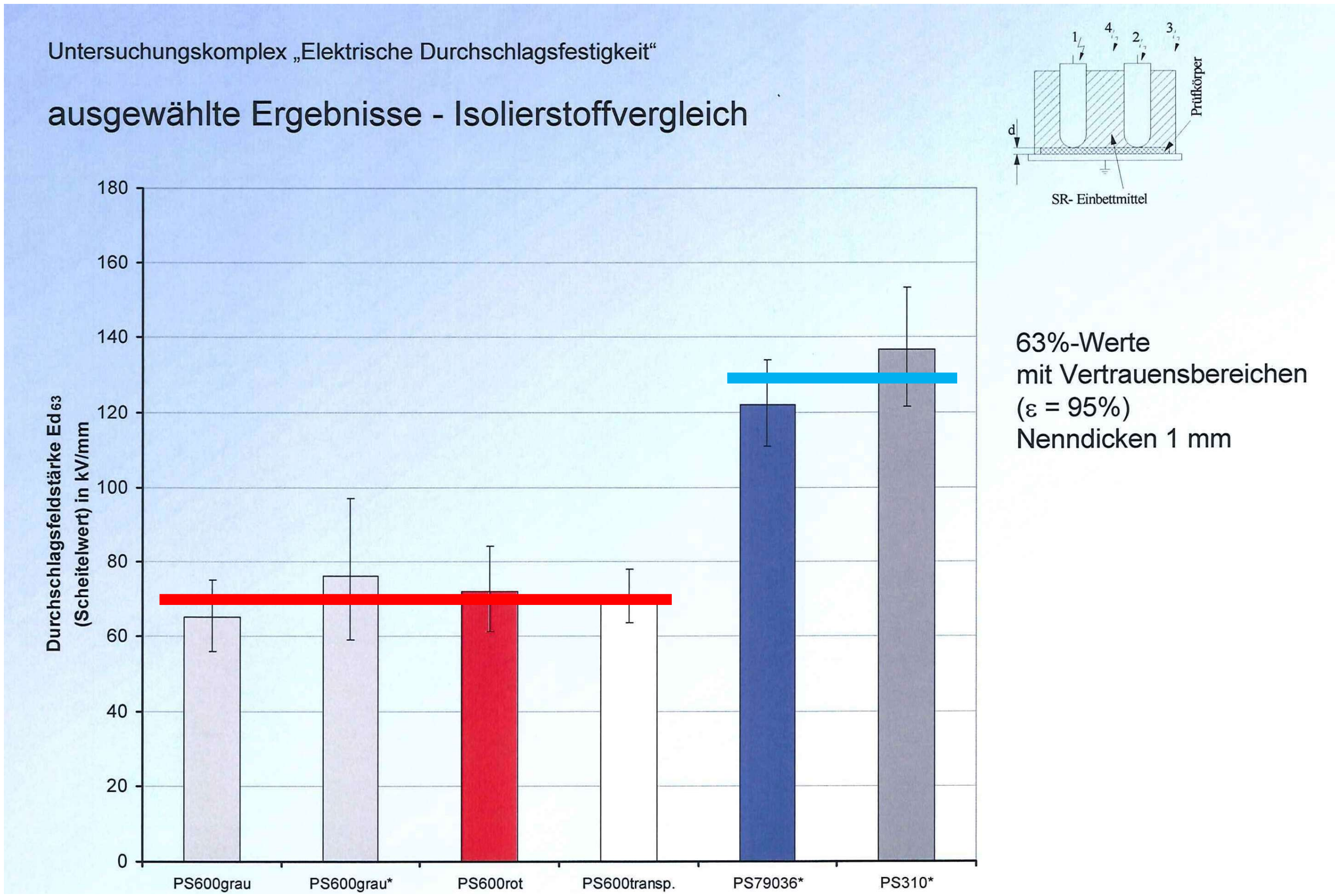




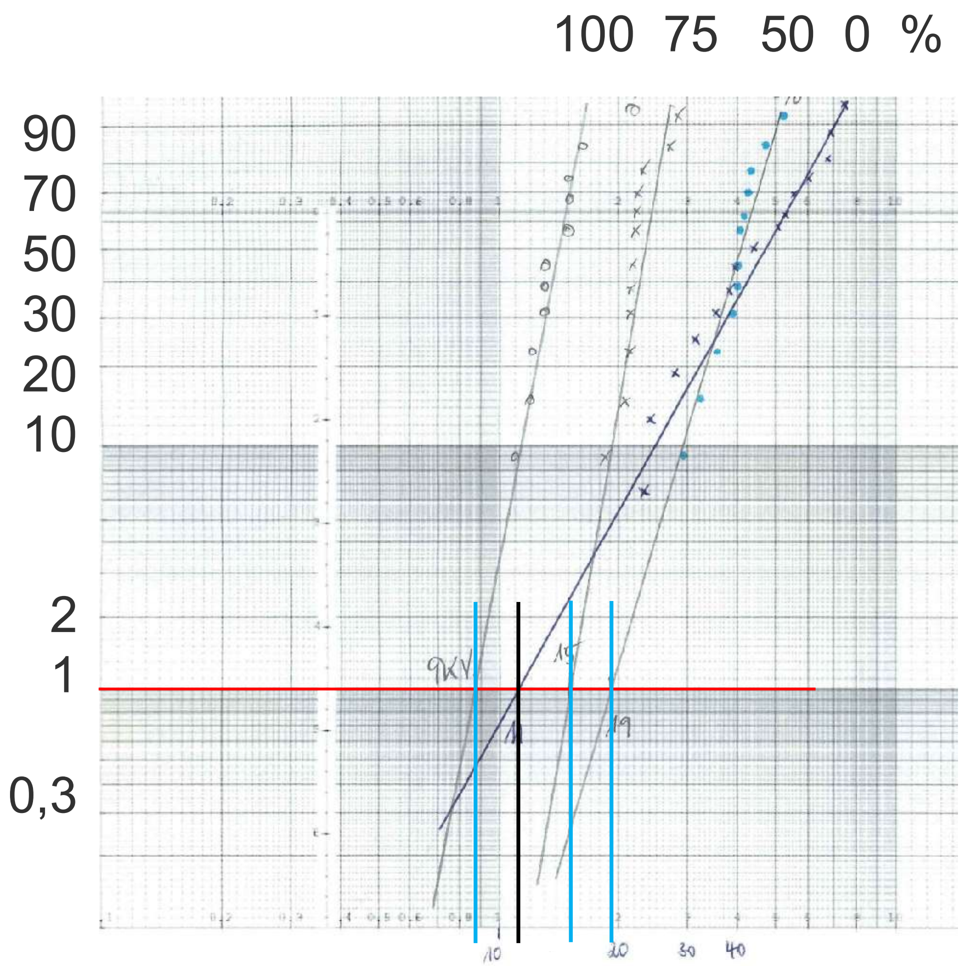




# Measurement of the Electrical Strength



# Comparative Evaluation of the Electrical Strength of Silicone Elastomers




Plotting data on Weibull-likelihood-paper allows a quick comparative evaluation of the influence of modifications in the electrical strength.

1%-likelihood-data may be used to estimate applicable max. field stress in the molded or extruded part.

## Specific Volume Resistivity of Conductive Silicone Elastomers

Wacker Chemie AG offers numerous silicone elastomers that are modified by containing special carbon blacks to provide an electrical conductivity.

Well-known and widely used materials are covered by our ELASTOSIL® 570-series.

