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 studied the variation of the conductivity of a mixture of copper and sodium nitrate powders as a function of concentration. Without compression even the pure copper powder is an insulator due to the oxide layer on powder particles. The specimen was encapsulated within an acrylic tube and compressed with a constant pressure of 14 bar. The mixture is an insulator when the fractional volume of the copper is below 15% since there are no conducting chains of copper particles across the specimen. The conductivity of the mixture varies approximately linearly when the volume percentage of copper is between 20% – 80%.

Overview
- Metal powder
- Experiments
- Results
- AC-conductivity
1 Metal powder

As a metal powder we have chosen copper (particle size = 0.01 – 0.005 mm) and as dielectric powder NaNO₃ (sodium nitrate). Sodium nitrate was fined in a mortal. The average particle size was estimated to be 0.025 mm. Starting from a pure copper, the concentration of the powder mix was changed 10% at a time. The percentage here means concentration in mass percent.

- Copper, Cu
- Sodium nitrate, NaNO₃

![Figure 1: Metal powder](image)

Left:
The concentration of copper particles is so low that there are not continuous paths along copper particles from one end of the powder specimen to the other.
Right:
There is a continuous chain of copper particles from point A to point B.

2 Experiments

At first we made the necessary equipment which covered power source, voltage meter, current meter, acrylic tube and two steel bars. The powder mix was placed inside acrylic tube and compressed between two steel bars. To make measurements more reliable we loaded the steel bars each time using the same weight (53 N). For each composition we measured the current a few times using different voltages. This was done to check that resistance remains the same.

Finally we measured the height of the powder mix inside the tube. Then we repeated the measurements using different concentration of the powder mix. The composition of powder was mixed to wanted concentration using mass per cent and a quite accurate digital balance. When we had done all the measurements we calculated the average resistance for each concentration. From the average resistance we subtracted the resistance of the steel bars. Now that we know the real resistance we can calculate the resistivity using area and height of the powder which was inside the tube.

Conductivity is just the inverse of the resistivity.
3 Results

An essential factor was the pressure, with which the powder was compressed between steel bars. When the pressure is removed the powder resumes its state of isulation. If the pressure was too low, even pure copper powder didn’t conduct electricity within the resolution limits of our meters. (We used digital meters in which the smallest measurable current is 0.1 μA.) The reason to this is, presumably, the oxide layer on the surface of copper particles. When the pressure is sufficiently high the particles are pressed against each other with a force which breaks the oxide layers. When the concentration of cooper was 30 mass % (about 15 volume %) or below, the conductivity of the mix was negligible. When we changed the mass percentages to volume percentages we noticed that conductivity rose

![Figure 3: Conductivity versus mass %](image)

almost in a linear way when the volume percentage of copper rose. This is because the copper particles form a network which conduct electricity. When there is more copper, the network is more complex and there are more copper bridges which conduct electricity. The minimum amount of copper which conducted was 15 volume %. This is the same value that an expert reported from the laboratories of Finnish oil company Neste.
4 AC-conductivity

A pure dielectric substance is an insulator for a direct current. Immediately after switching on the DC voltage there is a short pulse of current connected to the polarization of the substance. When the polarization has reached its saturation value the current goes to zero. The situation is different when a piece of dielectric material is in an alternating current circuit. Then there can be a continuous AC current when the frequency of the voltage is high enough so that the polarization does not saturate. The phenomenon is analogous to the behaviour of a capacitor in an AC circuit, where the impedance decreases as the frequency increases. The rise in the experimentally measured impedance at the powder specimen at frequencies above 10 kHz must be due to some energy consuming resonance mechanism in the specimen. The detailed nature of this mechanism is unknown for us.