Physical Chemistry

Electrochemistry

Conductivity and ions

Conductivity of solids

Time required: 20 min

Aims of the experiment

- To measure the conductivity of solids.
- To find the relationship between conductivity and resistance.
- To recognise that in solids, electrical conductivity is the motion of electrons.
- To subdivide solids into different conductor classes.
- To carry out conductivity measurements as an analytical investigation (resistance, conductance, current, current transport).

Principles

In solid materials, current transport is performed by electrons. This form of conductivity is called a 1st order conductor. In solids, there is a difference between conductors, semiconductors and insulators.

In this experiment, the conductivity of different solid matter samples will be examined. This will be evaluated using the current flow. In the process, a known voltage is applied to the solid matter and the current transport is determined using an amperemeter. In this way, conclusions can be drawn about the conductivity of the solid. From the current and the applied voltage, the conductivity of the sample can be calculated (see right):

As can be seen, the conductivity decreases as the resistance increases, and the conductivity increases with decreasing resistance.

According to Ohm's law	$U = R \cdot I$	U = Voltage [V] I = Current [A]
Then,	$R = \frac{U}{I}$	*R* = Resistance (Ω)
and the conductivity (conductance)	$G = \frac{1}{R} = \frac{I}{U}$	*G* = Conductivity (S[1/Ω]) [S]: Siemens

Fig. 1: Set-up of experiment and materials.

Risk assessment

In using the electrochemistry demonstration unit, the only voltages allowed are those not dangerous to the touch. Therefore, it can be assumed that there is no danger.

CAUTION! Do not select a higher voltage, since the maximum allowable current of 2000 mA will be exceeded and a short circuit may occur.

Equipment and chemicals

1	Electrochemistry demonstration unit	664 4071
1	Panel frame C50, two-level, for CPS	666 425
1	Electrochemistry table	666 472
1	Clip plugs, small, set of 2	590 02ET2
1	Electrochemistry accessories set	664 401
2	Connecting leads, 50 cm	from 664 401
2	Connecting leads, 25 cm	from 664 401
2	Connecting leads, 10 cm	from 664 401
1	Tweezers, blunt	from 664 401
2	Crocodile clips	from 664 401
1	Iron wire 2 m	from 664 401
1	Copper wire 2 m	from 664 401
1	Silicon disc	from 664 401
1	Plastic rod	from 664 401
1	Plastic sample, metal-coated	from 664 401

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Set-up and preparation of the experiment

Set-up of the experiment

Wind the 2 m long copper wire onto a pencil or the like to make an approx. 20 cm long coil.

Insert one clip plug into each of the outermost sockets of the demonstration unit table. Clamp the plug into the clip plug with the crocodile clips.

Preparation of the experiment

Since the metal wires have very low resistance, the internal resistance of the amperemeter, which would otherwise taint the measurement results, must in this case be uncoupled using the following circuit in Figure 2.

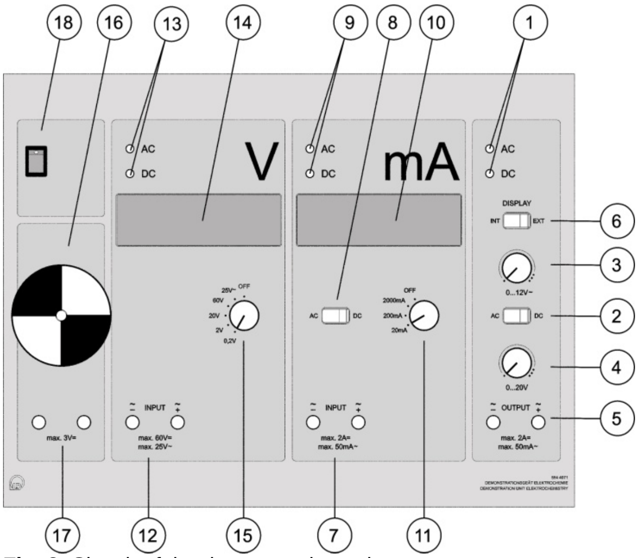

Fig. 2: Sketch of the demonstration unit.