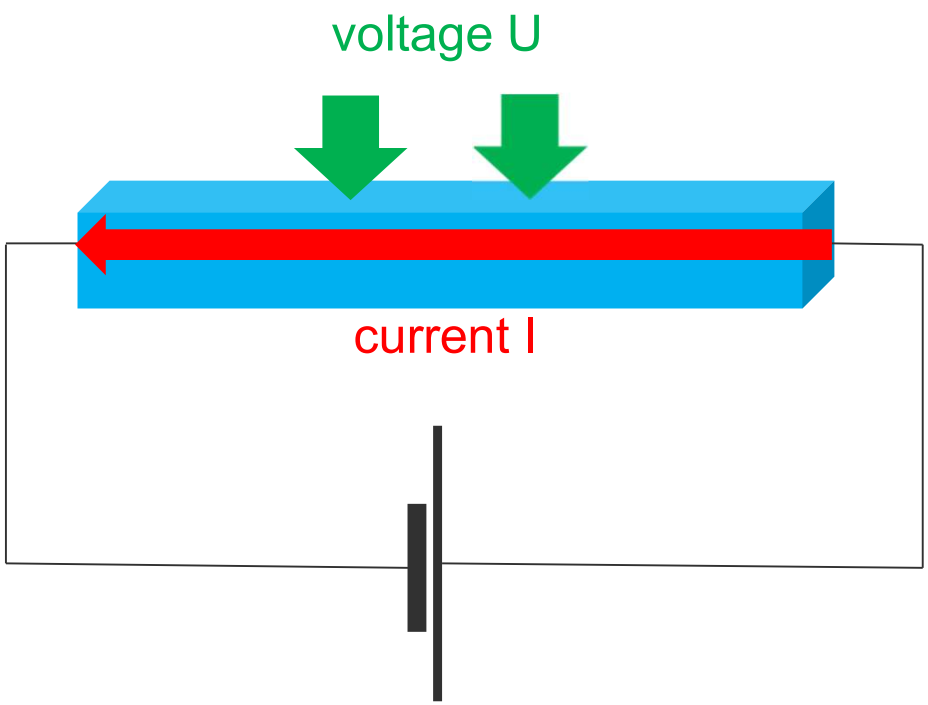
ELASTOSIL® 570/50, for example, comes with a specific volume resistivity of about 10 $\Omega$cm.

Experience shows that the proper measurement of this property is challenging and often leads to incorrect results and misinterpretations by the person taking the measurement.

## Specific Volume Resistivity

The attempt to determine the specific volume resistivity with the aid of standard multimeters or other two-wire devices often won't deliver useful results. Why is that so?

## Specific Volume Resistivity

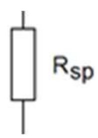



$$R = \frac{U}{I}$$

Heureka ?

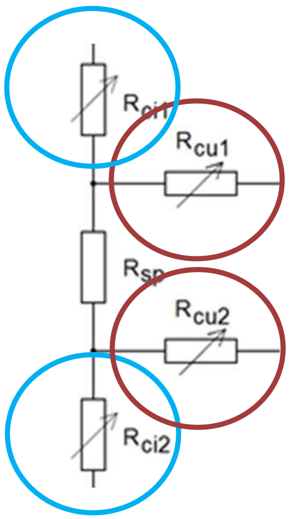
# Specific Volume Resistivity

Resistors that need to be taken into consideration.



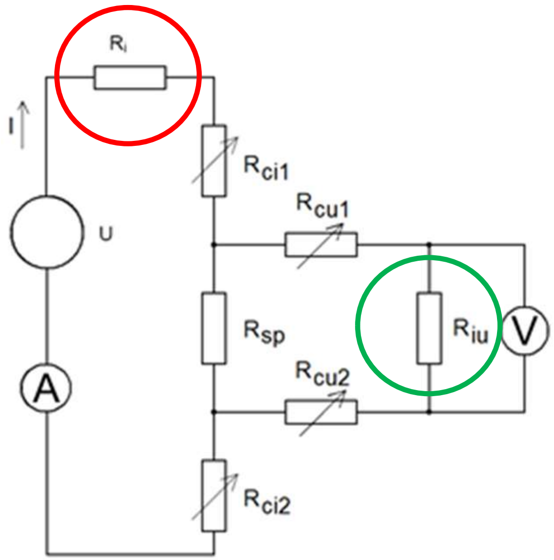

| | |
|---|---|
| $R_{Sp}$ | resistance of the specimen (in the area between the voltage electrodes) |

