

11th IYPT '98
solution to the problem no. 12
presented by the team of CzechRepublic

Powder conductivity

Measure and explain the conductivity of a mixture of metallic and dielectric powders with various proportions of the two components.

Abstract

We have divided our solution in two main parts – theoretical and experimental. In the theoretical part we have used percolation theory to express effect of a fraction of dielectricum and metal. Than we have used contact theory to express real values of the powder conductivity. We based our experimental solution on van der PAUW's method.

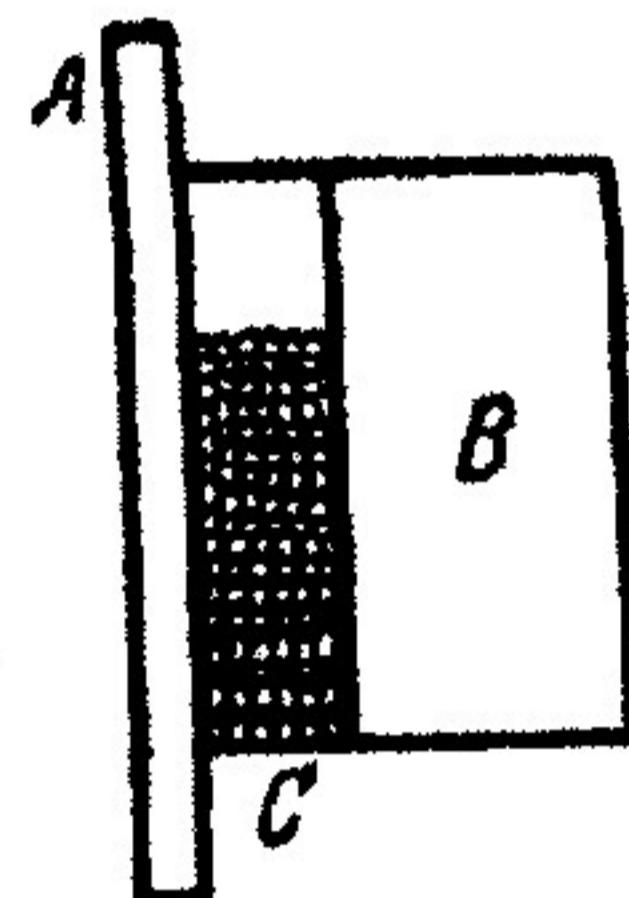
Overview

- Basic explanation
 - Microphone effect
- Contact resistivity
- Mixture – Percolation theory
- Results of the model
- Model details
- Experiments – van der Pauw's method
- Results of experiments
- 2D-experiments
- Conclusion

1 Basic explanation

- structure of powder
- contact resistivity
- pressure
- magnetic field
- melting
- humidity

1.1 Microphone effect



- carbon grains
- resistance varies with pressure of sound

Figure 1: Microphone

2 Contact resistivity

- grain resistivity
- contact area →
 - pressure p
 - hardness of material H

$$\begin{aligned}
 \text{contact diameter } b &= k \sqrt{\frac{p}{H}} \\
 \text{contact resistivity } R_c &= \frac{\rho}{\pi} \left(\frac{1}{b} - \frac{1}{D} \right) \\
 \text{powder conductivity } \sigma_p &\propto \left(\frac{p}{H} \right)^\varepsilon \\
 \frac{1}{2} < \varepsilon &< 1
 \end{aligned}$$

Ni ...	$16e + 7 \frac{\text{kg}}{\text{m}^2}$
Cu ...	$6e + 7 \frac{\text{kg}}{\text{m}^2}$
Pb ...	$0.3e + 7 \frac{\text{kg}}{\text{m}^2}$

3 Mixture – Percolation theory

- 1st used for a flow of a liquid through a random maze

Computer simulation

- random distribution of:

