# SIMPLE EXPERIMENTS WITH SEMICONDUCTORS AND LEDS

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## ABSTRACT

*In contrast to classical chapters of physics, only a few simple experiments are available for discussing semiconductors in the schools. This paper describes some simple experiments tested several times. By examining the electrical resistance of a Ge slice, some basic properties of semiconductors are illustrated like changes in resistance under the influence of heating or illumination. The possible application of semiconductor devices in further demonstrated by experimenting with light-emitting diodes (LEDs), known from everyday practice. The focus is on the description of experiments, and explanations are given only in terms of basic physics.*

## INTRODUCTION

As in the science of physics, experiments play a vital role also in physics teaching. The discussion of each topic in physics should ideally start with the presentation of a related experiment. The primary task with the experiments presented here, which do not need too many devices and can be carried out quickly, is to grab the attention of pupils and to motivate them to understand the explanation of the phenomenon.

Semiconductors play an important role electronic equipment used in modern everyday life. Young people are eager to learn how the devices they use work and it should be kept in mind that almost all the main features of those devices rely on semiconductors. It is important to realise that the introduction of semiconductors in secondary schools physics is unavoidable since they have become an inevitable part of the preparation for any engineering profession. In teacher training at universities the discussion of semiconductors takes place only after thorough quantum mechanical and material science courses. This may be the reason why so many teachers don’t even think of dealing with semiconductors. In fact, students are lacking the necessary knowledge of material structure required for a deeper understanding of the related phenomena. Here we show that a different approach might be more efficient: experimental investigation of some phenomena is also a valuable, especially when experiments are carried out by the students themselves.

The topic of semiconductors is also cross-curricular, bridging the gap between different science subjects, i.e., chemistry and physics. The efficiency of learning is higher for students if they recognise that the knowledge they have acquired in chemistry can be essential for their further comprehension of physics.

**EXPERIMENTAL INVESTIGATION OF THE CONDUCTIVITY OF GERMANIUM**

In our first experiment we measure the resistance of a germanium slice. To this end we need a multimeter, a slice of germanium, an insulating support, and electrical wires (Fig.1). We place the germanium crystal carefully on the insulating support and fix it. (We have to be careful because a thin layer of Ge crystal is very fragile.)

The multimeter is used in the "resistance measurement" mode and is connected to two edges of the germanium slice. The multimeter contains a built-in power supply, and the circuit is closed through the germanium. The multimeter displays the resistance of the germanium at room temperature. The resistance of a thin layer of germanium, as can be seen in Fig.2, is of the order of MΩ-s. This value is very high compared to the values measured on metals of similar geometry, but it is much smaller than the resistance of electrically insulating materials.

Spray on the Ge slice some kind of freezer spray, available in medication. The instrument indicates that the electrical resistance of the cooled germanium increases dramatically. Heat the germanium slice with a hairdryer above room temperature. The electrical resistance of the material decreases with increasing temperature (Fig.3). If the germanium sheet is illuminated with a table lamp its resistance decreases again (Fig.4).

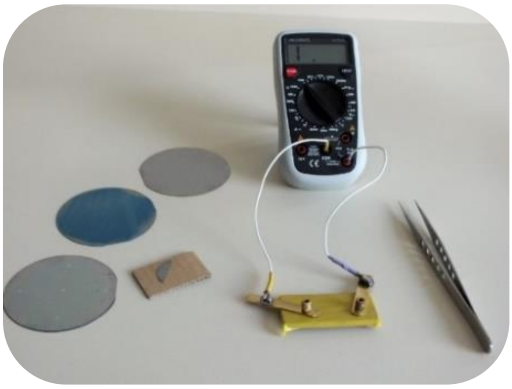

Fig.1. The tools needed


Fig.2. The multimeter shows us the resistance of the germanium at room temperature


Fig.3. When warming up the Ge crystal, its electrical resistance decreases


Fig.4. When illuminate the Ge crystal, its electrical resistance also decreases

The decrease in resistance under the influence of illumination is easily measurable. This change is interesting especially in comparison with that in metals. In the case of metals the electrical resistance increases parallel to the increase in temperature, and illumination does not cause any measurable change in resistance.