# Specific Volume Resistivity




| | |
|---|---|
| $R_{ci1}$, $R_{ci2}$ | contact resistance between the current-feeding electrodes and the specimen |
| $R_{Sp}$ | resistance of the specimen (in the area between the voltage electrodes) |
| $R_{cu1}$, $R_{cu2}$ | contact resistance between the specimen and the voltage-measuring electrodes |

# Specific Volume Resistivity




| | |
|---|---|
| $R_{iI}$ | internal resistance of the current source |
| $R_{ci1}$, $R_{ci2}$ | contact resistance between the current-feeding electrodes and the specimen |
| $R_{Sp}$ | resistance of the specimen (in the area between the voltage electrodes) |
| $R_{cu1}$, $R_{cu2}$ | contact resistance between the specimen and the voltage-measuring electrodes |
| $R_{iU}$ | internal resistance of the voltage measuring device |
| U | voltage |
| I | current |

A proper measurement requires a four-wire device with independent circuits for the current and the voltage. The circuit diagram of the measuring circuit for such a device and the specimen looks like shown above.

## Specific Volume Resistivity

With $U_{max}$ being the maximum available voltage of the source the main conditions for an accurate measurement with a low error are:

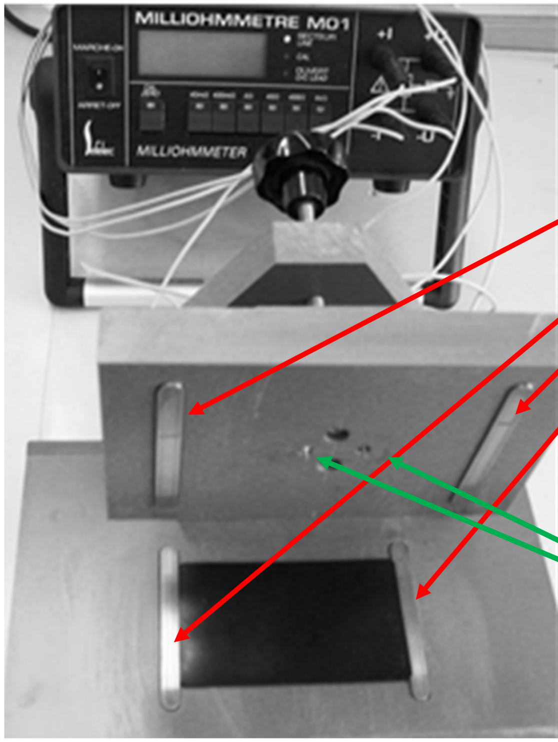
$$R_{iu} >> R_{cu1} + R_{cu2}$$

and

$$U_{max} > (R_{ci1} + R_{sp} + R_{ci2}) \times I$$

A four-wire milli-ohmmeter with an adjustable current source is the suitable device to measure the resistance and to calculate the resistivity of silicones with electrically conductive filers. A typical device and a possible design of an electrode are shown in following slide.

# Specific Volume Resistivity

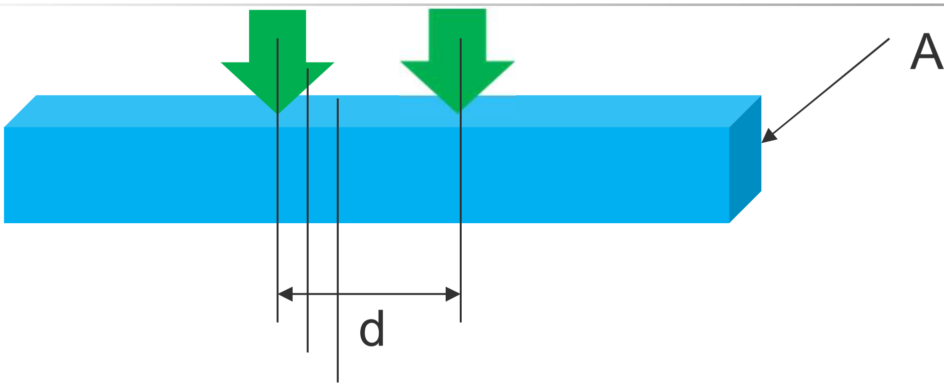



current feeding electrodes

The milliohmmeter provides an output in ohms.