\otimes	dielectrikum
\circ	metal

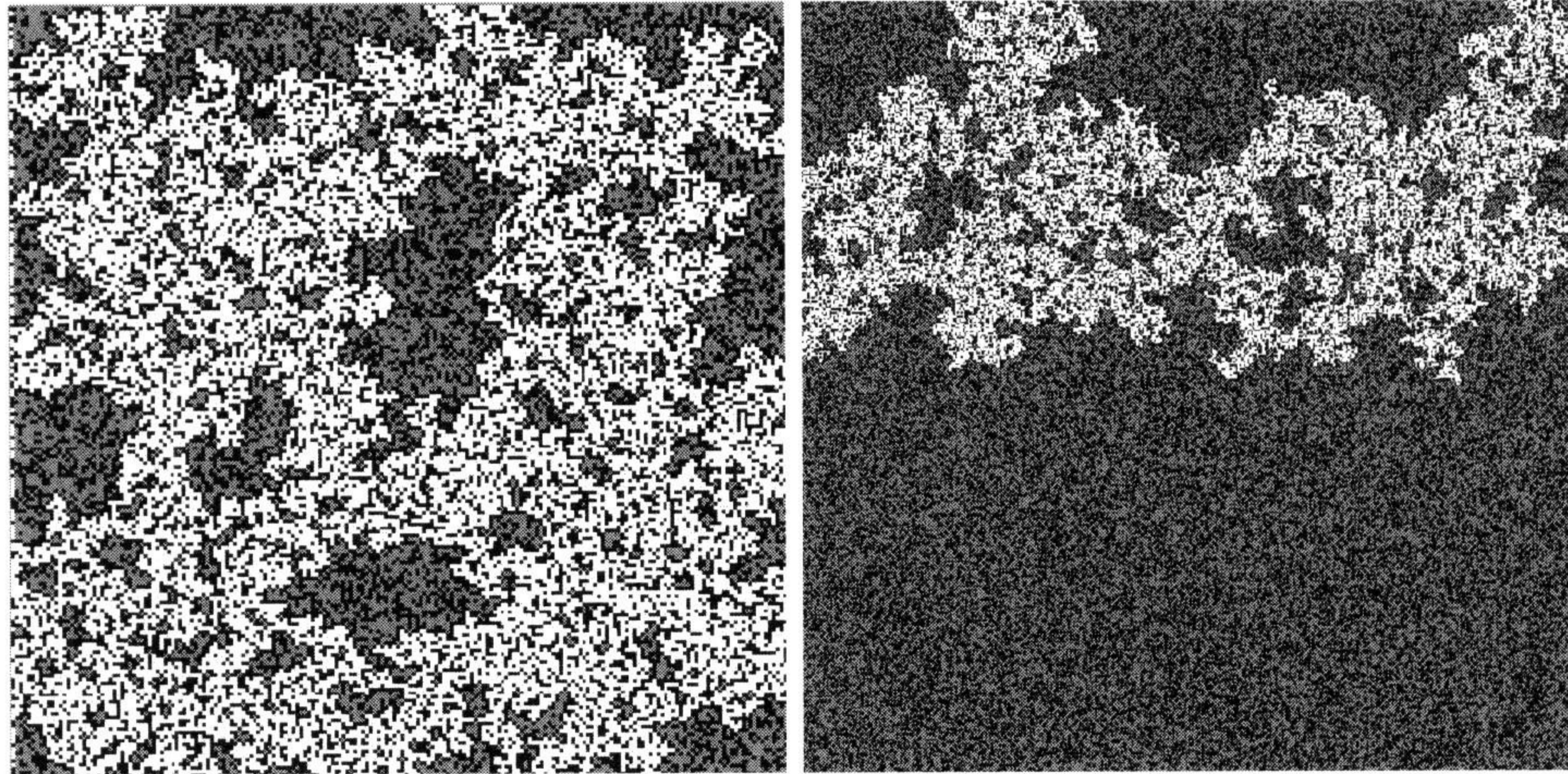


Figure 2: Simulation

- current goes through an existing chain
- | | | |
|--------------|-------|----|
| sides | | 2D |
| planes | | 3D |