For an elementary explanation of the conductivity of metals, we introduce the free electron model, the classical Drude model [1]. The structural foundation of this is already known for students from chemistry. In physics, we augment this picture with a more microscopic interpretation of currents by mentioning that the oscillating movement of the metal atoms around their equilibrium positions in the crystal hinders the free movement of electrons. This is considered to be the cause of electrical resistance of pure metals. The interpretation of conductivity of semiconducting materials is based on the knowledge of their chemical structure. In chemistry the elements of Group 4 and 5 are called metalloids, and it is noted that in these groups the metallic character increases from top to bottom. Take, e.g. diamond carbon, silicon and germanium. The crystal structure of each of these materials is tetrahedral, based on covalent bonds, a so-called diamond lattice. In the case of diamond, electrons in covalent bonding are strongly bound and there are, therefore, no free charge carriers in the crystal, diamond is thus electrically insulating. In the case of Si, and Ge, that are below the carbon in the periodic table, electrons can be more easily released from the bonds (for example by heating or illumination). In Si, more energy input is needed, which demands, e.g., more intensive heating. In the case of Ge, a significant increase in the number of free electrons is experienced already at moderate temperature rise or illumination.

The electrons set free by the methods described above conduct electricity just like the free electrons in metals. The increase of current due to the electrons set free by heat or illumination is much stronger than the decrease due to the enhanced thermal oscillation around the equilibrium atomic positions.

In addition to the abovementioned electron conductivity mechanism an electron-hole mechanism gives a further contribution to electric conduction. At medium level it is sufficient to add a remark on this. At advanced level we can elaborate more on the passive movement of the holes. Our experience is that at secondary school the concept of the “energy-band structure” [2] is unnecessary since a quantum mechanical foundation is hopeless to be given at this level.

## SIMPLE EXPERIMENTS WITH LIGHT EMITTING DIODES (LEDS)

In many appliances and instruments semiconductors are the basic components, of which the most commonly used are LEDs [3]. LEDs are well known as energy-saving light sources which directly convert electrical into light energy.

### The LED light output as a pole-dependent device

In terms of physics, a LED is a special semiconductor diode. Simple experiments illustrate that LED conducts electricity in one direction only. If we join the anode of LED to the positive pole of a battery, and the cathode to the negative pole, the LED conducts electricity, and lights up (Fig.5). This connection is in the forward direction (Fig.6). (For protecting the LED we apply a 100-ohm resistor.) Using reverse polarity, the LED does not light up.

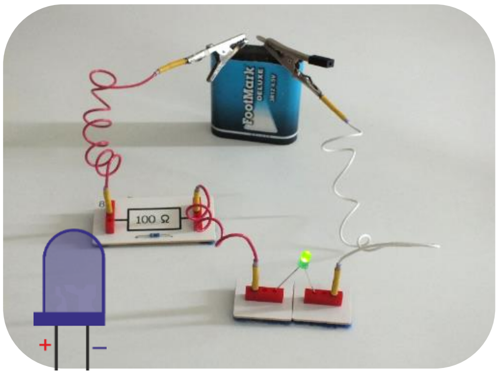


Fig.5. The LED lights up in the forward direction

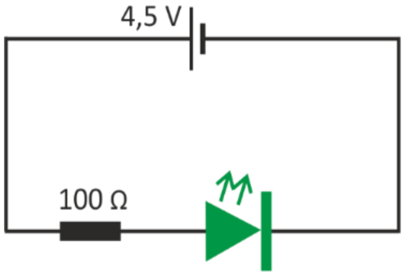


Fig.6. Schematics of an electrical circuit in the forward direction

**LED is a special semiconductor diode**

The fact that LEDs conduct electricity exclusively in one direction can be illustrated with another spectacular experiment. Take an approximately half meter double-stranded electric wire and a battery. If a LED is connected between the ends of the wires, the LED lights well (for protection we apply again a 100 ohm resistor in series). When rotating the light emitting diode at the end of the connecting wires, while holding the other end of it in our hand, the LED traces out a continuous circle of light (Fig.7).