voltage measuring electrodes

## Specific Volume Resistivity




$$R = \rho \frac{d}{A}$$

$$\rho = \frac{R\,A}{d}$$

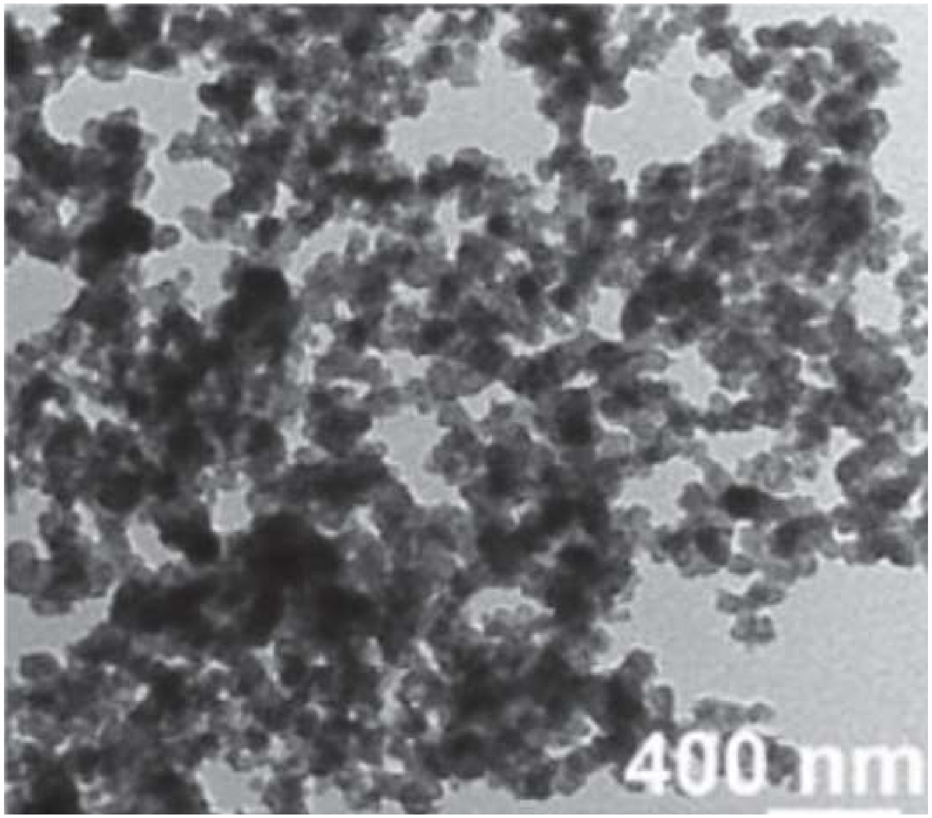
Assuming a specimen with both thickness and depth of 1 cm and an electrode distance of 2 cm between the voltage measuring electrodes shows a resistance of 20 Ω.