4 Results of the model

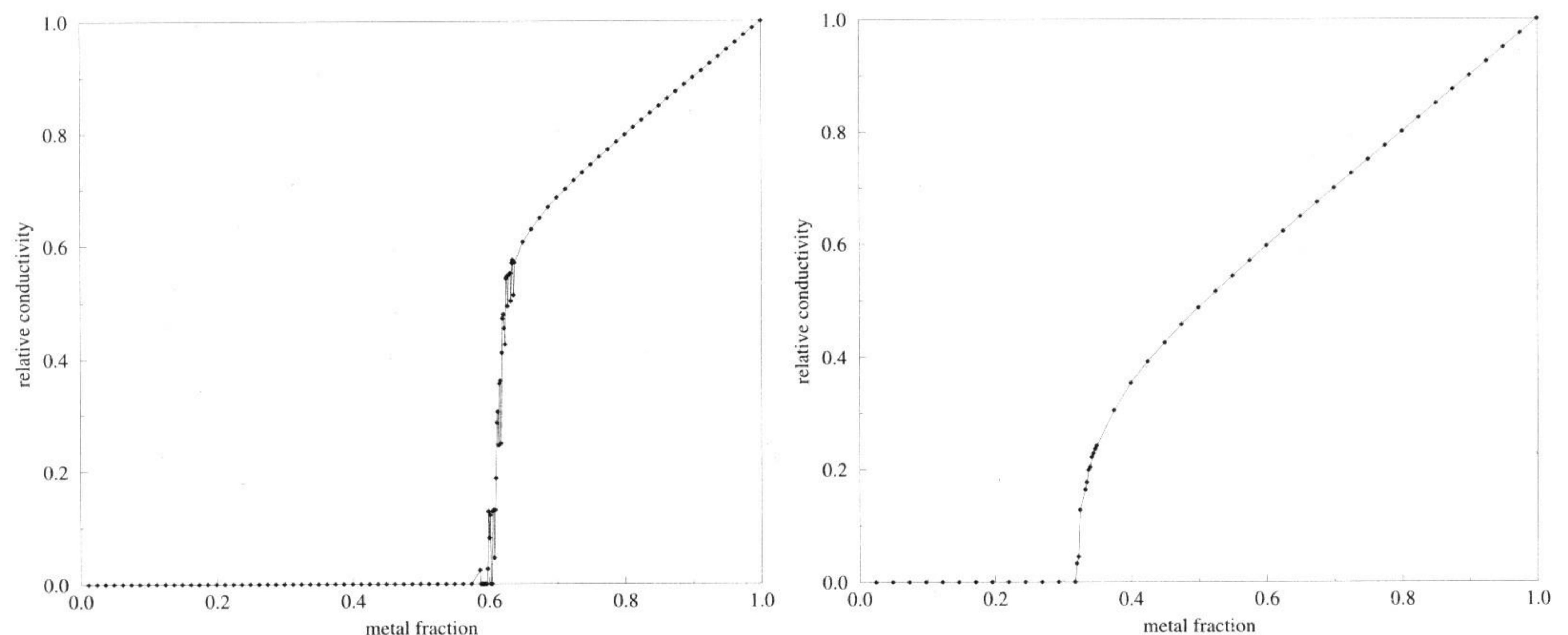


Figure 3: Metal fraction (left: 2D, $X_c = 0.61$, right: 3D, $X_c = 0.32$)