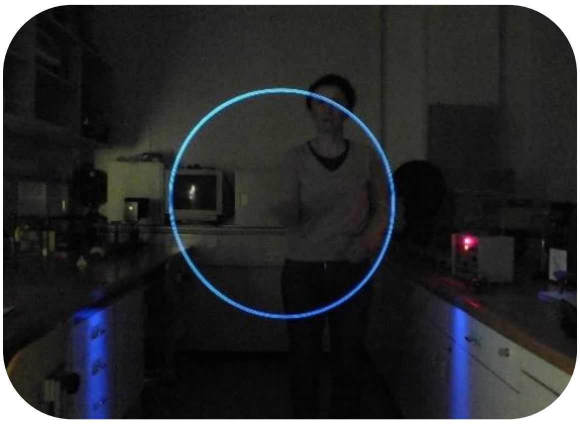

Fig.7. With direct current we see a continuously lighting circle

Fig.8. With alternating current we see an interruptedly lighting circle

In the second experiment we use alternating current with a frequency of 50 Hz. Apparently, the LED lights well again. However, when spinning the wire with the LED, we see an interruptedly lighting circuit (Fig.8). The reason is that the LED lights up in the forward direction and goes out in the reverse direction. This alternation is so fast that without the rotation it cannot be observed by naked eye.

**LED WORKS BEYOND A THRESHOLD ONLY**

We can illustrate with a very impressive and interesting experiment that a LED – as any other diode – works only above a certain opening threshold voltage. We need some moderately wet earth, two electrical wires, and direct current from an electric power supply, two electrodes made by metal plates, a voltmeter, a ruler, and a LED. The electrical circuit needed can be seen in Fig.9.

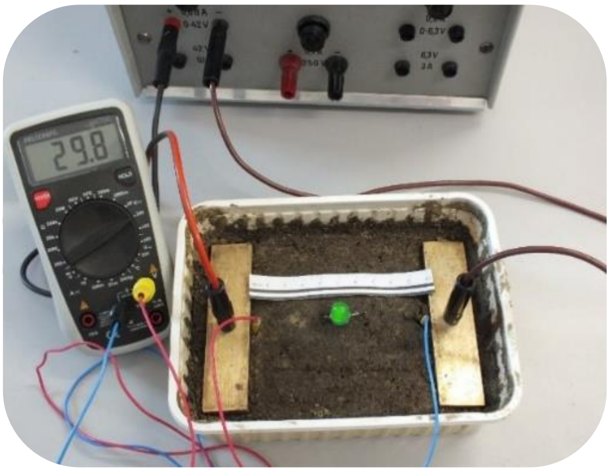

Fig.9. The electrical circuit used for the illustration of the existence of a potential threshold. The white ruler marks the direction of the electric field in the system

The distance between the two electrodes is about 10 centimetres. On the surface layer of the wet earth a nearly uniform electric field is formed. The voltmeter in Fig.9. shows about 30 Volts. We insert a LED into the wet earth. Make sure that the LED is to be inserted in forward direction. If the legs of the LED are far enough from each other, and are parallel to the ruler, the LED lights up, because the potential difference between the legs is higher than the threshold voltage. (In our experiment the distance between the legs of the LED was 2 centimetres. The maximum potential difference between the legs is thus about 6 Volts.) If we rotate the LED step by step, the potential difference between the legs decreases, the LED will provide dimmer light (Fig.10).