What is the specific volume resistivity?

$$\rho = \frac{20\,\Omega \cdot 1\,cm^2}{2\,cm}$$

$$\rho = 10\,\Omega \cdot cm$$

# Specific Volume Resistivity

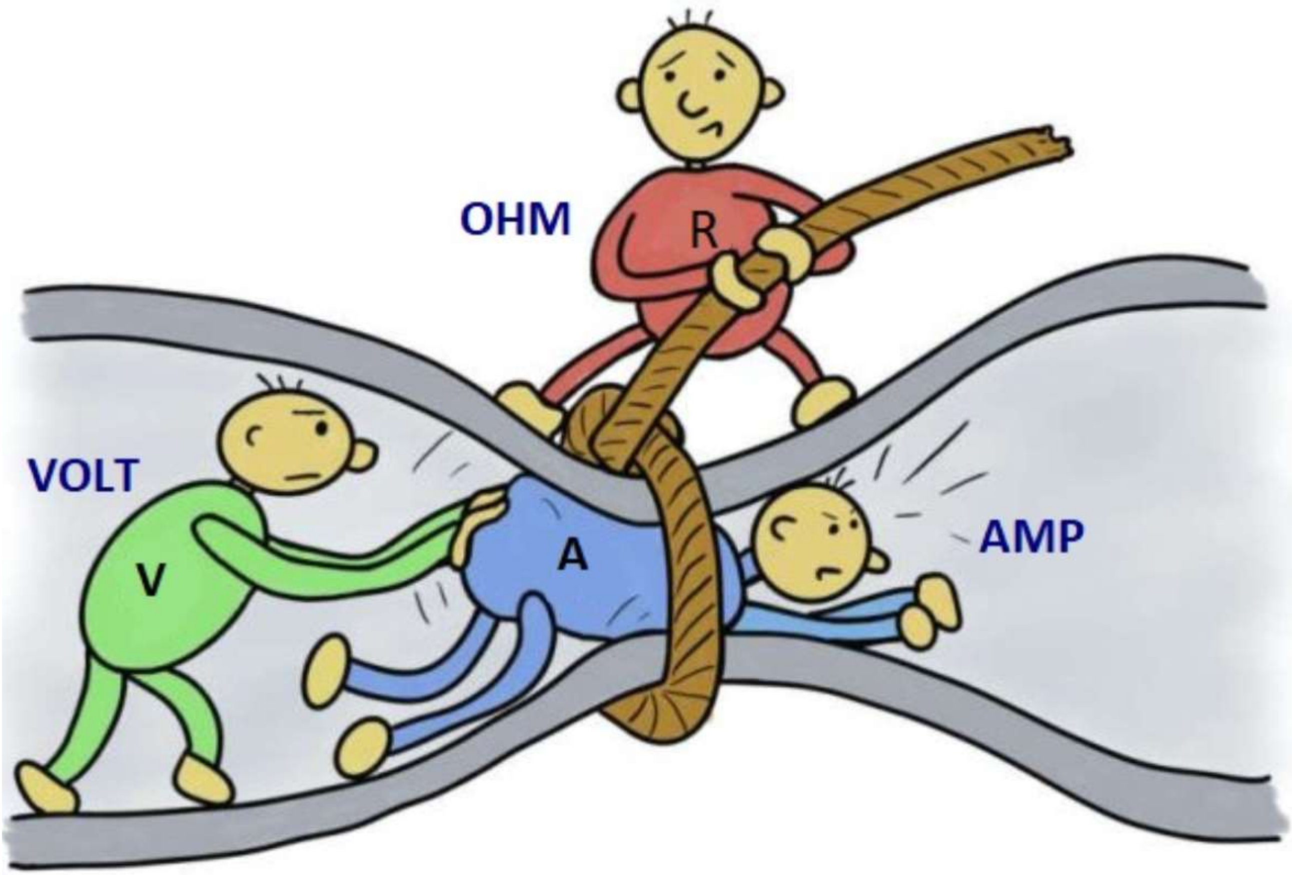



Aus: Claudia Kirschner, „Elektrisch leitfähige Silicone mit niedriger Viskosität“ , Dissertation, Uni Regensburg, 2019

Carbon black forms percolation networks when used as conductive filler in silicone elastomers.

That is why:

- the ability to conduct currents is very limited and
- the resistivity of such materials depends on the mechanical stress of the material and
- the electrodes need to be in touch with the carbon black particles during the measurement.




Thank you very much!