X_c ... threshold

$$\sigma \propto (X - X_c)^k, \quad X_c > X$$

5 Model details

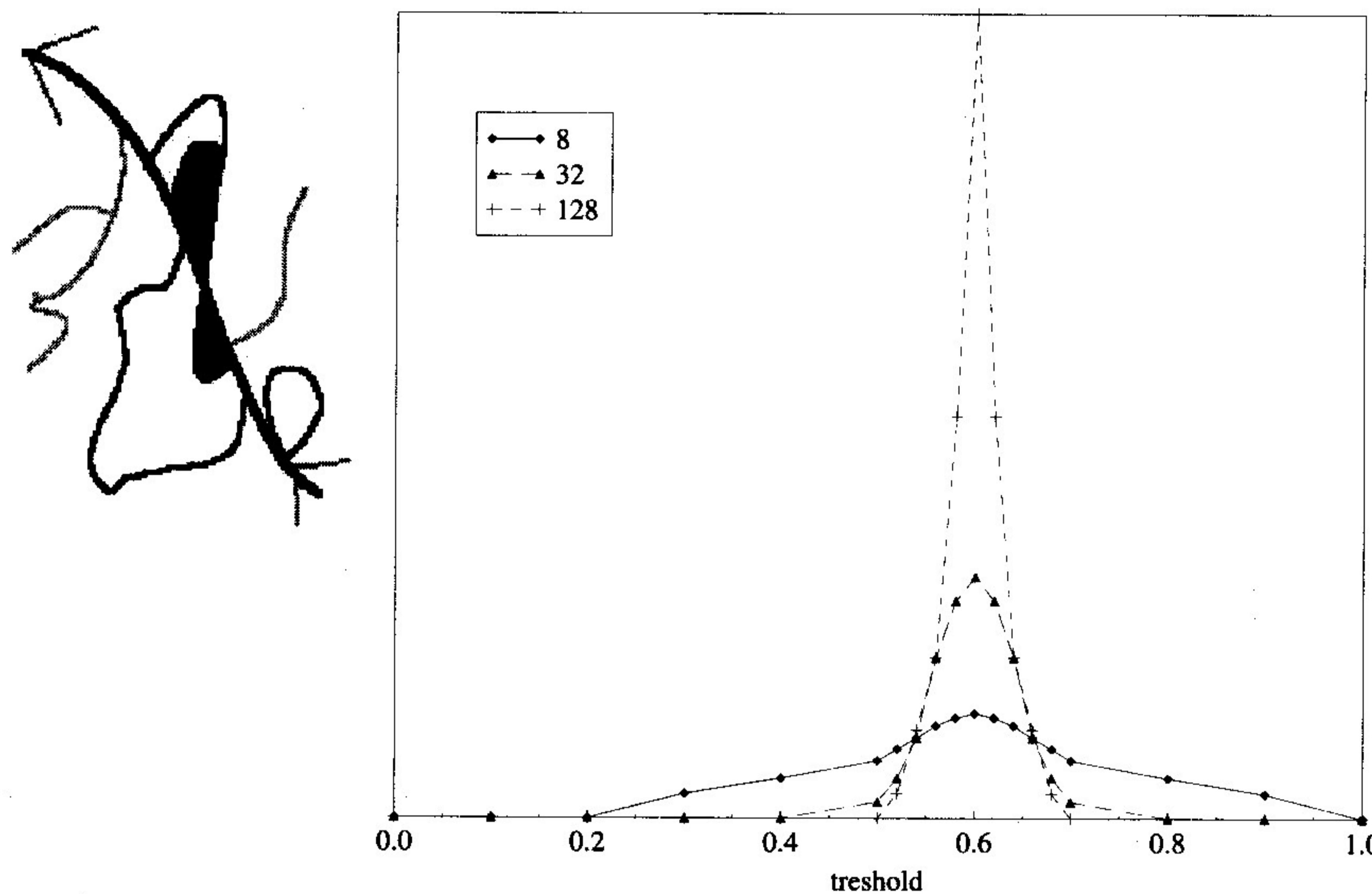
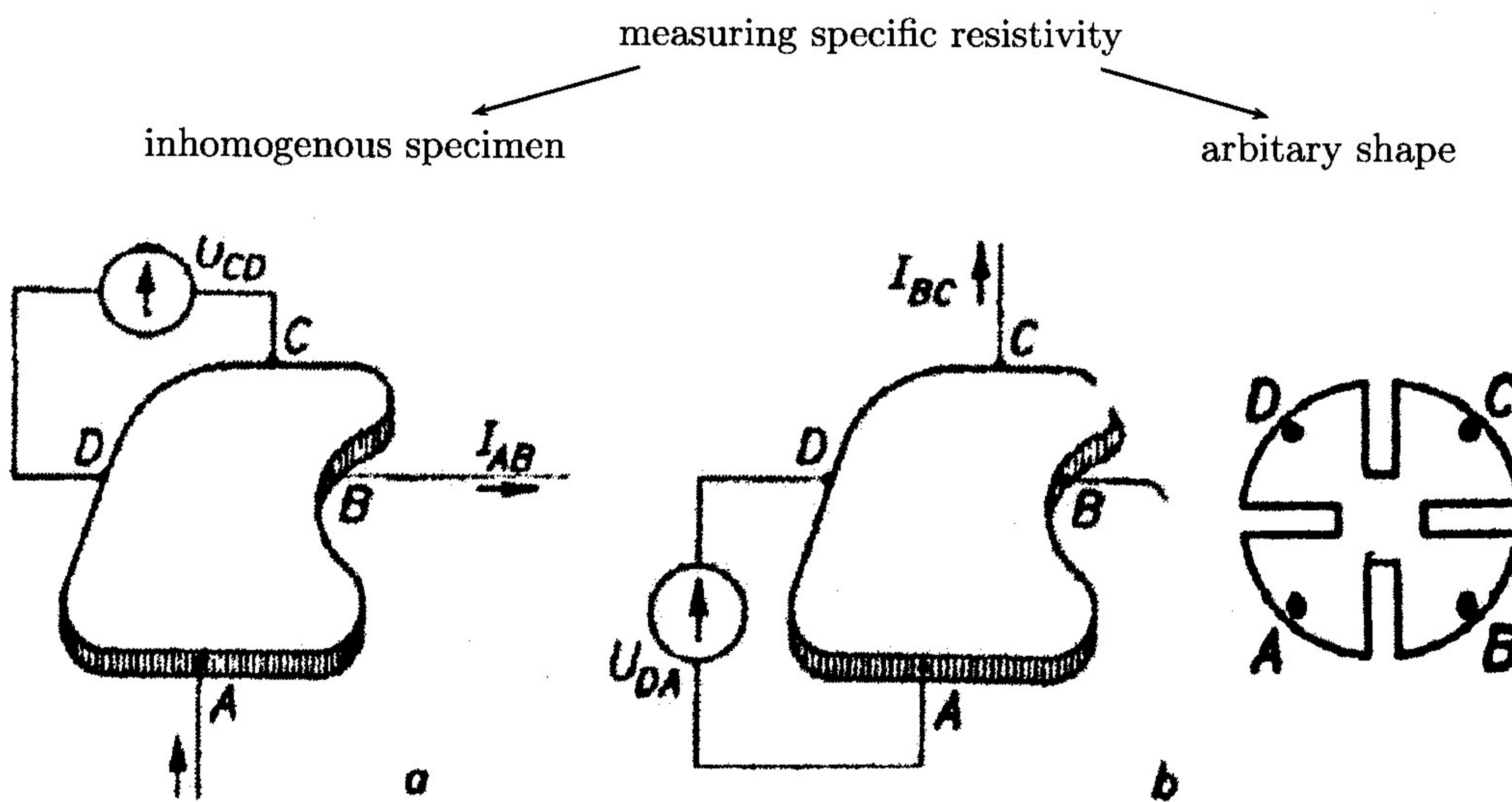