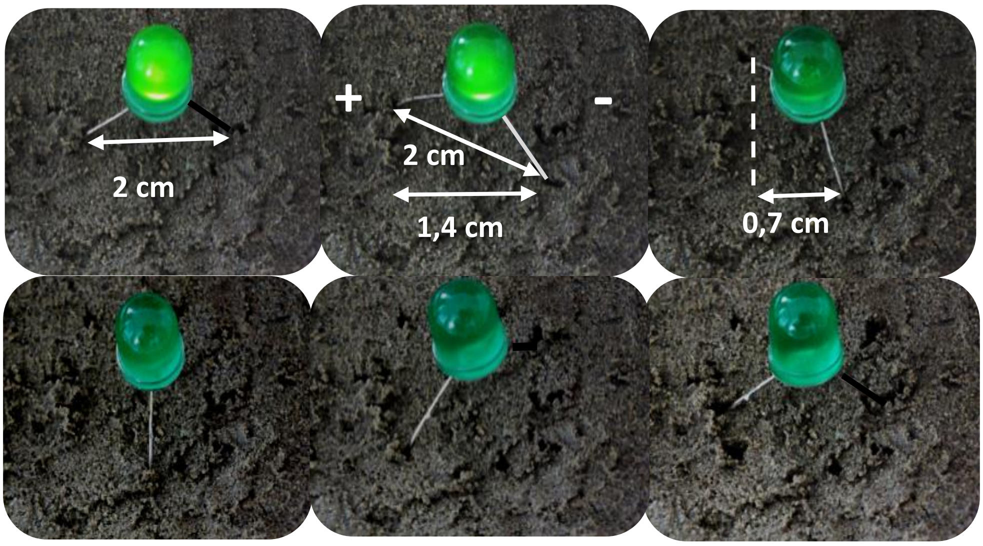


Fig.10. When slowly rotating the LED the light become dimmer, and at a threshold angle it goes off

Measuring the distance x between the legs parallel to the ruler when the LED goes off (in our experiment $x \approx 1.4$ cm, see the second panel of Fig.10), we can determine an approximate value of the threshold voltage as:

$$U_{th} \approx \frac{30\ \mathrm{V}}{10\ \mathrm{cm}} \cdot 1.4\ \mathrm{cm} \approx 4.2\ \mathrm{V}\ .$$

The LED does not light up, of course, if its legs are on an equipotential line (perpendicular to the ruler). In this case the potential difference between the legs is zero. If the LED is rotated further, the potential difference between the legs becomes negative, so it does not light up because the LED conducts electricity only in one direction.

### LED as a photovoltaic cell

A voltage can make a semiconductor light up, the reverse phenomenon is that light can generate voltage in a semiconductor. It can be shown by a simple experiment that LEDs can work as power supplies. In our experiment a LED is illuminated by another one from above (Figs.11, 12). Between the electrodes of the illuminated LED we measure voltage. By varying the intensity of illumination (e.g. by increasing and decreasing the distance between the LEDs) the measured voltage changes.

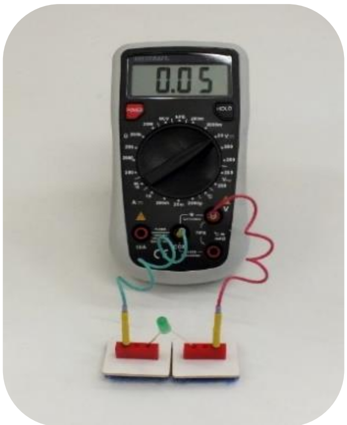


Fig.11. The LED's voltage is rather low in room light

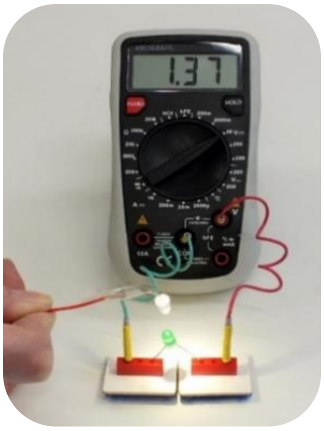


Fig.12. By illuminating the LED with another one, the voltage goes up

This experiment illustrates that LEDs and solar cells work in a similar way.

## CONCLUSIONS

Based on the students' previous knowledge on semiconductors, teachers may explain why metals conduct electricity and insulators don't; how the conductive and semiconductive features of materials depend on the temperature and light intensity.

The experiments shown here are suitable to illustrate semiconductor properties, and the functioning of some devices made from semiconductors. To give deeper explanations was not our goal, since for these the students' deeper previous knowledge would be necessary, such explanations could be provided e.g. in special mentor classes, if we can awake our students' interest.

## REFERENCES

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3. E. F. Schubert: *Light-Emitting Diodes*, Cambridge University Press, Cambridge, 2006