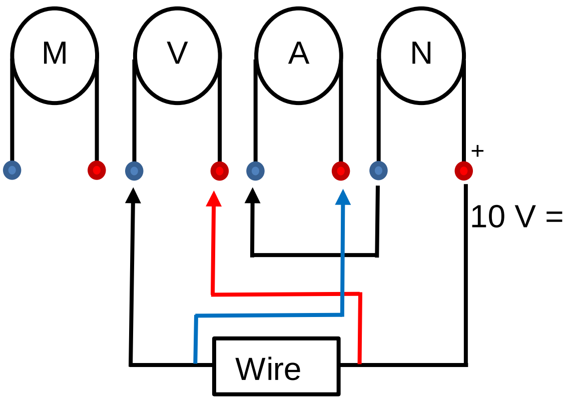

Fig. 3: Demonstration unit circuit for decoupling the internal resistance.

Set the changeover switches (2) and (8) on the electrochemistry demonstration unit (see Fig. 3) to the “DC” position (direct current). Turn on the external power source measurement using selector switch (6).

Performing the experiment

Clamp the 2 m long iron wire - wound into a coil - between the crocodile clips. Set a direct current voltage of 0.5 V using the control dial (4) (see Fig. 3). Take a reading of the resulting current (display (10)) and record in the table.

Do likewise with the copper wire, the silicon disc and the plastic samples. Here, carefully guide the silicon disc with the tweezers provided.

Observation

Table 1 plots the observed values of the individual measurements.

Tab. 1: Measurement results at room temperature.

Materials	Current [mA] at 0.5 V
Fe Wire	219
Cu Wire	1430
Si disc	0.3-0.4
PVC rod	0
Plastic, coated	6.6

Evaluation

In order to determine the conductivity, the formulas mentioned in the principles section are used.

For the conductivity of iron:

$$G = \frac{1}{R} = \frac{I}{U} = \frac{1}{2.28\,\Omega} = \frac{219\,mA}{500\,mV} = 0.438\,S \equiv 438\,mS$$

The conductivity of iron at room temperature is therefore 438 mS. All other conductivities are calculated in a similar fashion to the above calculations (see Tab. 2).

Tab. 2: Calculated conductivities & resistances of the measured substances.

Material	Resistance [Ω]	Conductivity [mS]
Iron	2.28	438
Copper	0.35	2860
Silicon	~1420	0.7
Plastic, coated	75.8	13.2

Result

It is clear that in this simple experiment, two of the three conductor groups can be observed.

1. Conductor (metal):

Iron and copper conduct electrical current well or very well.

The good conductivity of metals is based on metallic bonding. This is characterised by the existence of freely-moving (delocalised) electrons. They are not bound to a specific atomic nucleus, but distributed across the entire atomic matrix (as an “electron cloud”). In this way, the electrons can move about relative to the atomic matrix, allowing electrical impulses to be transferred.

Copper conducts electric current about 5 to 6 times better than iron. This results in a larger measured current in the experiment. The reason is the larger number of d-electrons in copper. Elementary copper has 11 electrons in the valence band. Iron has 8 valence band electrons.

2. Semiconductors (half-metals):

Silicon conducts electrical current poorly. The reason for the poor conductivity is explained by the semiconductor properties of silicon.

The semiconductors (half-metals: B, Si, Ge, As, Se, Sb, Te) have very low electrical conductivity at room temperature since very few electrons can escape from their respective atomic cores (so they stay in the valence band). Between the maximally occupied electronic state (the valence band) and the first of the lowest range of vacant electronic states (conduction band), there is a gap (*band gap*). To overcome this gap, energy is required. The energy can be fed to the system through thermal energy or photon energy.

3. Non-conductors (insulators):

The band gap of non-conductors (i.e. plastics, wood, paper, non-metals, etc.) between the valence band and the conduction band is too large, even in the crystalline structure, and this cannot be overcome.

Even plastics can be made to conduct electricity. This can be done by depositing a thin metal layer under high vacuum, or through galvanic application of a metallic layer, or by adding conducting substances during manufacture (incorporating gold nanoparticles into plastic vessels). The advantages of such plastics include a decorative, shiny appearance, prevention of electrostatic charge, shielding of interfering radiation and last but not least more cost-effective manufacture versus pure metal parts.

According to definition, iron and copper are conductors. On the other hand, plastic samples can be clearly declared to be non-conductors. The coated sample gets its conduction ability only from the metal layer. For silicon, no qualitative conclusion can be drawn as to the material group to which it belongs. In order to draw this conclusion, it is necessary to perform a temperature-dependent measurement (see C4.4.1.6).

A literature comparison cannot be done here since the conduction surface was not defined beforehand. A direct comparison can only be done through the specific conductivity. This indicates the resistance or conductivity per square meter of conduction surface.