Figure 4: Model-threshold

- conductivity is less than calculated
- chain-backbone + minor chains + dead ends

finit / infinit sample:
higher / less relative deviation of specific values

6 Experiments – van der Pauw's method



$$e^{\frac{-\pi R_{AB}t}{\rho}} + e^{\frac{-\pi R_{BC}t}{\rho}} = 1$$

$$\rho = \frac{\pi t}{\ln 2} \frac{R_{AC} + R_{BC}}{2} f\left(\frac{R_{AB}}{R_{BC}}\right)$$

7 Results of experiments

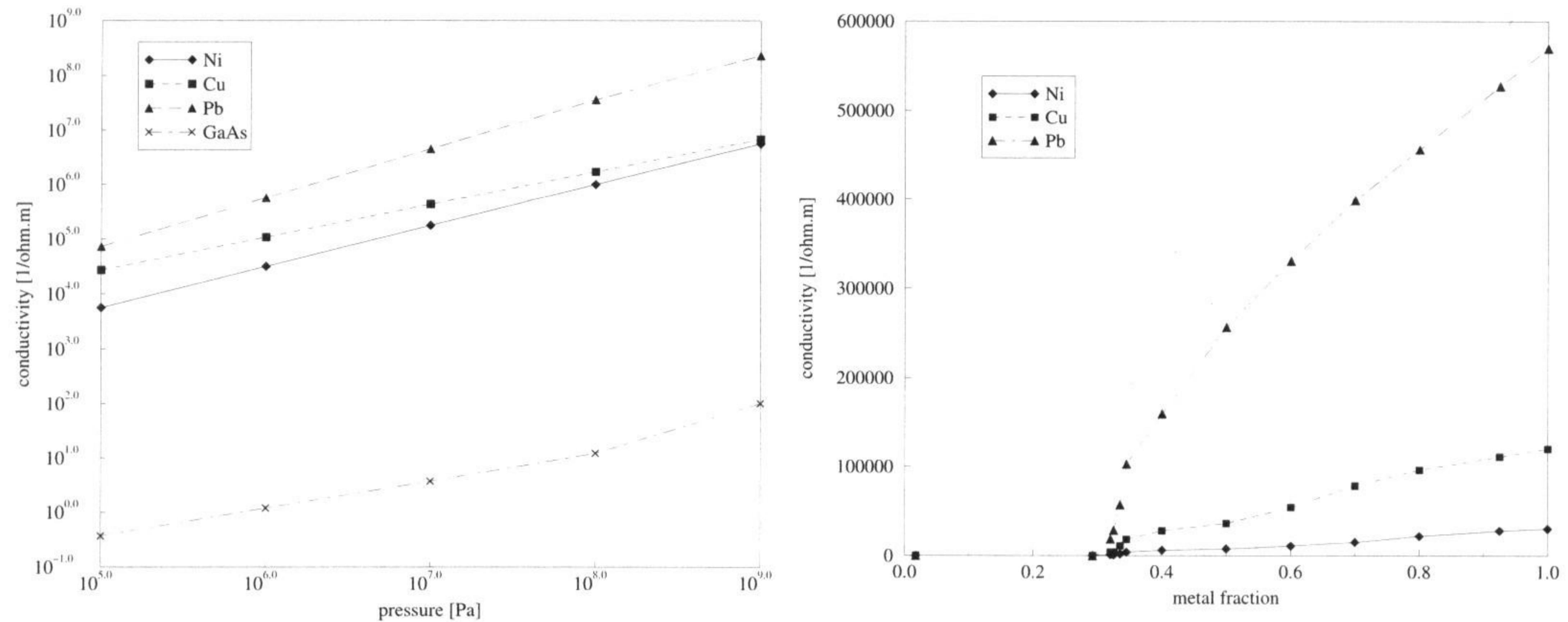


Figure 5: Conductivity

- hydraulic press, inaccurate
- grains obtained by a sander
- grains separated by a grid
- dielectricum – ceramics
- mixed with respect to volume
- grain diameter $d = 0.01 \dots 0.06$ mm
- found no dependence on diameter, pressure $\dots 1$ MPa

8 2D-experiments

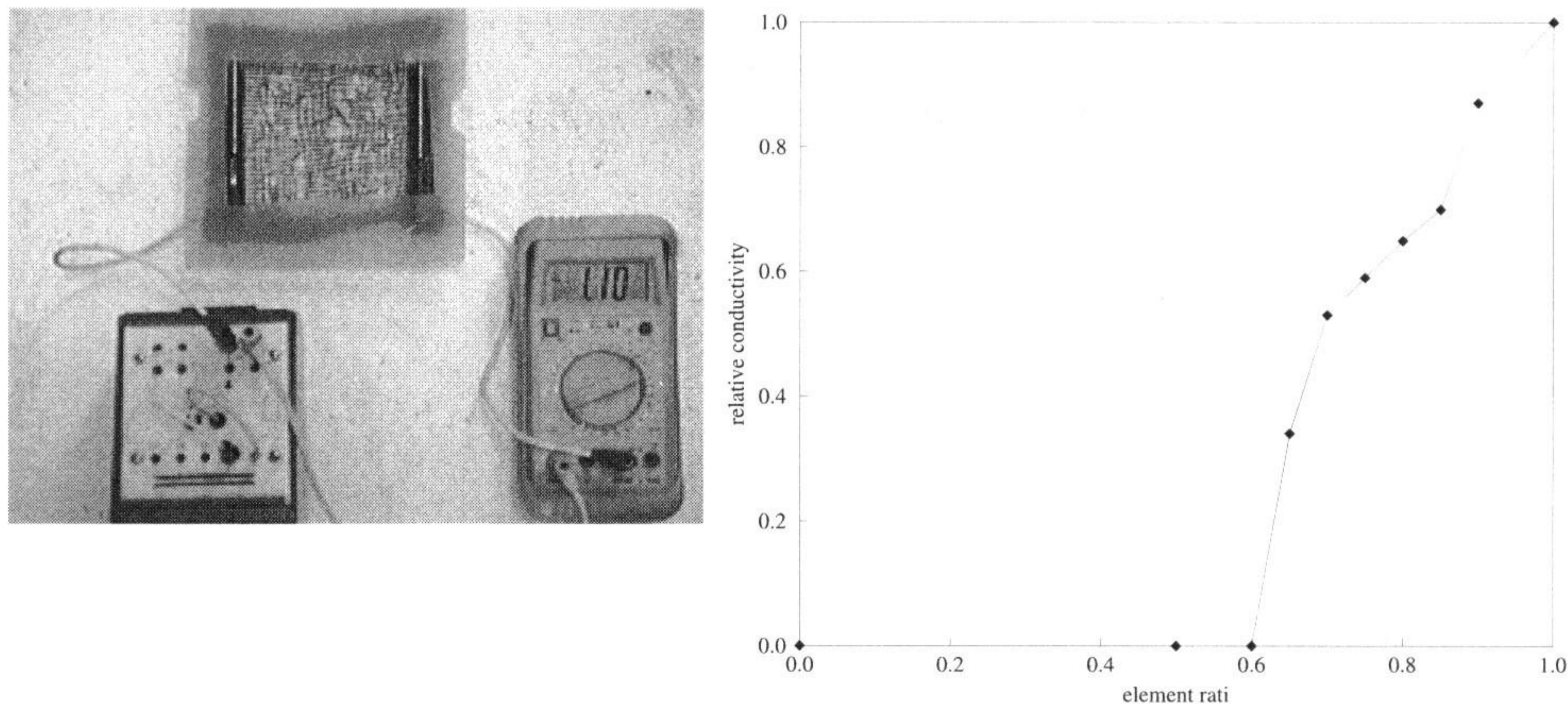


Figure 6: Experimental setup and results

- iron grid
- dielectric represented by punched holes

great agreement in threshold value, basic conductivity $\dots 6.5$ S

9 Conclusion

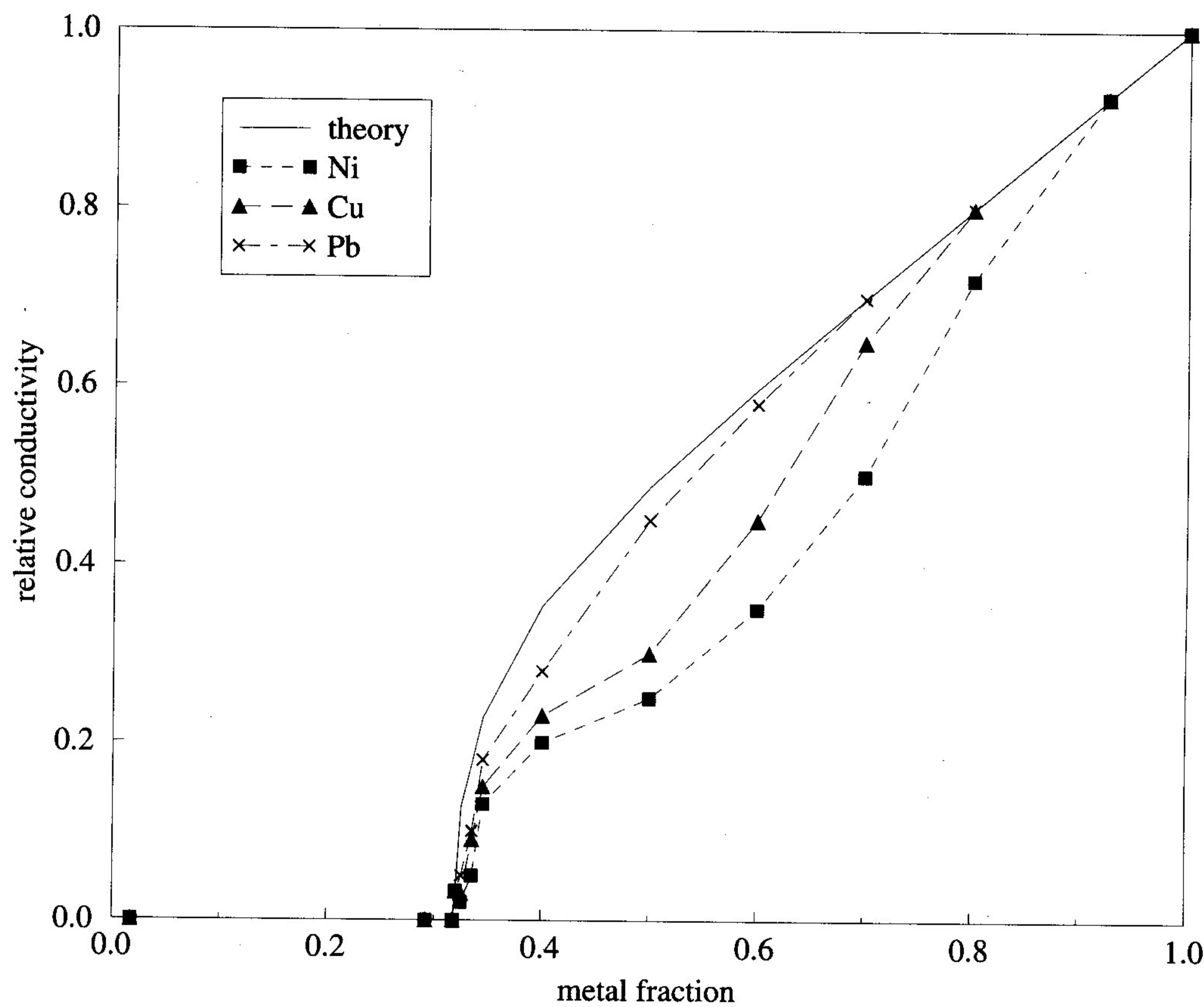


Figure 7: Relative conductivity

comparison: theory ↔ experiments

+ threshold
 - some other values (not ideal grinds)

- theoretical and experimental part
- proved dependence on pressure
- good agreement of the model and experiments